Natural Resources Canada

Green Mining Initiative Impact Study – Final Report

October 28, 2015

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Executive summary

Mining is important to Canada's economy. In 2013, the mining industry contributed $54 billion to Canada's gross domestic product ("**GDP**") and the industry accounted for almost 20% of Canadian goods exports.[1] The Canadian Government and provinces support the mining industry through a variety of programs, tax credits and other measures. The Green Mining Initiative ("**GMI**") was officially announced in 2009 and brought together green mining science and technology ("**S&T**") and research and development ("**R&D"**) work which had already been undertaken with various stakeholders in the mining sector by CanmetMINING as part of the Minerals and Metals Sector ("**MMS**").[2] GMI targets the development of innovative energy-efficient technologies required for mining to leave behind only clean water, rehabilitated landscapes and healthy ecosystems. It aims to improve the mining sector's environmental performance, to promote innovation in mining and to position Canada's mining sector as the global leader in green mining technologies and practices.[3]

While conducting R&D in Canada is certainly positive for the Canadian economy, government stakeholders want to better understand the broader socioeconomic impacts of the GMI and to assess whether investing in the GMI is a good use of taxpayer dollars. Accordingly, Natural Resources Canada ("**NRCan**") engaged HDR Corporation ("**HDR**") to assess and estimate the broader socioeconomic impacts of the GMI employing HDR's Sustainable Return on Investment ("**SROI**") methodology. SROI is a methodology developed by HDR to monetize (i.e., put a dollar value on) changes in socioeconomic outcomes. By doing so, SROI enables comparison of socioeconomic impacts to financial costs associated with a bringing about these changes and has been used by policymakers to assess the societal benefits and costs associated with government investments.

The objectives of this study – entitled the *Green Mining Initiative Impact Study* – are to quantify and monetize the socioeconomic impact of selected GMI technologies and projects from 2007 to present in the following areas:

- Economic competitiveness, productivity and market opportunities;
- Environment, including changes to regulations, protocols and guidelines;
- Miner health and safety, including changes to codes and regulations; and
- Other areas, including innovation in the mining sector, international capacity building, and professional development.

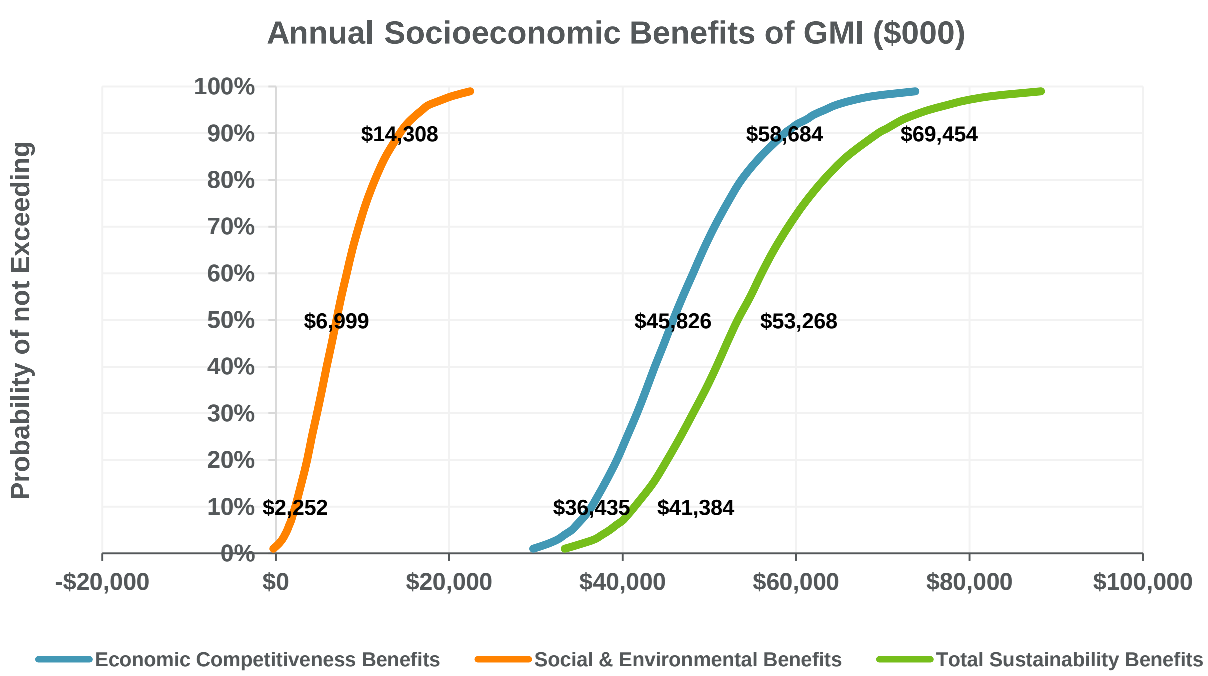
It should be noted that this Green Mining Initiative Impact Study encompassed projects which are categorized under the following Natural Resource Canada's Program Activity Architecture (PAA) sub-programs: *Green Mining* (sub-program 2.2.2) and *Mining Innovation* (sub-program

[1] Mining Facts (2014). The Mining Association of Canada. Retrieved from http://mining.ca/resources/mining-facts.
[2] Final Evaluation Report: Evaluation of the Green Mining Initiative (February 2015). Natural Resources Canada.
[3] Green Mining Initiative (2013). Natural Resources Canada. Retrieved from http://www.nrcan.gc.ca/mining-materials/green-mining/8178.

1.2.1). The projects selected for this study share the goal of achieving both environmental and economic benefits for Canada.

The total socioeconomic benefits of the projects selected for this GMI study are presented below. Only those effects that can be credibly monetized are included in the estimates of socioeconomic outcomes. The chart shows that with 80% confidence, the economic competitiveness benefits of the monetized GMI projects lie between $36 million to $59 million, the social & environmental benefits lie between $2 million to $14 million, and the total sustainability benefits lie between $41 million to $69 million. The median estimate of total annual GMI benefits for the monetized projects is $53 million. It is important to note that while the total sustainability benefits is a sum of the economic, social, and environmental impacts, values at any given level of confidence are not additive; each set of results forms a unique distribution of potential outcomes and should be interpreted individually.

Figure 1: Annual Socioeconomic Benefits of GMI Research and Projects ($000)



Based on the latest representative annual cost data, CanmetMINING expenditures for the 13 projects considered in this study amount to $1.26 million while the total expenditures including external in-kind contributions sum to a total of $9.9 million. Six of these projects have had benefits monetized as part of this study which make up $348 thousand and $8.4 million of the CanmetMINING and partner contributions respectively. The high proportion of in-kind external contributions further illustrates the catalyst effect of GMI research and projects that spur significant socioeconomic benefits. In fact, based on the SROI results, the socioeconomic benefits leveraged by these combined investments can range anywhere from 4.8 to 8.0 times the total GMI expenditures and from 119 to 201 times the government contributions with an 80% level of confidence. This means that the economic, social, and environmental benefits derived by various members of society outweigh the annual costs several times over. It's also important to note that while the costs reflect the complete set of projects in this study, only some of the projects had impacts that could be monetized at this point in time and several have shown great promise for tremendous future benefits. It is important to note that HDR's assessment of the socioeconomic impact of the GMI projects is solely based on the interviews completed as part of this study and on information provided by NRCan. Thus, it represents a conservative estimate of the impact of the GMI projects.

Figure 2 – Annual Return of GMI Research and Projects

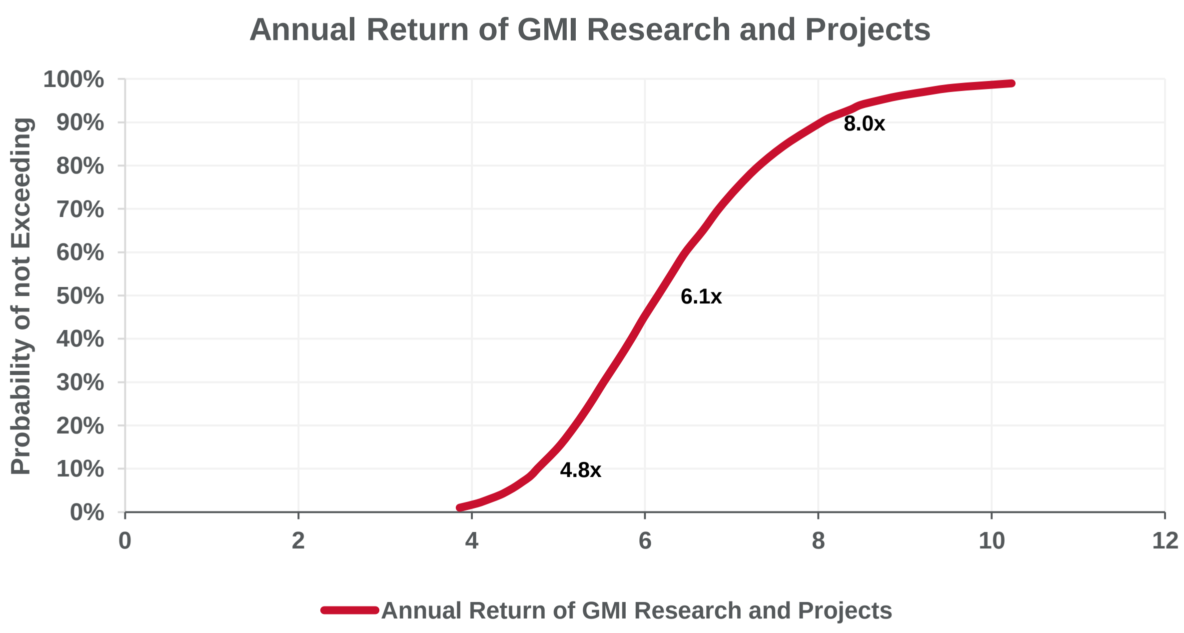
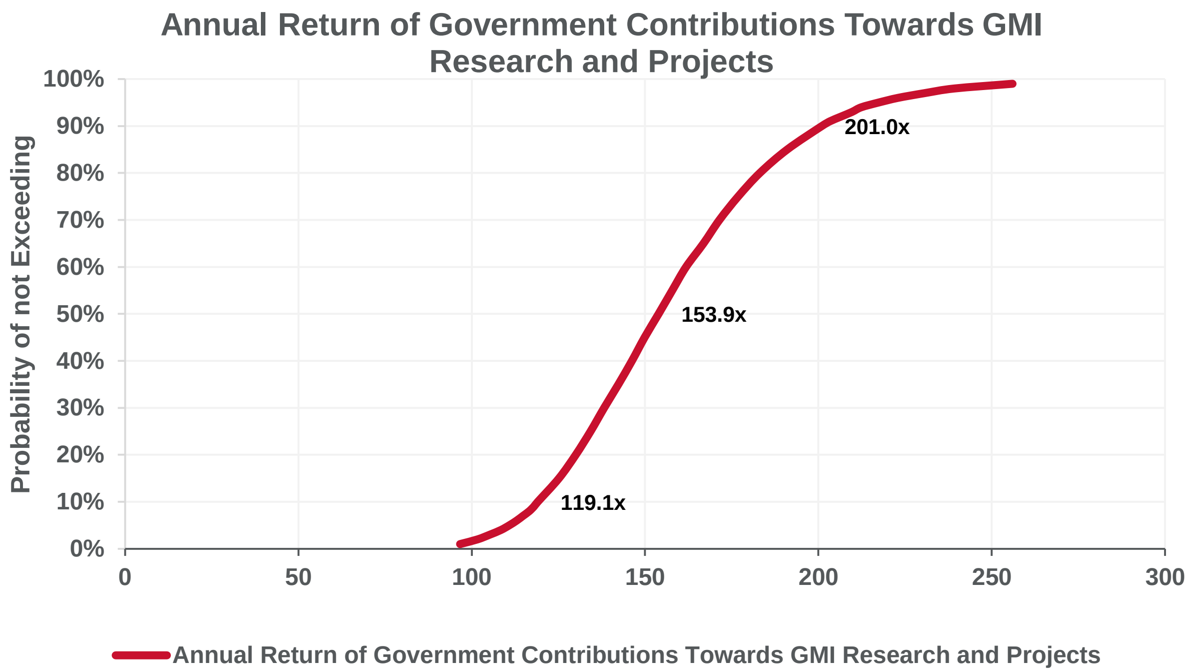


Figure 3 – Annual Return of GMI Research and Projects including both Government and Industry Contributions



1. Introduction

Background

Mining is important to Canada's economy. In 2013, the mining industry contributed $54 billion to Canada's gross domestic product ("**GDP**") and the industry accounted for almost 20% of Canadian goods exports.[4] The Canadian Government and provinces support the mining industry through a variety of programs, tax credits and other measures. The Green Mining Initiative ("**GMI**") was officially announced in 2009 and brought together green mining science and technology ("**S&T**") and research and development ("**R&D**") work which had already been undertaken with various stakeholders in the mining sector by CanmetMINING as part of the Mines and Minerals Sector ("**MMS**").[5] GMI targets the development of innovative energy-efficient technologies required for mining to leave behind only clean water, rehabilitated landscapes and healthy ecosystems. It aims to improve the mining sector's environmental performance, to promote innovation in mining and to position Canada's mining sector as the global leader in green mining technologies and practices.[6]

Under the GMI, research activities focus on six priorities:

- Northern Minerals Development;
- Strategic and Critical Metals Processing;
- Energy Efficiency in Mining and Milling;
- Mining Extraction Innovation
- Best Practices in Mining Environmental Management; and
- Clean Water.[7]

The GMI is comprised of a variety of research projects tied to one of the priorities above focused on improving economic, environmental, health and safety and social outcomes associated with mining. In doing so, the GMI generates socioeconomic benefits and impacts for Canadians and the mining industry that are important for policymakers, stakeholders and the broader public to assess and understand. Our review of thirteen specific GMI research projects GMI indicates that the GMI has helped generate the following types of socioeconomic impacts:

- Decreased greenhouse gas ("**GHG**") emissions;
- Decreased criteria air contaminants ("**CACs**") including particulate matter ("**PM**"), sulphur dioxide ("**SO_2**") and others;

[4] Mining Facts (2014). The Mining Association of Canada. Retrieved from http://mining.ca/resources/mining-facts.
[5] Final Evaluation Report: Evaluation of the Green Mining Initiative (February 2015). Natural Resources Canada.
[6] Green Mining Initiative (2013). Natural Resources Canada. Retrieved from http://www.nrcan.gc.ca/mining-materials/green-mining/8178.
[7] Green Mining Initiative (2013). Natural Resources Canada. Retrieved from http://www.nrcan.gc.ca/mining-materials/green-mining/8178.

- Decreased workplace injuries and fatalities;
- Improved energy efficiency/decreased energy costs;
- Increased productivity/time savings;
- Decreased mining and business costs/increased revenues;
- Decreased water usage;
- Decreased water contamination/acid mine drainage;
- Decreased land degradation impacts; and
- Decreased wildlife/fisheries impacts.

From 2009 to 2014, the Federal Government invested nearly $56 million in the GMI. The GMI operates under a leverage model, where research projects are co-funded by private sector or other public sector partners through cash or in-kind contributions. This plays an important role in magnifying the socioeconomic impact of the GMI and also helps ensure collaboration between industry, academia and the public sector. Based on the most recent evaluation of the GMI, the GMI is particularly successful at leveraging contributions from industry, academia and non-governmental organizations ("**NGOs**") – in 2011-12 financial and in-kind contributions totalled $47.2 million from partners, which is over 5-times base funding for the GMI program.[8] Few government S&T and R&D programs achieve this level of leverage.

While conducting R&D in Canada is certainly positive for the Canadian economy, government stakeholders want to better understand the broader socioeconomic impacts of the GMI and to assess whether investing in the GMI is provides economic, environmental and social impacts. Accordingly, Natural Resources Canada ("**NRCan**") engaged HDR Corporation ("**HDR**") to assess and estimate the broader socioeconomic impacts of the GMI employing HDR's Sustainable Return on Investment ("**SROI**") methodology. SROI is a methodology developed by HDR to monetize (i.e., put a dollar value on) changes in socioeconomic outcomes. By doing so, SROI enables comparison of socioeconomic impacts to financial costs associated with a bringing about these changes and has been used by policymakers to assess the societal benefits and costs associated with government investments. HDR has employed SROI to evaluate over $15 billion in capital expenditures and program funding, which provides a rich database to draw on for the present study. The specific objectives of this study are laid out below.

It should be noted that this Green Mining Initiative Impact Study encompassed projects which are categorized under the following Natural Resource Canada's Program Activity Architecture (PAA) sub-programs: *Green Mining* (sub-program 2.2.2) and *Mining Innovation* (sub-program 1.2.1). The projects selected for this study share the goal of achieving both environmental and economic benefits for Canada.

[8] Final Evaluation Report: Evaluation of the Green Mining Initiative (February 2015). Natural Resources Canada.

Study objectives

The objectives of the present study – entitled the *Green Mining Initiative Impact Study* – are to quantify and monetize the socioeconomic impact of selected GMI technologies and projects from 2007 to present in the following areas:

- Economic competitiveness, productivity and market opportunities;
- Environment, including changes to regulations, protocols and guidelines;
- Miner health and safety, including changes to codes and regulations; and
- Other areas, including innovation in the mining sector international capacity building, and professional development.

HDR was specifically engaged to complete the following tasks:

- Review the previous impact study;
- Meet with NRCan to review the scope of the study, the proposed questions and to discuss the approach to be taken;
- Finalize the questionnaire template;
- Develop a methodology that identifies the approach that will be taken;
- Consult and report progress updates periodically to the Director General "DG";
- Conduct interviews with clients to acquire the relevant information using the questionnaire template; and
- Produce a final report regarding the socioeconomic impact of the GMI.

Approach

The approach employed to meet the objectives of this study are described in detail in the table below.

Table 1 – Overview of approach

Phase	Activities
Phase 1: Project Initiation and Initial Review	• Develop the project plan, communication protocols and project charter. • Obtain and review all relevant reports on the GMI including the previous impact study. • Develop the draft reporting framework for the final report. • Conduct a formal, in-person kick-off meeting with NRCan to reconfirm

Phase	Activities
	objectives for this project and review the project plan and reporting framework. • Obtain and review information (e.g., past reports, research mandates and/or other documents) about the 12-15 GMI projects that form the scope of this study. For each research project, determine the key socioeconomic impact metrics.
Phase 2: Survey and Methodology Development	• Develop a draft version of the survey based on the socioeconomic impact categories determined in Phase 1 and the nature of the 12-15 GMI projects. The survey will be designed such that the interview can be completed in 30 minutes. • Submit the survey/interview guide to NRCan for review and comment. • Meet with NRCan to obtain feedback on the survey. • Update the survey based on comments and feedback received. • Draft letters of introduction on behalf of NRCan. • Obtain an interviewee list from NRCan, which includes contact information and connection to a specific GMI project(s). • Schedule interviews with interviewees.
Phase 3: Interviews	• Conduct interviews with up to 30 GMI clients and contributors based on the survey developed in Phase 2. • Submit notes to interviewee for review and comment. • Consolidate interview notes and document key findings with respect to the socioeconomic impacts of implementation of GMI technologies in a brief MS PowerPoint presentation. • Meet with NRCan to review key findings (e.g., with respect to socioeconomic impact categories: decreased GHGs/CACs, decreased lost workdays due to injury etc.) and discuss implications.
Phase 4: SROI	• Develop the SROI model to monetize identified socioeconomic impacts of the GMI. • Populate the model with data collected from the interviews and data and information from various other sources (e.g., academic literature, government reports) to monetize socioeconomic impacts. • Estimate the monetary value of socioeconomic impacts generated by implementation of the GMI and compare to government funding levels to calculate a leverage ratio. • Document findings in a brief memorandum and submit to NRCan for review and comment.
Phase 5: Reporting	• Develop a draft report that outlines and highlights key findings, describes the methodology employed and lists all data/assumptions used/made. The draft report will be based on the reporting framework

Phase	Activities
	established in Phase 1 of this project. • Submit the draft report to NRCan for review and comment. • Meet with NRCan to obtain feedback and to review comments. • Finalize based on a consolidated list of comments received from NRCan.

Limitations

HDR has relied upon the completeness, accuracy and fair presentation of all the information, data, advice, opinion or representations obtained from public sources and from NRCan (collectively, the "**Information**"). The findings in this report are conditional upon such completeness, accuracy and fair presentation of the Information. HDR has not verified independently the completeness, accuracy and fair presentation of the Information. Accordingly, HDR provides no opinion, attestation or other form of assurance with respect to the results of this study.

HDR reserves the right, at its discretion; to withdraw or make revisions to the report should HDR be made aware of facts existing at the date of the report which were not known to HDR when it prepared the report. The findings are as of October 2015 and HDR is under no obligation to advise any person of any change or matter brought to its attention after such date which might affect the report's findings and HDR reserves the right to change or withdraw this report.

This information has been prepared solely for the use and benefit of NRCan, and pursuant to a client relationship exclusively with HDR. HDR disclaims any contractual or other responsibility to others based on its use and, accordingly, this information may not be relied upon by anyone other than HDR. Any use that a third party makes of this report or reliance thereon, or any decision made based on it, is the responsibility of such third party. HDR accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions taken, based on this report.

Report structure

The structure of this report is outlined below:

- Section 2 provides an overview of the GMI and the projects selected for this study.
- Section 3 describes the methodology employed to estimate and assess the socioeconomic impact of the GMI employing HDR's SROI methodology.
- Results of the analysis are laid out in Section 4.
- Section 5 concludes with recommendations and key findings.

Note to reader

This report has been prepared by HDR based on data and information provided by NRCan, stakeholders and from other sources. HDR's assessment of the GMI's socioeconomic impact is based on this data. In preparing this report, HDR has strived to be as transparent as possible in terms of the methodology employed, data sources used and any assumptions made. It is important to note that HDR's assessment of the socioeconomic impact of the GMI projects is solely based on the interviews completed as part of this study and on information provided by NRCan. Thus, it represents a conservative estimate of the impact of the selected GMI projects.

2. Overview of GMI and research projects

Introduction

This section of the report provides an overview of the GMI and the specific GMI research projects selected for this study. NRCan recently completed an evaluation of the GMI, which included laying out a logic model. This logic model is used to describe the overarching mandate of the GMI and how activities conducted by NRCan via the GMI help achieve the stated goals of the GMI and NRCan. The GMI operates under a leverage funding model, an important feature of the GMI, which is also described in this section of the report.

Mandate and objectives

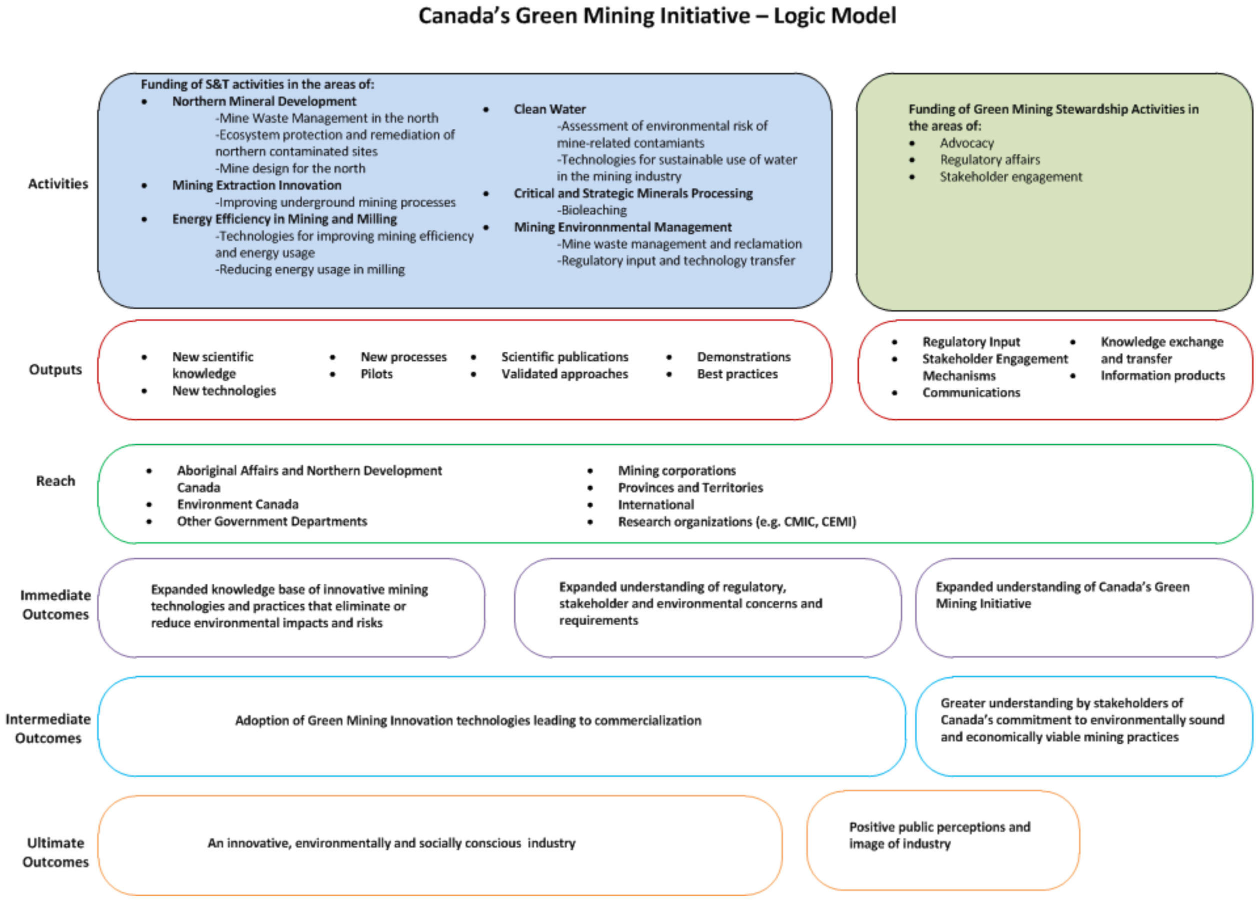
The GMI, under the collaborative leadership of NRCan, brings together various stakeholders to develop green technologies, processes and knowledge for sustainable mining. GMI targets the development of innovative energy-efficient technologies required for mining to leave behind only clean water, rehabilitated landscapes and healthy ecosystems. It aims to improve the mining sector's environmental performance, to promote innovation in mining and to position Canada's mining sector as the global leader in green mining technologies and practices.[9] Research activities under the GMI focus on the following priorities:

- Northern Minerals Development;
- Strategic and Critical Metals Processing;
- Energy Efficiency in Mining and Milling;
- Mining Extraction Innovation;
- Best Practices in Mining Environmental Management; and
- Clean Water.[10]

The GMI works collaboratively and closely with the mining industry, other federal departments, provincial and territorial governments, academia and stakeholders across other related sectors. The logic diagram below illustrates the workings of the GMI.

[9] Green Mining Initiative (2013). Natural Resources Canada. Retrieved from http://www.nrcan.gc.ca/mining-materials/green-mining/8178.
[10] Ibid.

Figure 4 – GMI logic model[11]



The GMI provides support in partnership with industry or other federal, provincial and/or territorial governments for S&T activities aligned to the research priorities listed above. This leads to new technologies, processes, scientific publications and demonstrations/pilots, which are then diffused via a variety of mechanisms to the mining industry in Canada and abroad and across the public sector. The selected GMI research projects include several mature projects that have had a tangible and demonstrable socioeconomic impact and some concept or early stage projects that focus on demonstrating technical feasibility. In terms of immediate outcomes, S&T activities conducted as part of the GMI result in an expanded knowledge base of innovative mining technologies and practices that eliminate or reduce environmental impacts and risks and a better understanding of the regulatory, stakeholder and environmental requirements. A better understanding of green mining technologies leads to adoption and commercialization of these technologies and/or know-how, which ultimately generates positive socioeconomic impacts across Canada. In addition to S&T activities, the GMI also performs various stakeholder engagement activities that ultimately help promote green mining technologies and improve the public perception of the mining industry.

[11] Final Evaluation Report: Evaluation of the Green Mining Initiative (February 2015). Natural Resources Canada.

Research priorities and projects

This GMI study is comprised of several research projects. As noted above, some of these are mature and predate the establishment of the GMI and others are still very much at the concept or pilot stage. The table below provides a high level overview of the projects that comprised the GMI between 2007 and present, and the types of socioeconomic benefits they help generate.

Figure 5 – Description of research projects

Project	Description
Certified Reference Materials	The Canadian Certified Reference Materials Project (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, whether mining is economical, whether a concentrate is undervalued, or whether emission control specifications are being met. Improved laboratory analyses through the use of CRMs can therefore affect decisions concerning the economics of exploration and mining, the commodity value, and actions to safeguard the environment.[12] As a result, the CCRMP has the potential to generate a wide variety of socioeconomic impacts.
Diesel Engine Emissions and Characterization and Certification for Underground Mine Use	The Diesel Engine Emissions and Characterization and Certification for Underground Mine Use ("Diesel Engine Certification") project has established a group of specialists in mine ventilation, ventilation automation, diesel-engine emissions control and certification, as well as underground contaminants monitoring and control. The goal for this project is to improve air quality and safety in the underground mine environment, and to evaluate approaches that may provide savings in both capital and operating expenses.[13]
Extraction and Stabilization of Radioactive Wastes	The Extraction and Stabilization of Radioactive Wastes Project develops methods and innovative techniques to characterize, treat and stabilize both solid and liquid forms of radioactive wastes. The research carried out by this project minimizes the environmental impact of the wastes generated by the mining and other industries.[14] Currently, the Extraction and Stabilization of Radioactive Wastes Project is focused on developing methods and approaches to deal with nearly 500 cubic metres of radioactive cement, which is a by-product of the production of medical isotopes at Chalk River Laboratories. Chalk River

[12] FAQs – Certified Reference Materials (2013). Natural Resources Canada. Retrieved from http://www.nrcan.gc.ca/mining-materials/certified-reference-materials/8147.
[13] Canadian Company Capabilities (2015). CanmetMINING. Retrieved from http://www.ic.gc.ca/app/ccc/srch/nvgt.do?lang=eng&prtl=1&sbPrtl=&estblmntNo=234567037879&profile=cmpltPrfl&profileId=1921&app=sold.
[14] Radioactive Waste Management (2013). Natural Resources Canada. Retrieved from http://www.nrcan.gc.ca/mining-materials/radioactive-waste-management/8838.

Project	Description
	Laboratories produces the significant share of the world's medical isotopes such as molybedenum-99, which is used to diagnose cancer and heart ailments. The shutdown of the National Research Universal ("NRU") reactor at Chalk River Laboratories in 2007 caused a worldwide shortage of medical isotopes.[15] The 500 cubic metres of radioactive cement stored at Chalk River would cost Canadian taxpayers up $500 million to dispose of using conventional methods.[16] More broadly, research conducted through the Extraction and Stabilization of Radioactive Wastes can help address Canada's broader nuclear liability, which is estimated at over $20 billion.[17] The Extraction and Stabilization of Radioactive Wastes Project has potential to generate significant socioeconomic benefits, generate public revenues through sale of weapons grade uranium to the United States, and decrease future costs faced by Canadian taxpayers.
Transformation/ Dissolution Protocols for Metals and Sparingly Soluble Inorganic Metal Compounds	The Transformation/ Dissolution Protocols for Metals and Sparingly Soluble Inorganic Metal Compounds Project focuses on classifying and characterizing nickel and nickel compounds with respect to its impact on the environment. Nickel in certain forms can be highly toxic and harmful to humans, animals and the broader environment – the Environmental Protection Agency ("EPA") classifies nickel refinery dust and nickel subsulfide as Group A (human carcinogen) and nickel carbonyl as Group B2 (probably human carcinogen) and Environment Canada classifies oxidic, Sulphidic and soluble inorganic nickel compounds as a toxic substance.[18] Understanding in what forms nickel compounds are less or more harmful to humans, animals and the environment is critical to the nickel mining industry in Canada and abroad and Canada is one of the largest producers of nickel – it was the 4th largest producer in 2014.[19] Research conducted through the Transformation/ Dissolution Protocols for Metals and Sparingly Soluble Inorganic Metal Compounds Project allows nickel producers to better characterize, classify and assess the nickel compounds, which generates various environmental benefits and cost savings. For instance, the International Maritime Organization's ("IMO") classification of harmful materials that are shipped in bulk requires much more restrictive and costly shipping practices. The cost of shipping an IMO

[15] Chalk River makes 1st isotopes in 15 months (2010). CBCNews. Retrieved from http://www.cbc.ca/news/technology/chalk-river-makes-1st-isotopes-in-15-months-1.941869.
[16] This is based on information HDR received from the stakeholder interviews. Conventional Methods refers to storing the radioactive material in a Nuclear Waste Management Organization ("**NMWO**") fuel repository.
[17] This is based on information received from the stakeholder interviews.
[18] Toxic Substances List – Schedule 1 (2015). Environment Canada. Retrieved from https://www.ec.gc.ca/lcpe-cepa/default.asp?lang=En&n=0DA2924D-1&wsdoc=4ABEFFC8-5BEC-B57A-F4BF-11069545E434.
[19] 10 Top Nickel-producing Countries (2015). Nickel | Investing News. Retrieved from http://investingnews.com/daily/resource-investing/base-metals-investing/nickel-investing/10-top-nickel-producing-countries/.

Project	Description
	classified harmful bulk product can be 10% to 30% more than otherwise and generally speaking over classification. Properly classifying nickel compounds (and other inorganic metal compounds), thus, generates significant cost savings for nickel producers and increases the competitiveness of Canada's nickel mining industry while maintaining appropriate regulations to protect humans and the broader environment. As part of this project, NRCan provides laboratory testing services for the Nickel Producers Environmental Research Association ("NiPERA").
Testing of Tendons and Other Ground Support Elements	The Testing of Tendons and Other Ground Support Elements project enables product developers to test various ground support products that are instrumental to the safety and production of underground mines. In 2003, NRCan acquired specialized impact-testing apparatus developed by Noranda in the late 1990s and moved it to Ottawa. Since its acquisition, NRCan has greatly modified and enhanced the impact-testing apparatus.[20] This apparatus is one of few in the world that enable dynamic impact-testing[21], which is increasingly becoming a key design parameter in underground mining.[22]
Contiscan	Contiscan is an electromagnetic, continuous surveillance system for monitoring mine hoist cables. The system enables real-time and normal speed detection of all critical parameters to ensure the integrity of hoisting cables and that they conform to existing regulations.[23] Regulations surrounding hoist cables are quite stringent in many jurisdictions including Canada, which is not surprising given the importance of hoist cables to underground mining and the level of stress hoist cables endure. Hoist cables need to be manually inspected on a weekly basis, which typically takes about an hour to complete. Contiscan removes the need to do so manually, thereby removing the need to shutdown the mine on a weekly basis, which increases the productivity of the mine. Because it is continuously scanning hoist cables, the safety factor associated with hoist cables, which specifies the amount of tonnes of muck[24] that can be moved, can be decreased to enable increased mine productivity. Such monitoring becomes more and more important as mines become deeper and hoist cables longer. Meglab, a private company based out of Val-d'Or,

[20] Plouffe, Michael; Ted Anderson and Ken Judge (2007). CANMET – Mining and Mineral Sciences Laboratories. Retrieved from http://www.saimm.co.za/Conferences/GroundSupport2008/581-596_Plouffe.pdf.
[21] This is based on interviews with stakeholders. The only other similar equipment is in Australia and the United States.
[22] Plouffe, Michael; Ted Anderson and Ken Judge (2007). CANMET – Mining and Mineral Sciences Laboratories. Retrieved from http://www.saimm.co.za/Conferences/GroundSupport2008/581-596_Plouffe.pdf.
[23] ContiScan – Continuous Monitoring Wire Ropes for Mine Hoisting Operations (2013). Presentation given to the 23rd World Mining Congress. Retrieved from http://www.meglab.ca/assets/documents/files/wmc2013_ppt_meglab_contiscan_13-03-27.pdf.
[24] Muck refers to ore or rock that has been broken by blasting.

Project	Description
	Quebec, has a license to manufacture and sell Contiscan, but the intellectual property ultimately belongs to NRCan. At present, the Contiscan project is still very much in the early/pilot stage.
Green Mines Green Energy	The GMGE project uses organic wastes such as municipal compost and forestry biosolids – materials that may typically go to landfill, to reclaim mining lands and grow energy crops. For instance, some estimates suggest that oilseed production on mine tailings could generate approximately 3,600 litres per hectare or nearly 5 million litres per year if just 1,300 of the more than 2,500 hectares of tailings in the Sudbury area are converted to agricultural land.[25] Tests completed through the GMGE project indicated that this approach has proven to be successful with corn, canola and switchgrass crops achieving higher yields at mine site experimental plots compared to crops grown at a reference agricultural land.[26] In addition to providing mining companies with another sources of revenue, the GMGE project can also generate broader socioeconomic benefits through the production of biofuels, provide another source of revenue for providers of biomass providers (i.e., the pulp and paper industry and municipalities), increase landfill waste diversion and potentially decrease acid mine leakage. GMGE, however, is still in the demonstration phase.
Mine Environmental Neutral Drainage Prediction Manual for Drainage Chemistry from Sulphidic Geological Materials	Since 1989, the Mine Environment Neutral Drainage ("MEND") project has worked to develop technologies to prevent and control acidic drainage – the single largest contributor to the mining industry's environmental liability. The MEND project was the first international initiative to develop technologies to reduce the effect of acidic drainage.[27] Technologies, processes and know-how developed through the MEND project have had a significant impact across Canada and in the mining industry. An evaluation of the MEND project completed in 1996 concluded that the project had generated total cost savings of roughly $340 million due to decreased opening, operating and closing costs.[28] The MEND prediction manual is a specific aspect of the broader MEND project, which provides technical guidelines with respect to the prediction of drainage chemistry from Sulphidic geological materials. It is very much considered the go-to reference document in the field of acid mine drainage and drainage

[25] National Collaboration (2013). Natural Resources Canada. Retrieved from http://www.nrcan.gc.ca/mining-materials/national-collaboration/8574.
[26] Green Municipal Fund Final Report – Green Mines Green Energy (2011). MIRARCO.
[27] National Collaboration (2013). Natural Resources Canada. Retrieved from http://www.nrcan.gc.ca/mining-materials/national-collaboration/8574.
[28] Evaluation Study of the Mine Environment Neutral Drainage Program (1996). MEND. Retrieved from http://mend-nedem.org/wp-content/uploads/59.pdf.

Project	Description
	chemistry, which is evidenced by the fact that it is referenced in various provincial mining acts.[29]
Characterization and Disposal of Sludges	Conventional techniques in the treatment of acidic mineral effluent, such as lime neutralization, tend to result in voluminous, hard to settle and metal laden sludge.[30] Disposing of these sludges poses several challenges for mining companies and not disposing of it in an appropriate manner can lead to significant environmental consequences. The Characterization and Disposal of Sludges project conducts research on identifying and assessing technologies and approaches to safely and cost-effectively dispose of sludges. Classifying and characterizing sludges is important to identifying appropriate approaches to disposing of it.
Application of Rotating Biological Contractor for Treatment of Gold Mill Effluent	Interviews not conducted.
Québec hoisting plants safety and optimization	Interviews not conducted.
Optimization of Cyanide for Gold/Silver Recovery / CANMET Enhanced Leaching Process (CELP)	The CANMET Enhanced Leaching Process (CELP) was developed through optimization studies aimed at reducing the amount of environmentally harmful cyanide required in gold and silver extraction processes. CELP is a proprietary technology and has shown tremendous cost savings promise for silver extraction in a laboratory setting, but has had limited industrial applications. A wider implementation of the process in the future is expected to generate cost savings through improvements in silver extraction efficiency and greatly reducing leaching cyanide concentration.
Microseismic Monitoring of Oil Sands	In partnership with IOL and CNRL, GMI has been involved in research and development of various oil sands extraction techniques and passive microseismic monitoring techniques. Since management from both companies declined to be interviewed, CanmetMINING provided the following discussion on the impacts of this project: The passive seismic monitoring was initially designed to detect leaks and oil well failures in the shale layer above the reservoir. Shortly after its implementation, it proved to be capable of detecting well failures deeper in the reservoir. The shallow type of failure happens less often but can have catastrophic

[29] For instance, stakeholder interviews indicated that the MEND prediction manual is part of the Ontario Mining Act and Quebec's Mining Act.
[30] Zinck, Janice (2005). Review of Disposal, Reprocessing and Reuse Options for Acidic Drainage Treatment Sludge. CANMET Mining and Mineral Sciences Laboratory.

Project	Description
	consequences from an environmental point of view due to the danger of aquifer contamination. The deeper failures are less of a concern from an environmental point of view but can have negative consequences for oil production. The GMI work has helped avoid both types of leaks. Past research has made it possible to detect 10-20 oil wells failures every single year. Although only a few of these failures are shallow enough to cause leakage to surface, the fact that they were detected in time and taken care of has avoided many leaks as the ones experiences by CNRL in 2013 with undeniable environmental benefits. Other positive impacts of avoiding oil leakage lies in avoiding water contamination, cleaning costs and negative impacts on wildlife.

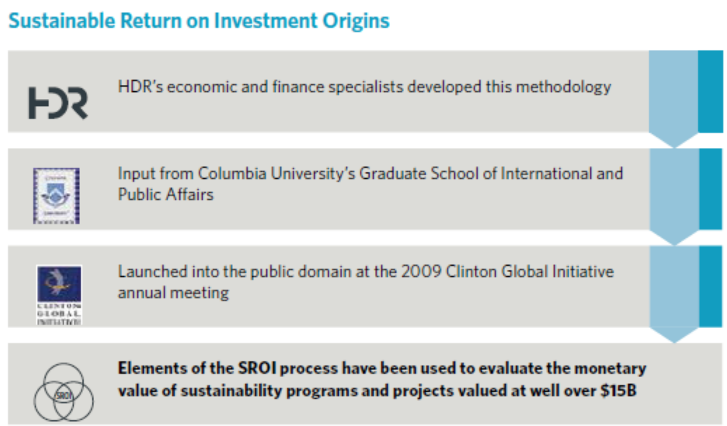
3. Methodology

Introduction

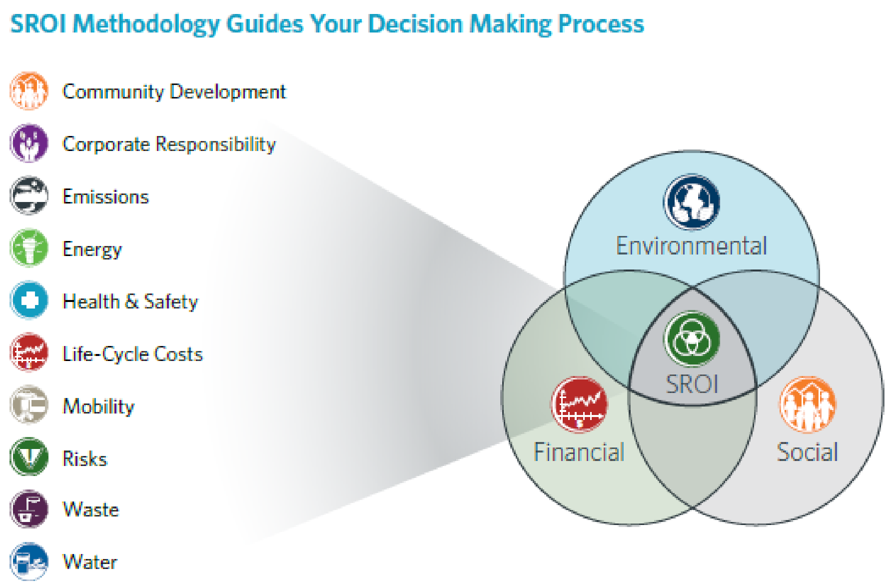
This section of the report provides an overview of the methodology employed to estimate the socioeconomic impact of the selected GMI projects based on HDR's SROI methodology. An overview and description of SROI is first provided followed by a description of how it was tailored to meet the requirements of this study. The stakeholder interview process is also described and documented in this section of the report. A detailed description of the methodology employed and data sources used can be found in the Appendix.

Overview of SROI

SROI originated from a commitment to action by HDR to develop a new generation of public decision support metrics for the Clinton Global Initiative ("**CGI**") with input from Columbia University's Graduate School of International and Public Affairs. Since it was launched at the 2009 CGI annual meeting, it has been used to evaluate projects with capital expenditures in excess of $15 billion.



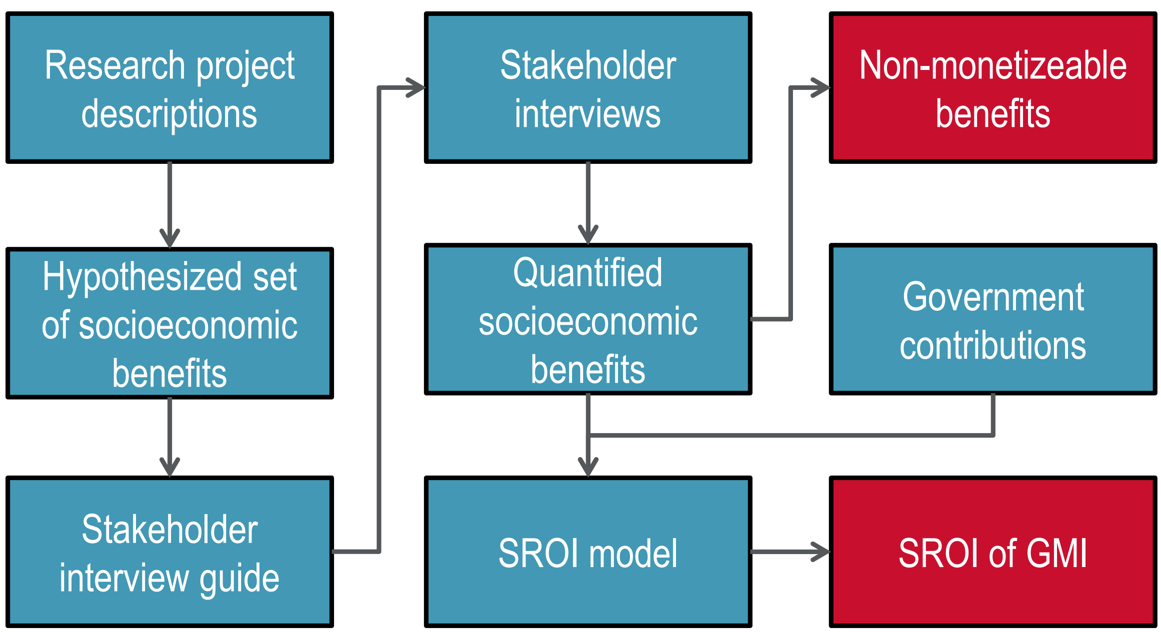
SROI focuses on credibly and transparently estimating the monetary value of socioeconomic impacts such as decreased GHG emissions reductions, decreased CACs, improved health and safety, cleaner water, improved productivity, increased energy efficiency, decreased traffic congestion and a host of other socioeconomic benefits.



Methodology to estimate SROI of the GMI

The methodology employed to estimate the SROI of the GMI is illustrated in the diagram below.

Figure 6 – Methodology to estimate SROI of the GMI



First, descriptions of the specific GMI research projects included in this study were obtained from NRCan. This information was then reviewed, which enabled HDR to determine a potential list of socioeconomic benefits that each specific project helps generate. An interview guide was then developed to obtain the necessary independent quantitative data to enable monetization of socioeconomic impacts as a result of the GMI projects. NRCan commented on the interview guide and then provided a list of stakeholders to interview (see below for a description of the interview process). Interviews were then conducted to obtain the necessary independent quantitative data and information to enable monetization of the socioeconomic impacts of the GMI employing HDR's SROI methodology. Some benefits and socioeconomic impacts are not possible to quantify and monetize on a credible basis based on the empirical evidence available (i.e., what is referred to as non-monetizable benefits in the diagram above). This information was not used as part of the SROI analysis, but was used to more qualitatively assess the socioeconomic impact of the selected GMI projects. Data was then obtained from NRCan regarding funding for the GMI, which was used to calculate the SROI of the GMI projects.

It is important to note the following regarding the SROI methodology employed:

- NRCan provided HDR specific guidance to focus on socioeconomic impacts that the GMI has historically provided as opposed to what the GMI could generate on a forward looking basis. Research projects, like for example the Green Mines Green Energy ("**GMGE**") project, are still very much in demonstration phase. Accordingly, they have generated only minor socioeconomic impacts to date despite having significant potential.

- Socioeconomic impacts are only monetized if the following two conditions are met: (1) credible data and information is obtained from stakeholders regarding changes in socioeconomic outcomes realized to date (e.g., a specific reduction in GHG or decreased injuries) and (2) there is sufficient and credible publicly available information that can be relied upon that enables monetization of changes in socioeconomic outcomes (e.g., dollar per tonne of GHG reduction). This is in fact a very high threshold to achieve. As a result, one should interpret the SROI results as a conservative, but highly credible estimate of the value generated by the GMI. Furthermore, the absence of benefit quantification for a given project or effect does not in any way imply that benefits do not exist or that the benefits are insignificant.

- All data and information used to quantify and monetize the SROI of the GMI projects is presented in the Appendix. This level of detail is provided so users of this report can appropriately critique and assess the methodology employed and input values used.

- HDR's SROI methodology employs Monte Carlo simulation to reflect the risk associated with the estimation of the socioeconomic impacts of the GMI projects. This approach is well suited for the current impact study given that several of the stakeholders interviewed could only provide quantitative data regarding changes in socioeconomic outcomes as a range (e.g., a 5% to 10% reduction in energy costs). Other stakeholders were highly uncertain about some of the quantitative data they were providing. Where warranted, this uncertainty was reflected in the size of the range around the point estimate. For instance, if a stakeholder indicated that they thought that one of the GMI projects generated a 10% reduction in workplace injuries, but did not have a lot of confidence around this estimate, then a range of 0% to 10% could have been used in the SROI model. All else being the same, HDR adhered to the principal of conservatism in selecting ranges and to formulate distributional assumptions.

- It is important to stress that HDR's assessment of the monetary value of socioeconomic benefits generated by the GMI projects is largely based on data and information obtained from the interviews conducted as part of this study. Thus, the SROI results only reflect the number on the interviews conducted and the quality of the information received.

- While SROI typically incorporates all life cycle impacts of a project, this study looks at GMI socioeconomic impacts from a "representative year" standpoint based on SROI methodology and principles, and does not attempt to quantify forward-looking impacts.

The following section the report describes the stakeholder interview process.

Stakeholder interviews

As noted above, interviews with stakeholders were the primary means of obtaining the necessary quantitative data and information HDR used to monetize socioeconomic impacts. At the outset of this project, HDR contacted project managers to discuss the type of data and information required. NRCan then provided HDR a list of stakeholders for each GMI project selected for this study. GMI project managers were asked to contact stakeholders prior to HDR reaching out to them to ensure that they could provide the quantitative information required. NRCan then sent an email letter to each stakeholder formally asking them to participate in an interview. The letter also described why this study was being undertaken (see the Appendix for an example). HDR then contacted each stakeholder to setup a time to meet. The interview guide was sent in advance of each meeting. Stakeholders interviewed had direct experience of the specific research project, but were not currently employees of NRCan. Individuals selected to be interviewed where chosen on the basis of who would be best positioned to provide the necessary quantitative information. Interviews were conducted in June, July, August, September and October of 2015. The table below shows the individuals that were interviewed and they are categorized by the specific research project to which they had experience with and the organizations they are currently with.

Table 2 – List of stakeholders interviewed by project

Project	Stakeholder interviewed and organization
Certified Reference Materials	Valerie Kuch, SGS
Diesel Engine Emissions and Characterization and Certification for Underground Mine Use	Claude Ferland, Association minière du Québec
Extraction and Stabilization of Radioactive Wastes	Mark Chapman, Canadian Nuclear Labs
Transformation/Dissolution Protocols for Metals and Sparingly Soluble Inorganic Metal Compounds	Emily Garman, Nickel Producers Environmental Research Association

Project	Stakeholder interviewed and organization
Testing of Tendons and Other Ground Support Elements	Francois Charette, Normet
Contiscan	Dominic Valade, Meglab
Green Mines Green Energy	Michael Payne, Black Lake Environmental
	Lisa Lanteigne, Vale
	Joe Fyfe, Glencore
Mine Environmental Neutral Drainage Prediction Manual for Drainage Chemistry from Sulphidic Geological Materials	Ron Nicholson, Ecometrix Incorporated
	Kim Bellefontaine, B.C. Ministry of Energy and Mines
Characterization and Disposal of Sludges	Bernard Aubé, AMEC
	Robert Prairie, Eco-Services CSF
Application of Rotating Biological Contractor for Treatment of Gold Mill Effluent	Interviews not conducted.
Québec hoisting plants safety and optimization	Interviews not conducted.
Optimization of Cyanide for Gold/Silver Recovery / CANMET Enhanced Leaching Process (CELP)	Guy Deschênes, BBA
Microseismic Monitoring of Oil Sands	Interviewees declined to participate in an interview for this project, but HDR received written comments from Domenic Torriero of Canadian Natural Resources Limited and from Kristie Tarr of NRCan.

HDR also had several discussions over the course of this engagement with project managers at NRCan and in some cases multiple interviews were conducted with project managers and with stakeholders listed above. Generally, interviews lasted about an hour even though they were only scheduled for 30 minutes. The interview guide (shown in the Appendix) was used as a rough guide to direct interviews. The questions asked to each stakeholder depended on the specific research project and the types of socioeconomic impacts the project could potentially generate.

Again, the objective of the stakeholder interviews was to obtain the necessary independent quantitative data and information that could enable HDR to monetize the socioeconomic impacts of the GMI projects. Given the importance of the stakeholder interviews to the study approach, HDR asked NRCan project managers to contact each stakeholder to ensure that they could provide the necessary quantitative information. Despite this additional step taken, stakeholders found it very difficult to answer the questions with a high degree of confidence. This uncertainty was reflected in the SROI analysis.

4. Socioeconomic Impact of GMI

Introduction

This section of the report provides the results of the SROI analysis, the socioeconomic impact of the selected GMI projects. The tables below outline for which projects sufficient data and information was received to enable monetization of the socioeconomic impacts. These monetized impacts are classified into "Economic Competitiveness Benefits" which include increased economic competitiveness, productivity and market opportunities, and "Social & Environmental Benefits" which encompass enhanced health and safety and improved environmental outcomes. While improved outcomes in other areas including innovation, international capacity building and professional development are not monetized and thus not reflected in the SROI results, they are vital components of the GMI.

Table 3: Summary of Socioeconomic Impacts: Certified Reference Materials

Project name	Certified Reference Materials
Project description	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, whether mining is economical, whether a concentrate is undervalued, or whether emission control specifications are being met. Improved laboratory analyses through the use of CRMs can therefore affect decisions concerning the economics of exploration and mining, the commodity value, and actions to safeguard the environment. As a result, the CCRMP has the potential to generate a wide variety of socioeconomic impacts.
NRCan funding	$283 thousand
Partner funding	$125 thousand
Impacts	Decreased GHG emissions ● Decreased CACs ● Decreased workplace injuries and fatalities ● Improved energy efficiency/decreased energy costs ● Increased productivity/time savings ● Decreased mining and business costs/increased revenues ● Decreased water usage ● Decreased water contamination/acid mine drainage ● Decreased land degradation impacts ● Decreased wildlife/fisheries impacts ● **Impacts quantified**: No impacts were quantified; however, revenues that NRCan receives from the sale of Certified Reference Materials manuals could potentially be included as a benefit. **Impacts not quantified**: socioeconomic impacts cannot be quantified due to a lack of accurate and reliable data. CCRMP does not keep the data on who is using the information they provide and what is in demand.

Table 4: Summary of Socioeconomic Impacts: Diesel Engine Emissions and Characterization and Certification for Underground Mine Use

Project name	**Diesel Engine Emissions and Characterization and Certification for Underground Mine Use**
Project description	The Diesel Engine Emissions and Characterization and Certification for Underground Mine Use (“Diesel Engine Certification”) project has established a group of specialists in mine ventilation, ventilation automation, diesel-engine emissions control and certification, as well as underground contaminants monitoring and control. The goal for this project is to improve air quality and safety in the underground mine environment, and to evaluate approaches that may provide savings in both capital and operating expenses.
NRCan funding	$36 thousand
Partner funding	$54 thousand
Impacts	Decreased GHG emissions ($000): **$2,567** Decreased CACs ($000): **$2,435** Improved energy efficiency/decreased energy costs ($000): **$514** Decreased mining and business costs/increased revenues: ● **Impacts quantified**: The major benefit of this project has been a more efficient use of diesel engines for ventilation purposes. The value of this benefit was estimated by 1. Taking the annual diesel and electricity consumption from specific metallurgical underground mine diesel and electricity – of which ventilation comprises a large majority – across Canada excluding Ontario where the project is not in effect. 2. Applying an assumption of 0% to 5% (with an expected value of 2.5%) reduction in emissions as a result of more efficient controls. 3. Applying emission factors for the avoided diesel and electricity use including the reduced emissions from taking load off the power grid (+/-25% with an 80% confidence). 4. Multiplying the results by social values of **greenhouse gas (GHG) and criteria air contaminants (CAC)** emissions which are further broken down into impacts on human health and vegetation based on economic literature. 5. An additional $500 thousand in annual **cost savings** was applied based on data from one participating mine, indicating that the cost savings would be significantly greater if taken across all mines impacted by the project. All values were estimated with ranges of uncertainty and assuming an 80% level of confidence. **Impacts not quantified**: While there are clearly significant energy cost savings across underground mines, data obtained as part of this project was insufficient to reliably estimate the actual cost savings realized by mine operators.

Table 5: Summary of Socioeconomic Impacts: Extraction and Stabilization of Radioactive Wastes

<table>
<tr><th>Project name</th><th>Extraction and Stabilization of Radioactive Wastes</th></tr>
<tr><td>Project description</td><td>The Extraction and Stabilization of Radioactive Wastes Project develops methods and innovative techniques to characterize, treat and stabilize both solid and liquid forms of radioactive wastes. The research carried out by this project minimizes the environmental impact of the wastes generated by the mining and other industries. Currently, the Extraction and Stabilization of Radioactive Wastes Project is focused on developing methods and approaches to deal with nearly 500 cubic metres of radioactive cement, which is a by-product of the production of medical isotopes at Chalk River Laboratories. Chalk River Laboratories produces the significant share of the world’s medical isotopes such as molybedenum-99, which is used to diagnose cancer and heart ailments. The shutdown of the National Research Universal (“NRU”) reactor at Chalk River Laboratories in 2007 caused a worldwide shortage of medical isotopes. The 500 cubic metres of radioactive cement stored at Chalk River would cost Canadian taxpayers up $500 million to dispose of using conventional methods. More broadly, research conducted through the Extraction and Stabilization of Radioactive Wastes can help address Canada’s broader nuclear liability, which is estimated at over $20 billion. The Extraction and Stabilization of Radioactive Wastes Project has potential to generate significant socioeconomic benefits, generate public revenues through sale of weapons grade uranium to the United States, and decrease future costs faced by Canadian taxpayers.</td></tr>
<tr><td>NRCan funding</td><td>$85 thousand</td></tr>
<tr><td>Partner funding</td><td>$15 thousand</td></tr>
<tr><td>Impacts</td><td><table>
<tr><td>Decreased mining and business costs/increased revenues</td><td>●</td></tr>
<tr><td>Decreased water contamination/acid mine drainage</td><td>●</td></tr>
<tr><td>Decreased land degradation impacts</td><td>●</td></tr>
<tr><td>Decreased wildlife/fisheries impacts</td><td>●</td></tr>
</table>
Impacts quantified: No impacts were quantified. This project is still in the early stages of its lifecycle and its potential benefits are expected to be realized in the future. While it’s hard to estimate any such future benefits, the expectation is that it would be in the millions of dollars.

Impacts not quantified: The potential benefits of reduction and proper radioactive waste disposal are great, ranging from ecological benefits and reduced environmental risks, to cost savings and other market opportunities related to medical isotopes and weapons grade uranium.</td></tr>
</table>

Table 6: Summary of Socioeconomic Impacts: Transformation/Dissolution Protocols for Metals and Sparingly Soluble Inorganic Metal Compounds

Project name	Transformation/Dissolution Protocols for Metals and Sparingly Soluble Inorganic Metal Compounds
Project description	The Transformation/ Dissolution Protocols for Metals and Sparingly Soluble Inorganic Metal Compounds Project focuses on classifying and characterizing nickel and nickel compounds with respect to its impact on the environment. Nickel in certain forms can be highly toxic and harmful to humans, animals and the broader environment – the Environmental Protection Agency ("EPA") classifies nickel refinery dust and nickel subsulfide as Group A (human carcinogen) and nickel carbonyl as Group B2 (probably human carcinogen) and Environment Canada classifies oxidic, Sulphidic and soluble inorganic nickel compounds as a toxic substance. Understanding in what forms nickel compounds are less or more harmful to humans, animals and the environment is critical to the nickel mining industry in Canada and abroad and Canada is one of the largest producers of nickel – it was the 4th largest producer in 2014. Research conducted through the Transformation/ Dissolution Protocols for Metals and Sparingly Soluble Inorganic Metal Compounds Project allows nickel producers to better characterize, classify and assess the nickel compounds, which generates various environmental benefits and cost savings. For instance, the International Maritime Organization's ("IMO") classification of harmful materials that are shipped in bulk requires much more restrictive and costly shipping practices. The cost of shipping an IMO classified harmful bulk product can be 10% to 30% more than otherwise and generally speaking over classification. Properly classifying nickel compounds (and other inorganic metal compounds), thus, generates significant cost savings for nickel producers and increases the competitiveness of Canada's nickel mining industry while maintaining appropriate regulations to protect humans and the broader environment. As part of this project, NRCan provides laboratory testing services for the Nickel Producers Environmental Research Association ("NiPERA").
NRCan funding	$172 thousand
Partner funding	$20 thousand
Impacts	Decreased mining and business costs/increased revenues ● Decreased water contamination/acid mine drainage ● Decreased wildlife/fisheries impacts ● **Impacts quantified**: No impacts were quantified. The project interview revealed that the majority of the socioeconomic benefits come from ensuing better environmental management rather than cost savings. **Impacts not quantified**: Socioeconomic impacts were not monetized due to lack of available underlying data, but the project interview indicated clear links to industry cost savings as well as reduced health and ecological risks.

Table 7: Summary of Socioeconomic Impacts: Testing of Tendons and Other Ground Support Elements

<table>
<tr><th>Project name</th><th>Testing of Tendons and Other Ground Support Elements</th></tr>
<tr><td>Project description</td><td>The Testing of Tendons and Other Ground Support Elements project enables product developers to test various ground support products that are instrumental to the safety and production of underground mines. In 2003, NRCan acquired specialized impact-testing apparatus developed by Noranda in the late 1990s and moved it to Ottawa. Since its acquisition, NRCan has greatly modified and enhanced the impact-testing apparatus. This apparatus is one of few in the world that enable dynamic impact-testing, which is increasingly becoming a key design parameter in underground mining.</td></tr>
<tr><td>NRCan funding</td><td>$8 thousand</td></tr>
<tr><td>Partner funding</td><td>$8 thousand</td></tr>
<tr><td>Impacts</td><td>
<table>
<tr><td>Decreased workplace injuries and fatalities</td><td>●</td></tr>
<tr><td>Increased productivity/time savings</td><td>●</td></tr>
<tr><td>Decreased mining and business costs/increased revenues ($000)</td><td>$13,664</td></tr>
<tr><td>Decreased water usage</td><td>●</td></tr>
</table>
Impacts quantified: The result of this project is a more efficient form of bolting systems that reduce the amount of bolts required and cost less on a unit basis. The annual cost reduction was calculated by multiplying the number of bolts sold in Canada by the incremental unit cost savings per bolt with variability in values based on historical sales and the range of expected cost savings to various mines. It's important to note as well that only Canadian sales were taken into consideration to reflect benefits to the Canadian public, but incorporating international sales would yield a much higher value. All values were estimated with ranges of uncertainty and assuming an 80% level of confidence.
Impacts not quantified: Several benefits were identified during the project interview, including a reduction in water usage due to a reduced need to drill as many holes. An expected reduction in rock bursts also means fewer injuries which is understandably sensitive data and would have to be collected from individual mines which are reluctant to share such information.
</td></tr>
</table>

Table 8: Summary of Socioeconomic Impacts: Contiscan

Project name	Contiscan
Project description	Contiscan is an electromagnetic, continuous surveillance system for monitoring mine hoist cables. The system enables real-time and normal speed detection of all critical parameters to ensure the integrity of hoisting cables and that they conform to existing regulations. Regulations surrounding hoist cables are quite stringent in many jurisdictions including Canada, which is not surprising given the importance of hoist cables to underground mining and the level of stress hoist cables endure. Hoist cables need to be manually inspected on a weekly basis, which typically takes about an hour to complete. Contiscan removes the need to do so manually, thereby removing the need to shutdown the mine on a weekly basis, which increases the productivity of the mine. Because it is continuously scanning hoist cables, the safety factor associated with hoist cables, which specifies the amount of tonnes of muck that can be moved, can be decreased to enable increased mine productivity. Such monitoring becomes more and more important as mines become deeper and hoist cables longer. Meglab, a private company based out of Val-d'Or, Quebec, has a license to manufacture and sell Contiscan, but the intellectual property ultimately belongs to NRCan. At present, the Contiscan project is still very much in the early/pilot stage.
NRCan funding	$24 thousand
Partner funding	$28 thousand
Impacts	Decreased workplace injuries and fatalities: ● Improved energy efficiency/decreased energy costs: ● Increased productivity/time savings: ● Decreased mining and business costs/increased revenues: ● **Impacts quantified**: No impacts were quantified because the project is still in the early stages of its lifecycle and a system has not yet been sold to a producer, but a clear potential monetary benefit would be an increase in productivity and ability to hoist greater volumes of muck and ore. **Impacts not quantified**: Benefits that are expected to be realized in the future include productivity cost savings from hoisting greater volumes as mentioned above, cost savings from a reduced number of cables required for purchase and in-person inspections, and most importantly from improved system safety.

Table 9: Summary of Socioeconomic Impacts: Green Mines Green Energy

Project name	Green Mines Green Energy
Project description	The GMGE project uses organic wastes such as municipal compost and forestry biosolids – materials that may typically go to landfill, to reclaim mining lands and grow energy crops. For instance, some estimates suggest that oilseed production on mine tailings could generate approximately 3,600 litres per hectare or nearly 5 million litres per year if just 1,300 of the more than 2,500 hectares of tailings in the Sudbury area are converted to agricultural land. Tests completed through the GMGE project indicated that this approach has proven to be successful with corn, canola and switchgrass crops achieving higher yields at mine site experimental plots compared to crops grown at a reference agricultural land. In addition to providing mining companies with another sources of revenue, the GMGE project can also generate broader socioeconomic benefits through the production of biofuels, provide another source of revenue for providers of biomass providers (i.e., the pulp and paper industry and municipalities), increase landfill waste diversion and potentially decrease acid mine leakage. GMGE, however, is still in the demonstration phase.
NRCan funding	$81 thousand
Partner funding	n/a
Impacts	(see below)

Decreased GHG emissions	●
Decreased CACs	●
Decreased mining and business costs/increased revenues ($000)	$100
Decreased water contamination/acid mine drainage	●
Decreased land degradation impacts ($000)	$81
Decreased wildlife/fisheries impacts	●

Impacts quantified: Growing switchgrass on roughly 64 hectares (has ranged from 59 to 69 ha) of tailings ponds is estimated to save at least $100 thousand per year in **dust suppressant costs** (with a range of $90-110 thousand) which would otherwise be necessary for the area, and provides **land degradation impacts** which also encompasses some minor carbon sequestration benefits from the increased vegetation. The social value ranges were derived from economic literature. All values were estimated with ranges of uncertainty and assuming an 80% level of confidence.

Impacts not quantified: Some additional benefits which could not be monetized due to both a lack of quantifiable data and the relatively early stages of the project include a reduction in water contamination and contamination run-off or leeching, greater cost savings from reduced hay and dust suppressant costs, greater carbon sequestration, improved aesthetics, and the potential to grow larger crops for sale and energy production.

Table 10: Summary of Socioeconomic Impacts: Mine Environmental Neutral Drainage Prediction Manual for Drainage Chemistry from Sulphidic Geological Materials

<table>
<tr><th>Project name</th><th>Mine Environmental Neutral Drainage Prediction Manual for Drainage Chemistry from Sulphidic Geological Materials</th></tr>
<tr><td>Project description</td><td>Since 1989, the Mine Environment Neutral Drainage (“MEND”) project has worked to develop technologies to prevent and control acidic drainage – the single largest contributor to the mining industry’s environmental liability. The MEND project was the first international initiative to develop technologies to reduce the effect of acidic drainage. Technologies, processes and know-how developed through the MEND project have had a significant impact across Canada and in the mining industry. An evaluation of the MEND project completed in 1996 concluded that the project had generated total cost savings of roughly $340 million due to decreased opening, operating and closing costs. The MEND prediction manual is a specific aspect of the broader MEND project, which provides technical guidelines with respect to the prediction of drainage chemistry from sulphidic geological materials. It is very much considered the go-to reference document in the field of acid mine drainage and drainage chemistry, which is evidenced by the fact that it is referenced in various provincial mining acts.</td></tr>
<tr><td>NRCan funding</td><td>$21 thousand</td></tr>
<tr><td>Partner funding</td><td>$100 thousand</td></tr>
<tr><td>Impacts</td><td>
<table>
<tr><td>Decreased mining and business costs/increased revenues ($000)</td><td>$10,887</td></tr>
<tr><td>Decreased water contamination/acid mine drainage</td><td>●</td></tr>
<tr><td>Decreased land degradation impacts</td><td>●</td></tr>
<tr><td>Decreased wildlife/fisheries impacts</td><td>●</td></tr>
</table>
Impacts quantified: The MEND prediction manual benefits were derived from some broadly defined assumptions that the manual has provided sufficient guidance to improve acid drainage control and reclamation cost planning across the Canadian mining industry. The project interview revealed that the manual could potentially assist mining companies in avoiding significant unexpected reclamation costs and reducing associated environmental liabilities by as much as half. As such, an assumption was made that 10%-30% of ongoing annual expenditures on mine reclamation and decommissioning activities in Canada (historically ranging from $50 million to $60 million) have been avoided as a result of this project. All values were estimated with ranges of uncertainty and assuming an 80% level of confidence.
Impacts not quantified: Most of the potential impacts from better acid main drainage planning and management including reduced water contamination, land degradation, and ecological impacts are difficult and virtually impossible to identify due to the challenge of identifying the effects that are truly attributable to the MEND prediction manual versus other industry literature and standards. That said, there appears to be a wide agreement in the international community on the benefits of having access to such proven best practice guidelines.
</td></tr>
</table>

Table 11: Summary of Socioeconomic Impacts: Characterization and Disposal of Sludges

Project name	Characterization and Disposal of Sludges
Project description	Conventional techniques in the treatment of acidic mineral effluent, such as lime neutralization, tend to result in voluminous, hard to settle and metal laden sludge. Disposing of these sludges poses several challenges for mining companies and not disposing of it in an appropriate manner can lead to significant environmental consequences. The Characterization and Disposal of Sludges project conducts research on identifying and assessing technologies and approaches to safely and cost-effectively dispose of sludges. Classifying and characterizing sludges is important to identifying appropriate approaches to disposing of it.
NRCan funding	$56 thousand
Partner funding	$6 thousand
Impacts	Increased productivity/time savings ● Decreased mining and business costs/increased revenues ● Decreased water contamination/acid mine drainage ● Decreased land degradation impacts ● Decreased wildlife/fisheries impacts ● **Impacts quantified**: No impacts were quantified due to lack of available underlying data. **Impacts not quantified**: The largest benefits this project generates are cost saving in sludge disposal and productivity improvements, but quantifying impacts would require collecting data from individual mines. Denser sludge would also contain less water and require less land and reduced land degradation impacts.

Table 12: Summary of Socioeconomic Impacts: Application of Rotating Biological Contractor for Treatment of Gold Mill Effluent

Project name	Application of Rotating Biological Contractor for Treatment of Gold Mill Effluent
Project description	Interviews not conducted.
NRCan funding	$110 thousand
Partner funding	$15 thousand
Impacts	Decreased water contamination/acid mine drainage ● Decreased wildlife/fisheries impacts ● **Impacts quantified**: Unable to assess without interviews. **Impacts not quantified**: Unable to assess without interviews.

Table 13: Summary of Socioeconomic Impacts: Québec hoisting plants safety and optimization

Project name	**Québec hoisting plants safety and optimization**
Project description	Interviews not conducted.
NRCan funding	$183 thousand
Partner funding	$48 thousand
Impacts	Decreased workplace injuries and fatalities: ● Increased productivity/time savings: ● **Impacts quantified**: Unable to assess without interviews. **Impacts not quantified**: Unable to assess without interviews.

Table 14: Summary of Socioeconomic Impacts: Optimization of Cyanide for Gold/Silver Recovery / CANMET Enhanced Leaching Process (CELP)

Project name	**Optimization of Cyanide for Gold/Silver Recovery / CANMET Enhanced Leaching Process (CELP)**
Project description	The CANMET Enhanced Leaching Process (CELP) was developed through optimization studies aimed at reducing the amount of environmentally harmful cyanide required in gold and silver extraction processes. CELP is a proprietary technology and has shown tremendous cost savings promise for silver extraction in a laboratory setting, but has had limited industrial applications. A wider implementation of the process in the future is expected to generate cost savings through improvements in silver extraction efficiency and greatly reducing leaching cyanide concentration.
NRCan funding	$40 thousand
Partner funding	$41 thousand
Impacts	Improved energy efficiency/decreased energy costs: ● Increased productivity/time savings: ● Decreased mining and business costs/increased revenues ($000): $16,000 Decreased water contamination/acid mine drainage: ● **Impacts quantified**: While the only industrial application of this technology is currently at a single mine (Kupol), it carries significant benefits in **improved silver processing and extraction, reduced cyanide consumption volumes, and cyanide destruction cost savings**. The annual estimated savings were provided directly in the project interview and consisted of $12.6 million in revenues from improved silver extraction, $1.4 million in reduced cyanide consumption costs, and $2 million in cost savings from avoided cyanide destruction and processing costs. It's expected that there would additional capital expenditure savings from avoided cyanide processing plants, but these were not annualized as part of the $16 million total. The benefits are directly proportional to the production volumes and licensing the technology to other mines would likely drive significant benefits. All

	values were estimated with ranges of uncertainty and assuming an 80% level of confidence. **Impacts not quantified**: Additional benefits include all the implications of reduced environmental contamination and use of harmful cyanide as well as general process efficiencies.

Table 15: Summary of Socioeconomic Impacts: Microseismic Monitoring of Oil Sands

Project name	Microseismic Monitoring of Oil Sands
Project description	In partnership with IOL and CNRL, GMI has been involved in research and development of various oil sands extraction techniques and passive microseismic monitoring techniques. Since management from both companies declined to be interviewed, CanmetMINING provided the following discussion on the impacts of this project: The passive seismic monitoring was initially designed to detect leaks and oil well failures in the shale layer above the reservoir. Shortly after its implementation, it proved to be capable of detecting well failures deeper in the reservoir. The shallow type of failure happens less often but can have catastrophic consequences from an environmental point of view due to the danger of aquifer contamination. The deeper failures are less of a concern from an environmental point of view but can have negative consequences for oil production. The GMI work has helped avoid both types of leaks. Past research has made it possible to detect 10-20 oil wells failures every single year. Although only a few of these failures are shallow enough to cause leakage to surface, the fact that they were detected in time and taken care of has avoided many leaks as the ones experiences by CNRL in 2013 with undeniable environmental benefits. Other positive impacts of avoiding oil leakage lies in avoiding water contamination, cleaning costs and negative impacts on wildlife.
NRCan funding	$162 thousand
Partner funding	$8,150 thousand
Impacts	Decreased GHG emissions: ● Decreased CACs: ● Decreased workplace injuries and fatalities: ● Improved energy efficiency/decreased energy costs: ● Increased productivity/time savings: ● Decreased mining and business costs/increased revenues ($000): $5,859 Decreased water usage: ● Decreased water contamination/acid mine drainage ($000): $2,666 Decreased land degradation impacts: ● Decreased wildlife/fisheries impacts: ● **Impacts quantified**: The ability to identify and fix shallow well failures in an effective and timely manner can carry significant value in **avoided**

	loss of productivity, cleanup costs, and water contamination as well as other environmental damage. Based on recent events and data, it was assumed that microseismic modeling prevents 10-20 well failures per year with 5% of those being shallow enough to cause surface leaks. Each of these spills would be between 0 and 2677 barrels in volume based on industry statistics, with spill cleanup costs ranging from $1900 to $11,000 per barrel and $550 to $5300 per barrel in environmental damage. All values were estimated with ranges of uncertainty and assuming an 80% level of confidence. **Impacts not quantified**: While this project's major benefits have been estimated and quantified, the early detection of shallow well failures would result in reduced well downtime and improved production, provide opportunities to fix minor failures before they become major issues.

Summary by Project

An overall summary of the socioeconomic impacts of the selected GMI projects is provided in Table 16. GMI related expenditures through NRCan funding, partner funding and the quantified socioeconomic benefits are displayed for each project. Where socioeconomic effects exist but are not quantifiable at this time, a green dot is displayed.

Table 16: Summary of Socioeconomic Impacts by Project

	Expenditures ($000)			Benefits ($000)										
Project	NRCan funding	Partner funding	**Total funding**	Decreased GHG emissions	Decreased CACs	Decreased workplace injuries and fatalities	Improved energy efficiency/decreased energy costs	Increased productivity/time savings	Decreased mining and business costs/increased revenues	Decreased water usage	Decreased water contamination/acid mine drainage	Decreased land degradation impacts	Decreased wildlife/fisheries impacts	**Total benefits**
Certified reference materials	$283	$125	**$408**	●	●	●	●	●	●	●	●	●	●	●●●●● ●●●●●
Diesel engine certification	$36	$54	**$90**	$2,570	$2,439		$514		●					$5,522
Extraction and stabilization of radioactive wastes	$85	$15	**$100**						●		●	●	●	●●●●
Transformation/dissolution protocols for metals and sparingly soluable inorganic metal compounds	$172	$20	**$192**						●		●		●	●●●
Testing of tendons and other ground support elements	$8	$8	**$16**			●		●	$13,660	●				$13,660
Contiscan	$24	$28	**$51**			●	●	●	●					●●●●
Green Mines/Green Energy project	$81	n/a	**$81**	●	●				$100		●	$81	●	$181
MEND Prediction Manual for Drainage Chemistry from Sulphidic Geologic Materials	$21	$100	**$121**						$10,913		●	●	●	$10,913
Characterization and disposal of sludges	$56	$6	**$62**	●					●		●	●	●	●●●●●
Application of RBC for treatment of gold mill effluent	$110	$15	**$125**								●		●	●●
Québec hoisting plants safety and optimization	$183	$48	**$231**			●		●						●●
Optimization of cyanide for gold/silver recovery	$40	$41	**$81**				●	●	$16,000		●			$16,000
Microseismic monitoring of oil sands	$162	$8,150	**$8,312**	●	●	●	●	●	$5,909	●	$2,661	●	●	$8,570
Total	$1,260	$8,610	$9,870	$2,567	$2,435				$31,023		$2,666	$81		$54,847

Economic competitiveness benefits

The key economic competitiveness benefits identified and monetized from project interviews included savings from diesel engine certification, ground support element testing, avoided dust suppressants for tailings ponds, reduced reclamation costs and reserve fund contributions, and finally avoided oil spill clean-up costs from prevented well failures. The top impact stems from the sale of significantly more cost effective bolts for ground support. Next in terms of magnitude of impact is the reduction in reclamation and decommissioning reserve fund contributions from the anticipated reduction in future reclamation costs as a result of better planning brought on by the Canadian Mine Environment Neutral Drainage Manual. The detailed inputs and assumptions as well as calculations for each impact are depicted in the tables and structure and logic diagrams in Appendix C.

Table 17: Summary of Economic Competitiveness Benefits

Benefit Category	Mean Expected Annual Value
Financial Cost Savings (Diesel Engine Certification)	$514,000
Financial Cost Savings (Ground Support Element Testing)	$13,660,000
Financial Cost Savings (Avoided Dust Suppressant for Tailings Ponds)	$100,000
Financial Cost Savings (Reduced Reclamation Costs and Reserve Fund Requirements)	$10,913,000
Financial Cost Savings (Avoided Oil Spill Cleanup Costs from Prevented Well Failures)	$5,909,000
Financial Cost Savings (Reduced Cyanide Use and Improved Silver Extraction)	$16,000,000

In addition to these monetizable cost savings and economic productivity benefits, GMI projects provide other impacts that are not quantifiable at this time.

Social & environmental benefits

The top social and environmental benefits identified as part of the various project interviews and monetized as part of this SROI study included reduced greenhouse gas emissions, improved health outcomes, reduced damage to vegetation, land remediation aspects, and avoided environmental damage from prevented well failures and associated oil spills. Of these, the avoided greenhouse gas emissions, improved health, and avoided oil spills had significant impacts. The greenhouse gas emissions and health impacts both stemmed from more efficient underground mine ventilation operations reducing energy consumption from diesel generators and the power grid. The value of avoided oil spills represented successful prevention of shallow well failures through microseismic modeling.

Table 18: Summary of Social and Environmental Benefits

Benefit Category	Mean Expected Value
Value of Reduced Greenhouse Gas Emissions	$2,567,000
Value of Improved Health	$2,200,000
Value of Reduced Damage to Vegetation	$235,000
Value of Land Remediation	$81,000
Value of Avoided Oil Spill Environmental Damage Costs from Prevented Well Failures	$2,666,000

The detailed inputs and assumptions as well as calculations for each impact are depicted in the tables and structure and logic diagrams in Appendix C.

In addition to these monetizable social and environmental impacts, GMI projects provide other impacts that are not quantifiable at this time.

Other benefits

In addition to the socioeconomic impacts above, GMI research and projects serve as a vital catalyst to promoting industry stewardship, mining sector innovation, promoting Canada's international reputation and global industry development with many impacts extending around the world, as well as skills and intellectual capital development.

Socioeconomic benefits of GMI based on SROI methodology

The total socioeconomic benefits based on HDR's SROI methodology are presented below. Probabilistic curves representing the range of potential impacts in Figure 7 depict high variability in potential annual outcomes, but significant benefits nonetheless. The chart shows that with 80% confidence, the economic competitiveness benefits of the monetized GMI projects lie between $36 million to $59 million, the social & environmental benefits lie between $2 million to $14 million, and the total sustainability project benefits lie between $41 million to $69 million. The median estimate of total annual GMI benefits from these projects is $53 million. It is important to note that while the total sustainability benefits is a sum of the economic, social, and environmental impacts, values at any given level of confidence are not additive; each set of results forms a unique distribution of potential outcomes and should be interpreted individually. It is important to note that HDR's assessment of the socioeconomic impact of the GMI projects is solely based on the interviews completed as part of this study and on information provided by NRCan. Thus, it represents a conservative estimate of the impact of the GMI projects.

The economic and financial impacts (blue curve below) are significantly higher than the social and environmental impacts (orange curve). This is not a reflection of relatively lower social and economic impacts of the various GMI projects, but is rather a manifestation of several factors. First, companies are much more predisposed to closely tracking their costs and revenues than say the increase in biodiversity in their operating regions. Second, social and environmental impacts are much more difficult to identify, quantify, and monetize by nature than market-based financial and economic impacts. Finally, environmental impacts can often take much longer to mature (e.g. plants to grow), become apparent, and provide sufficient evidence to assign a monetary value.

Figure 7 – Annual Socioeconomic Benefits of GMI

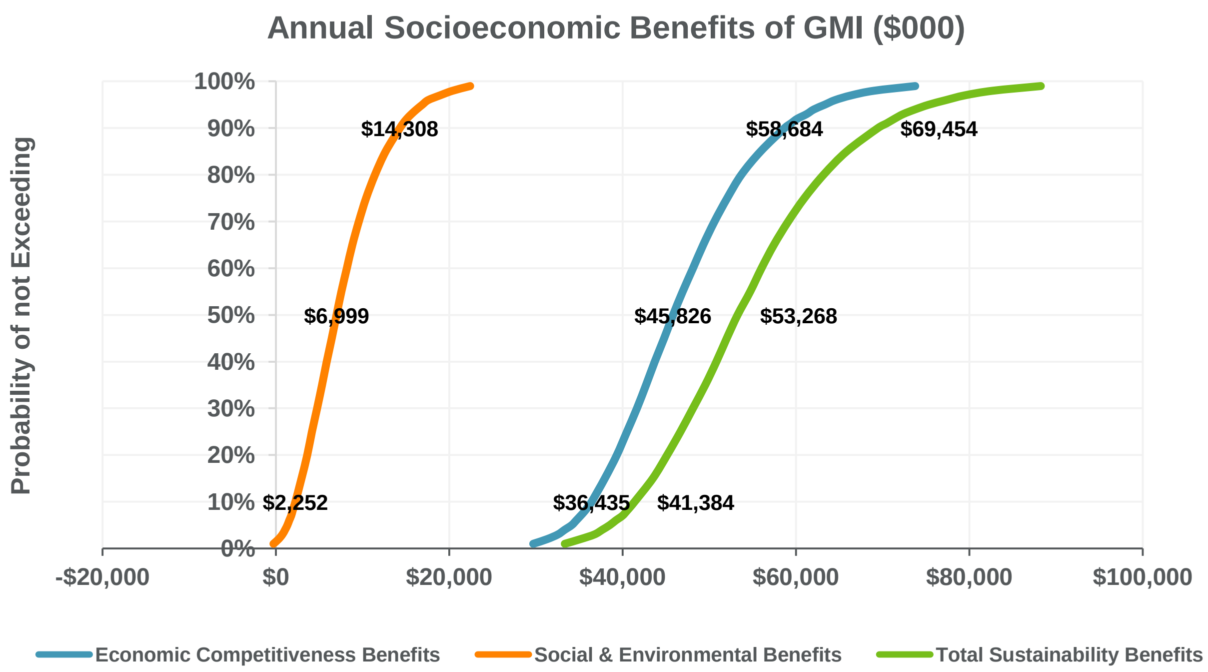
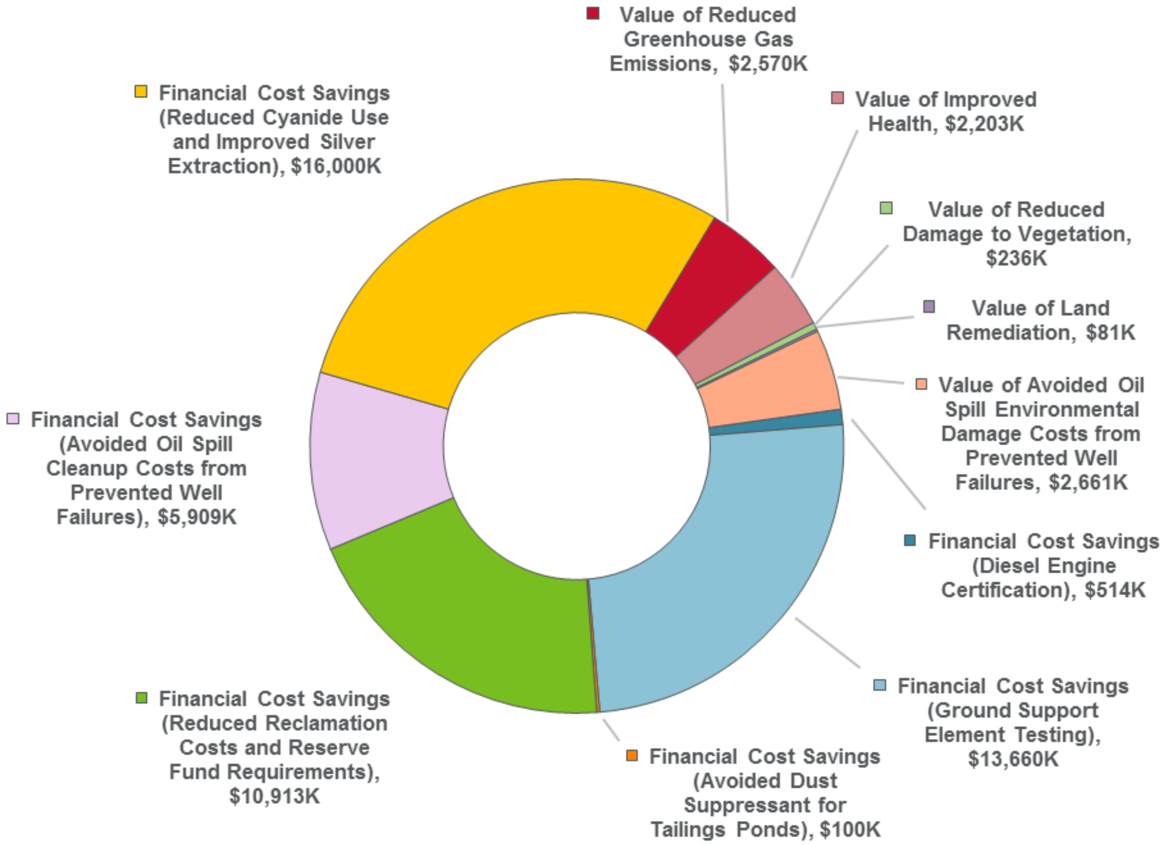


Figure 8 presents the mean expected annual values of the monetized GMI projects by specific impact. Although the top three impacts consist of financial cost saving impacts, each one has significant social and environmental implications – improved underground mine safety through better ground support element testing, reduced reclamation cost reserve requirements through more effective prediction of drainage chemistry from Sulphidic geological materials representing the market value of future environmental liabilities, and avoided oil spills from shallow well failure prevention. As mentioned in earlier discussion, some of the smaller impacts represent projects that are still in their infancy but which can potentially yield tremendously positive benefits in the future.

This allocation of impacts based on their mean expected values helps illustrate the wide array of socioeconomic impacts facilitated by some of GMI's projects and which make up the overall SROI results – a list which is by no means exhaustive from a conceptual standpoint.

Figure 8 – Mean Expected Annual Socioeconomic Benefits of GMI by Impact Category



Leverage model

Based on the latest representative annual cost data, CanmetMINING expenditures for the 13 projects considered in this study amount to $1.26 million while the total expenditures including external in-kind contributions sum to a total of $9.9 million. Six of these projects have been monetized as part of this study which make up $348 thousand and $8.4 million of the CanmetMINING and partner contributions respectively. The high proportion of in-kind external contributions further illustrates the catalyst effect of GMI research and projects that spur significant socioeconomic benefits. In fact, based on the SROI results, the socioeconomic benefits leveraged by these combined investments can range anywhere from 4.8 to 8.0 times the total GMI expenditures and from 119 to 201 times the government contributions with an 80% level of confidence. This means that the economic, social, and environmental benefits derived by various members of society outweigh the annual costs several times over. It's also important to note that while the costs reflect the complete set of projects in this study, only some of the projects had impacts that could be monetized at this point in time and several have shown great promise for tremendous future benefits.

Figure 9 – Annual Return of GMI Research and Projects

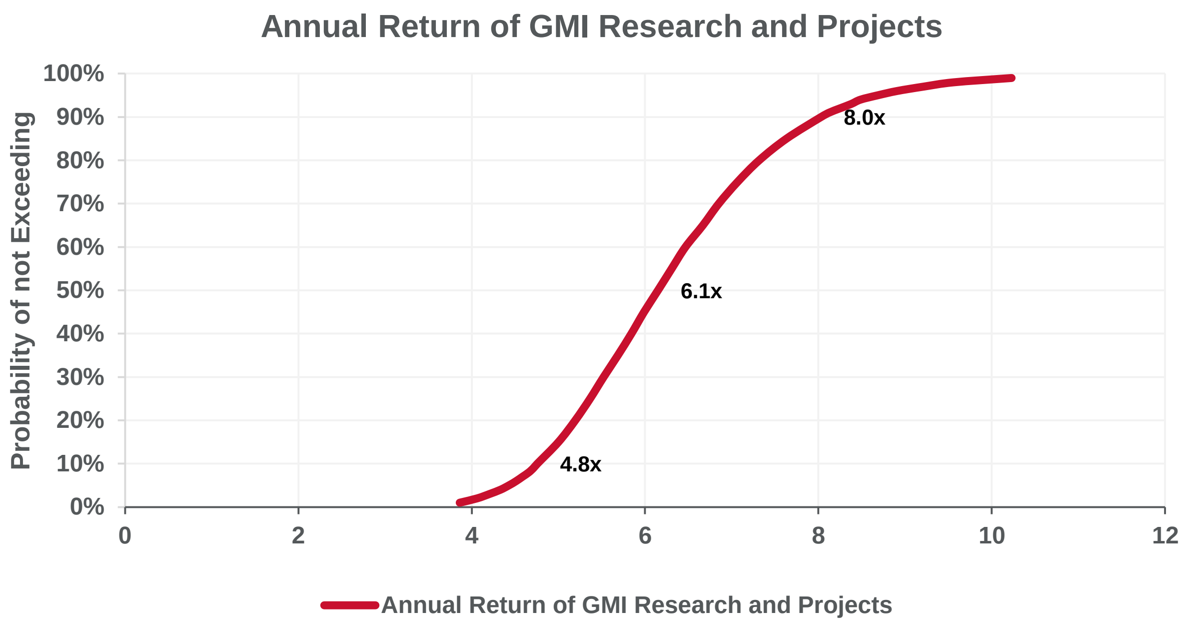
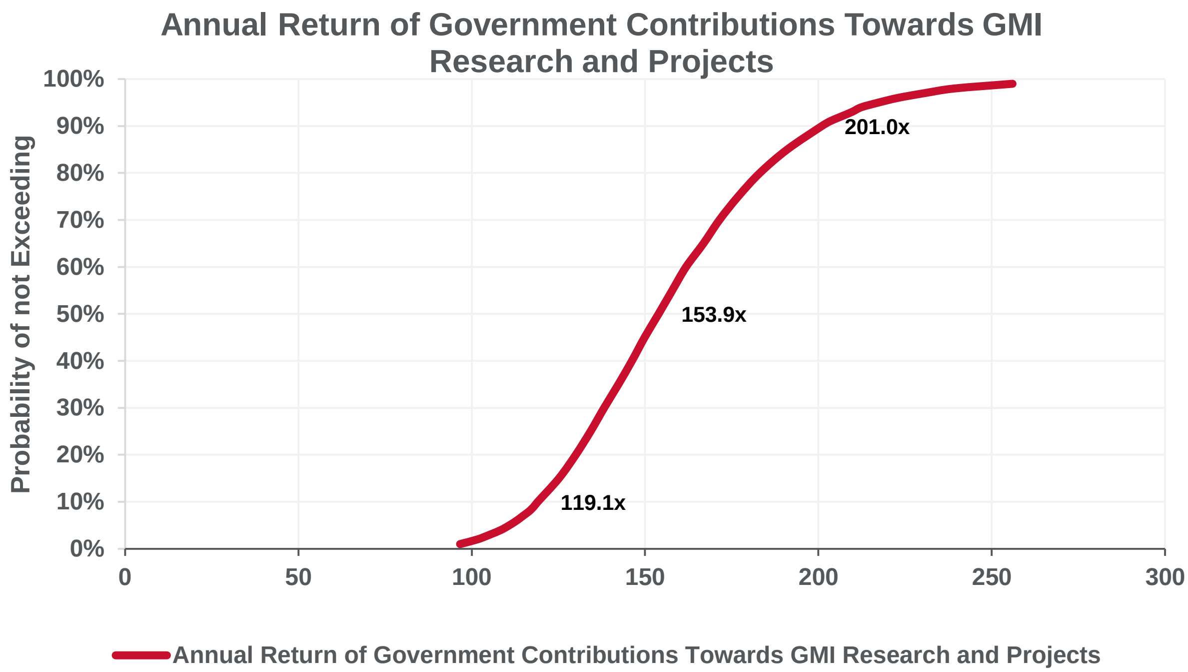


Figure 10 – Annual Return of GMI Research and Projects including both Government and Industry Contributions



Appendix A – Letter of introduction

HDR Corporation ("**HDR**") is engaged by Natural Resources Canada ("**NRCan**") to assess the impact of the Green Mining Innovations ("**GMI**") program. Specifically, HDR is looking to better understand how research conducted through GMI has led to the following types of socioeconomic impacts:

- Decreased greenhouse gas emissions;
- Decreased criteria air containments, volatile organic compounds, particulate matter, and sulfur dioxide;
- Reduced workplace injuries/deaths;
- Improved energy efficiency/decreased energy costs;
- Increased productivity/time savings;
- Decreased mining and business costs/increased revenues;
- Decreased water usage and contamination;
- Decreased land degradation impacts;
- Decreased wildlife/fisheries impacts; and
- Other socioeconomic impacts.

HDR will be conducting a series of interviews to obtain quantifiable data and information that would enable assessment GMI's socioeconomic impact.

As a program participant/stakeholder your have been selected to take part in one of these interviews. Each interview will last 30 minutes, will be conducted over the phone and the interview guide will be sent in advance. At the end of each interview HDR will provide you with their meeting notes to ensure that they have appropriately captured your comments and insights.

We ask that you make yourself available to HDR and provide them with the data and information they need to complete their assessment of GMI.

Alex Kotsopoulos (alex.kotsopoulos@hdrinc.com) from HDR will reach out to you to setup a time for an interview.

Thank you,

NRCan

Appendix B – Stakeholder interview guide

Interview guide

Introduction

HDR Corporation ("**HDR**") was engaged by Natural Resources Canada ("**NRCan**") to assess the impact of the Green Mining Innovations ("**GMI**") program. HDR is looking to better understand how research conducted through GMI has led to the following types of socioeconomic impacts:

- Decreased greenhouse gas emissions;
- Decreased criteria air contaminants including nitrogen oxide, volatile organic compounds, particulate matter and sulfur dioxide;
- Reduced workplace injuries/deaths;
- Improved energy efficiency/decreased energy costs;
- Increased productivity/time savings;
- Decreased mining and business costs/increased revenues;
- Decreased water usage and contamination;
- Decreased land degradation impacts;
- Decreased wildlife/fisheries impacts; and
- Other socioeconomic impacts.

HDR is conducting interviews with GMI program participants to obtain quantifiable data and information to enable monetization of the socioeconomic benefits of GMI, which is the key objective of this study. To be clear, the focus of this study is on monetizing (i.e., placing a dollar value on) socioeconomic impacts where we can obtain enough information through interviews to credibly monetize benefits. To this end, we have prepared this interview guide to facilitate discussions with program participants and stakeholders. **Only a subset of the questions listed below likely applies to your program.**

At the end of this interview we will provide you with a copy of our notes and ask you to ensure that we have adequately and appropriately captured your comments and to add any additional comments you may have.

Interview questions

GENERAL QUESTIONS

1. Please provide an overview of your research program and describe why it is important for the mining sector.

2. Specify from the list below the types of socioeconomic impacts technology, processes, products and/or know-how that research conducted through GMI has resulted in:
    - Decreased greenhouse gas emissions;
    - Decreased criteria air contaminants including nitrogen oxide, volatile organic compounds, particulate matter and sulfur dioxide;
    - Reduced workplace injuries/deaths;
    - Improved energy efficiency/decreased energy costs;
    - Increased productivity/time savings;
    - Decreased mining and business costs/increased revenues;
    - Decreased water usage and contamination;
    - Decreased land degradation impacts;
    - Decreased wildlife/fisheries impacts; and
    - Other socioeconomic impacts.
3. Please describe and specify how technology, processes, know-how and/or products developed through research conducted by GMI are currently being used in Canada's mining sector.

SOCIOECONOMIC IMPACTS

To monetize the socioeconomic impact of the GMI we need to collect quantitative data and information regarding how research conducted through GMI led to socioeconomic benefits. For instance, if research conducted by GMI led to increased productivity then we need to know the number of person hours saved as a result of implementation of this research. We also need to understand how you developed this estimate and any data and information supporting your assessment. **<u>The objective of this study is to only quantify and monetize socioeconomic impacts where we have enough information to do so.</u>**

4. **If your research program has resulted in <u>decreased greenhouse gas emissions</u>** (<u>skip this question if the answer is no</u>), please describe how it does so and estimate the incremental absolute or percent reduction in greenhouse gas emissions relative to the baseline.
    a. What information do you have to support your assessment and can you make this available to us?
    b. What level of confidence/certainty do you attach to your estimate above?
5. **If your research program has resulted in <u>decreased contaminants including nitrogen oxide, volatile organic compounds, particulate matter and sulfur dioxide</u>**

(skip this question if the answer is no), please describe how it does so and the incremental absolute or percent reduction in contaminants including nitrogen oxide, volatile organic compounds, particulate matter and sulfur dioxide.

a. What information do you have to support your assessment and can you make this available to us?

b. What level of confidence/certainty do you attach to your estimate above?

6. **If your research program has resulted in reduced workplace injuries/deaths** (skip this question if the answer is no), please describe how it does so and the incremental absolute or percent reduction in workplace injuries/deaths?

   a. What information do you have to support your assessment and can you make this available to us?

   b. What level of confidence/certainty do you attach to your estimate above?

7. **If your research program has resulted in improved energy efficiency/decreased energy costs** (skip this question if the answer is no), please describe how it does so and the incremental absolute or percent improvement in energy efficiency/decreased energy costs?

   a. What information do you have to support your assessment and can you make this available to us?

   b. What level of confidence/certainty do you attach to your estimate above?

8. **If your research program has resulted in increased productivity/time savings** in terms of person-years (skip this question if the answer is no), please describe how it does so and the incremental absolute or percent increase in productivity/time savings?

   a. What information do you have to support your assessment and can you make this available to us?

   b. What level of confidence/certainty do you attach to your estimate above?

9. **If your research program has resulted in decreased mining and business costs/increased revenues** (skip this question if the answer is no), please describe how it does so and the incremental absolute or percent decrease in mining and business costs/increase in revenue?

   a. What information do you have to support your assessment and can you make this available to us?

   b. What level of confidence/certainty do you attach to your estimate above?

10. **If your research program has resulted in decreased water usage** (skip this question if the answer is no), please describe how it does so and the incremental absolute or percent decrease in water use?
    a. What information do you have to support your assessment and can you make this available to us?
    b. What level of confidence/certainty do you attach to your estimate above?
11. **If your research program has resulted in decreased land degradation impacts** in terms of decreased land use (skip this question if the answer is no), please describe how it does so and the incremental absolute or percent decrease in land use?
    a. What information do you have to support your assessment and can you make this available to us?
    b. What level of confidence/certainty do you attach to your estimate above?

OTHER QUESTIONS

We recognize that some benefits/impacts of GMI are difficult and in some cases impossible to quantify and monetize with any degree of accuracy, but are important nonetheless. The following questions relate to assessing some of these more qualitative impacts.

12. In addition to the socioeconomic impacts listed above, are there other quantitative or qualitative benefits that GMI has resulted in?
13. Without GMI would you and your company have conducted this research in Canada?
14. From your perspective, how important is GMI to promoting Canada's mining sector within Canada and abroad?
15. Does the work and research conducted through GMI increase the international reputation of Canada's mining sector?
16. Do you have any other comments about GMI?

CONCLUSION

We will provide you with our notes from the interview and ask you to ensure that we have adequately captured your comments and insights. If you have any other comments beyond what we noted please feel free to add to our notes.

Thank you,

Alex Kotsopoulos

Appendix C – SROI methodology and data sources

This section presents the structure and logic diagrams that illustrate the calculation methodology behind each monetized impact. Note that financial cost savings from diesel engine certification and avoided use of dust suppressant chemicals are not depicted by diagrams as they were direct cost inputs from stakeholder interviews and were simply modeled with a range of uncertainty around the values.

Figure 11 – Reduced Greenhouse Gas Emissions

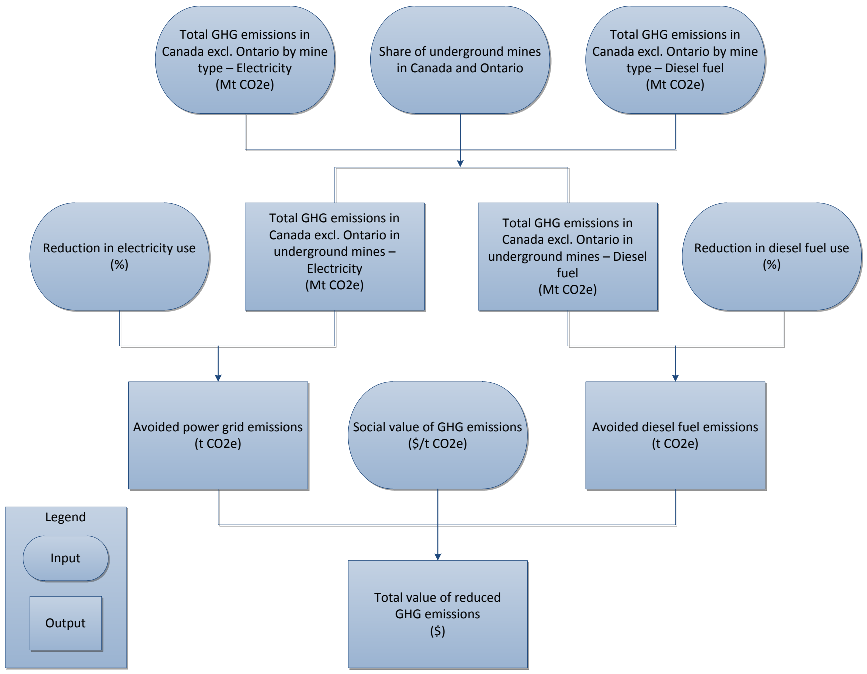


Figure 12 – Improved Health

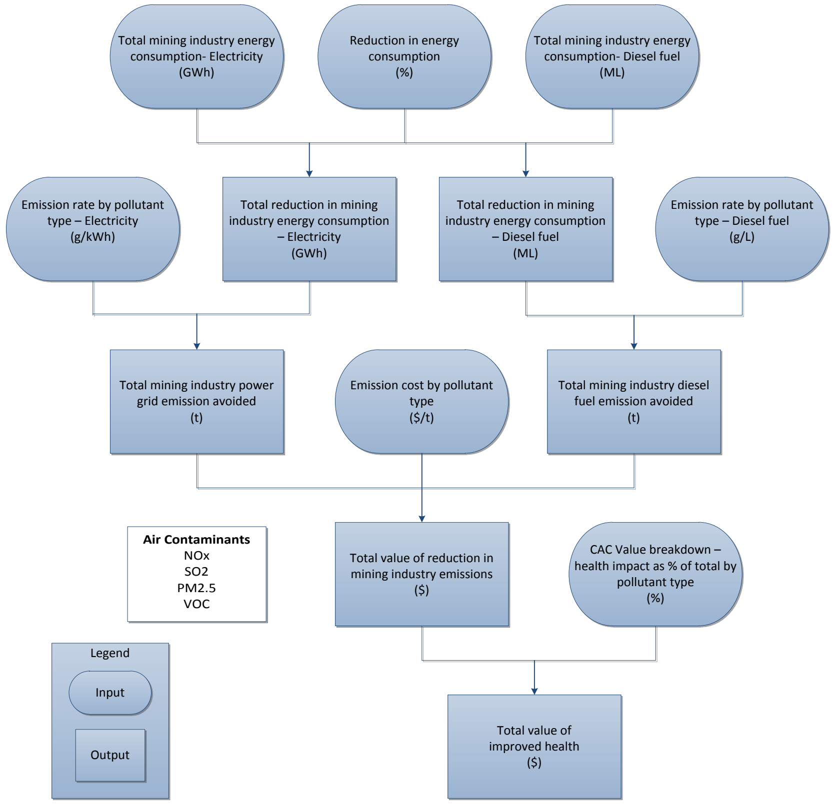


Figure 13 – Reduced Damage to Vegetation

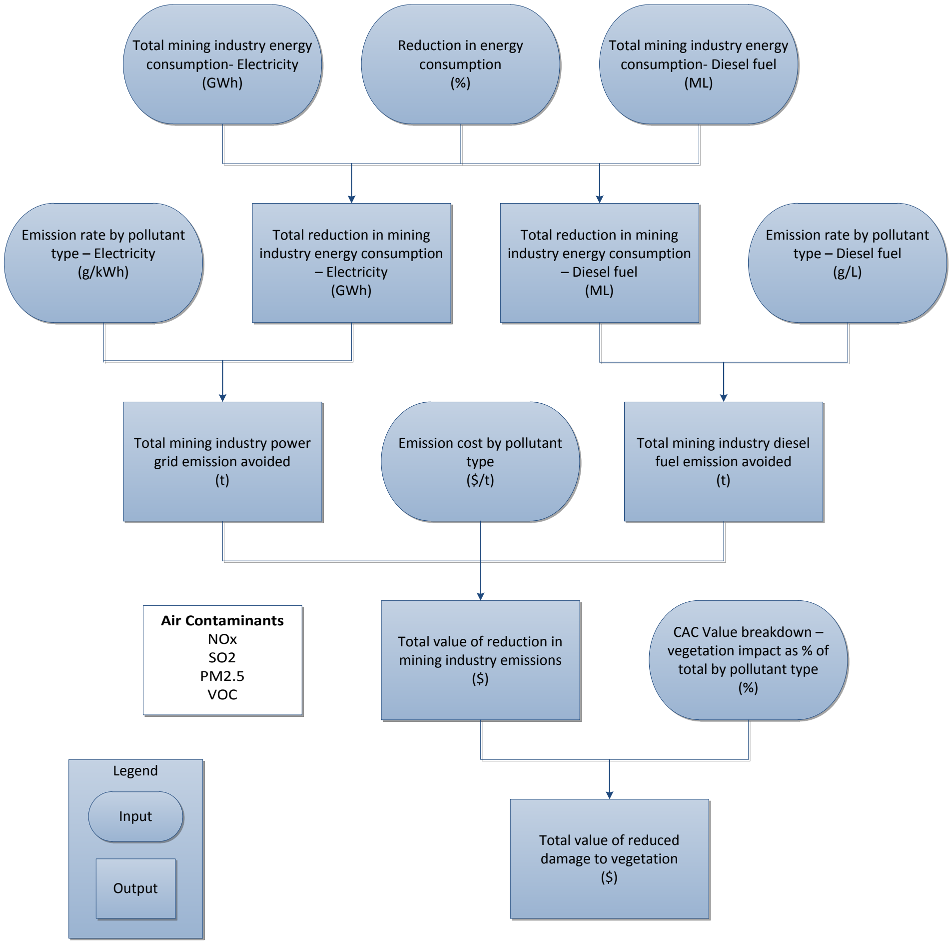


Figure 14 – Land Remediation

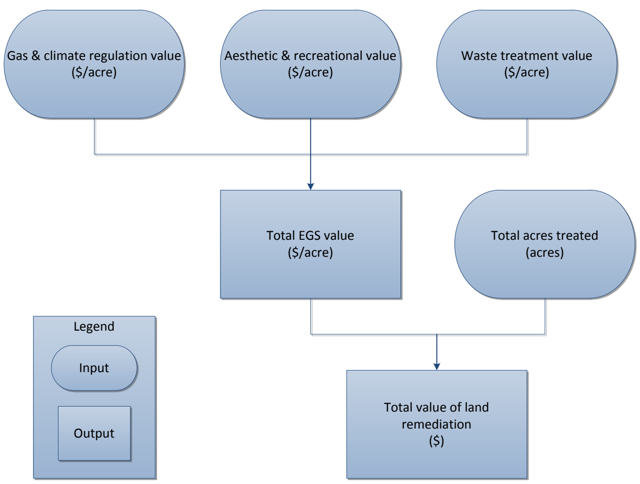


Figure 15 – Avoided Oil Spill Environmental Damage Costs from Prevented Well Failures

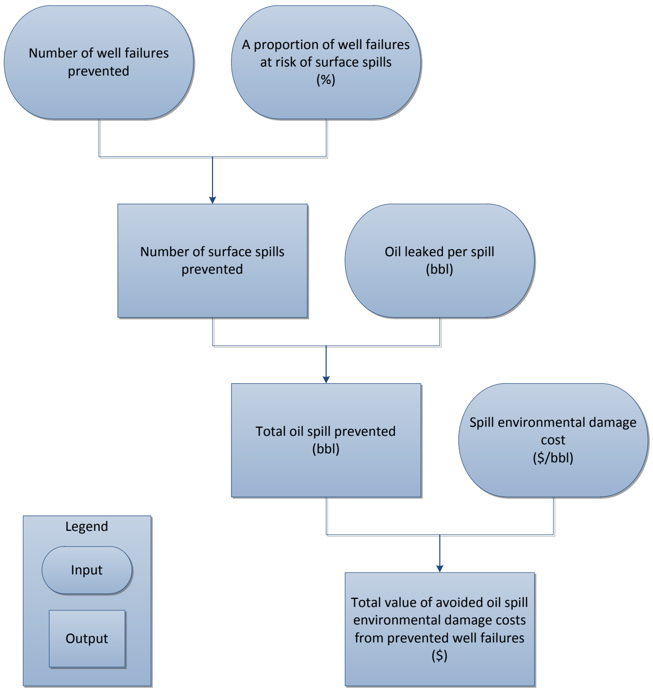


Figure 16 – Financial Cost Savings (Ground Support Element Testing)

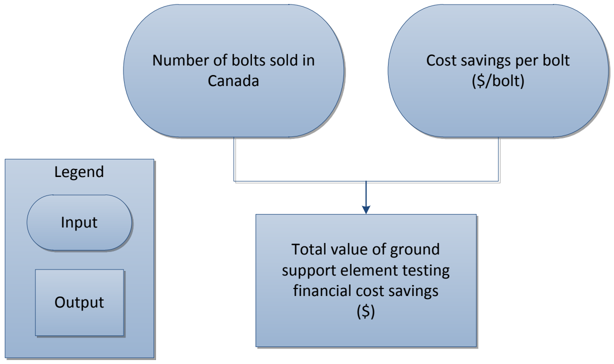


Figure 17 – Financial Cost Savings (Reduced Reclamation Costs and Reserve Fund Requirements)

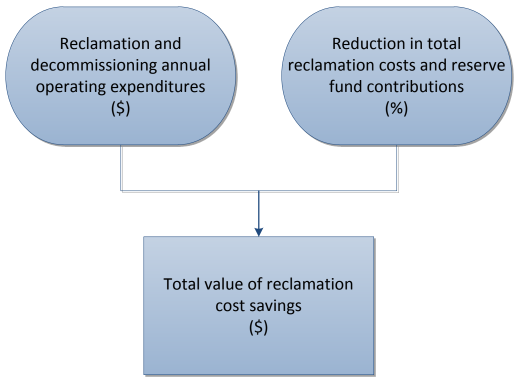
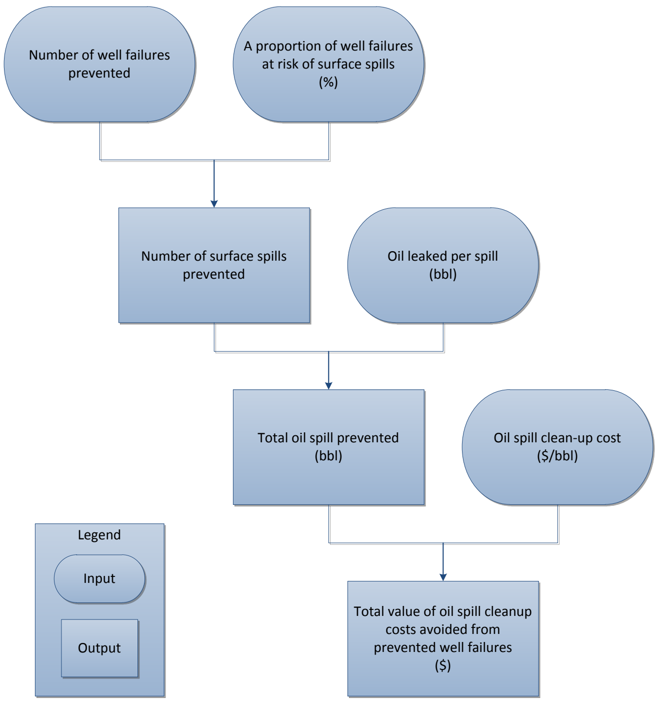


Figure 18 – Financial Cost Savings (Avoided Oil Spill Cleanup Costs from Prevented Well Failures)



Variable	Value	Source and notes
Number of well failures prevented	10-20	A note on interview questions to IOL and CNRL, Shahriar Talebi, July 23, 2015.
Proportion of well failures at risk of surface spills	5%	Assumption based on the note on interview questions to IOL and CNRL, Shahriar Talebi, July 23, 2015

Variable	Value	Source and notes
Oil spill clean-up cost	$6,315/bbl	The expected value generated from minor and major pipeline leak clean-up costs. Based on Environmental Research Consulting: Modeling Oil Spill Response and Damage Costs. 2004. Presented in Public Interest Benefit Evaluation of the Enbridge Northern Gateway Pipeline Project: Update and Reply Evidence. Prepared by Wright Mansell Research Ltd. July 2012.
Oil spill environmental damage cost	$2,850/bbl	The expected value generated from minor and major pipeline leak environmental damage costs. Based on Public Interest Benefit Evaluation of the Enbridge Northern Gateway Pipeline Project: Update and Reply Evidence. Prepared by Wright Mansell Research Ltd. July 2012.
Oil leaked per spill	1,243 bbl/spill	The expected value generated from onshore average leak size in Northeast National Petroleum Reserve (Alaska, Final Amended IAP/EIS, January 2005).
Cost saving per bolt/m	$152 per bolt/m	The expected value based on cost of Pattern 2 and Pattern 3 primary and secondary bolts.
Number of bolts sold in Canada	90,000	Francois Charette Interview
Diesel fuel heat content	5.755 mmbtu/bbl	EIA, Annual Energy Outlook 2015, Appendix G, Conversion factors.
Share of underground mines in Canada	40%	The mining Association of Canada, Facts & Figures of the Canadian Mining Industry 2013
Total GHG emissions in Canada excl. Ontario – Electricity – 2012, varies by year	0.496 Mt	Natural Resources Canada Comprehensive Energy Use Database Tables, tables 9-12. Aggregate of Copper, Nickel, Lead and Zinc, Iron, Gold and Silver and Other Metal mines. Ontario values were subtracted from Canada-wide values to obtain Canada excl. Ontario values.
Total GHG emissions in Canada excl. Ontario – Diesel fuel - 2012, varies by year	0.558 Mt	
Total mining industry energy consumption – Electricity – 2012, varies by year	3131 GWh	
Total mining industry energy consumption – Diesel fuel – 2012, varies by year	191 ML	
Reduction in energy use as a result of Diesel Engine Certification	2.5%	Assumption based on industry research and stakeholder discussions
CO2 emission rate – Diesel fuel	2,789.80 g/L	Emission values represent expected values based on data sourced from Environment Canada Air Pollutant Emission Inventory Search. Total electric power
NOx emission rate – Diesel fuel	72.38 g/L	

Variable	Value	Source and notes
SO2 emission rate – Diesel fuel	4.76 g/L	generation in mining industry for Canada and Ontario was sourced from Statistic Canada, CANSIM: Table 127-0002 Electric power generation, by class of electricity producer.
PM2.5 emission rate – Diesel fuel	5.09 g/L	
VOC emission rate – Diesel fuel	5.75 g/L	
NOx emission rate – Canada excl. Ontario Power Grid	0.30 g/kWh	
SO2 emission rate – Canada excl. Ontario Power Grid	0.56 g/kWh	
PM2.5 emission rate – Canada excl. Ontario Power Grid	0.01 g/kWh	
VOC emission rate – Canada excl. Ontario Power Grid	0.002 g/kWh	
Cost of CO2 emissions	$72.11	US DOT / NHSTA, Corporate Average Fuel Economy for MY 2012-MY 2016 Passenger Cars and Light Trucks (2010), Muller et al. Measuring the damages of air pollution in United States (2007), ECDG, "Damages per tonne emission of PM2.5, NH3, SO2, NOx and VOCs from each EU25 Member State (excluding Cyprus) and surrounding seas", Average for 25 Member States (2005), ECDG, "Estimates of the marginal external costs of air pollution in Europe"; EU average (2002). Currency conversions are based on the exchange rate CAD/USD = 1.10386 in 2014. Vegetation impacts shares are equal to 100% - health impact share.
Cost of NOx emissions	$3,422.26	
Cost of SO2 emissions	$3,957.00	
Cost of PM2.5 emissions	$11,418.58	
Cost of VOC emissions	$1,740.01	
NOx health impact as % of total	86.8%	
SO2 health impact as % of total	97.9%	
PM2.5 health impact as % of total	98.1%	
VOC health impact as % of total	95.0%	
Financial cost savings from Diesel Engine Certification	$513,680	Based on Annual Savings at the Niobec Mine
Gas & climate regulation value	$39.03/acre	Earth Economics, Valuing the Puget South Basin: Revealing Our Best Investments 2010.
Aesthetic & recreational value	$339.46/acre	
Waste treatment value	$50.98/acre	
Total acres of land treated	158 acres	Based on tailings pond area currently being used for biofuel crops by Vale and Glencore (approximately 64ha total).

Variable	Value	Source and notes
Reclamation and decommissioning annual operating expenditures	$55.75 M	An expected value based on operating expenditures data sourced from Statistics Canada Table 153-0052 “Capital and operating expenditures on environmental protection, by North American Industry Classification System (NAICS) and type of activity, Canada, every 2 years”. Operating expenditures data used is specifically for reclamation and decommissioning in the mining and quarrying industry.
Reduction in total reclamation costs and reserve fund contributions	10-30%	Assumption based on industry research and stakeholder interviews
Savings from avoided dust suppressant costs	$100,000/year	Interview with Joe Fyfe, Glencore
Savings from reduced cyanide use, improved silver extraction, and avoided AVR plant investment as a result of employing CELP for silver extraction	$16M/year	Interview with Guy Deschênes, BBA consisting of $12.6 million in revenues from improved silver extraction, $1.4 million in reduced cyanide consumption costs, and $2 million in cost savings from avoided cyanide destruction and processing costs.