Proceedings Tailings and Mine Waste 2015
Vancouver, BC, October 26 to 28, 2015

Tailings, managing for the future

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ABSTRACT

The need for a new approach to dealing with tailings is urgent. Concerns over the social and environmental effects of mining, as well as federal and provincial regulations and future amendments to the *Metal Mining Effluent Regulations* (MMER), are placing increasing pressure on the industry to reduce or mitigate their impacts. Development of cost-effective, next-generation solutions is needed. This requires investment in R&D and innovation. However, just spending on R&D is not enough: a clear path to implementation is required before the sought-after results of reduced cost of compliance and asset retirement liabilities can be realized. This requires integration across multiple participants in innovation cycles. The era of mining companies driving integration using internal R&D may be over. Companies must now outsource R&D. Canadian mining entities active in environmental R&D include Research and Technology Organizations, regulators, universities, environmental technology developers, service providers and industry associations. They operate independently or in partnership to coordinate and leverage funding for industry-defined R&D priorities; but improved integration and focus are necessary to deliver more effective outcomes. This review maps Canadian mining stakeholders along the supply chain that are actively involved in developing improved tailings handling and water treatment technologies based on needs of the industry.

Keywords: R&D, innovation, Canadian supply chain, environment, mine waste

1 INTRODUCTION: A BIG CHALLENGE GETTING BIGGER

The volume of waste rock and tailings generated by the mining industry has grown dramatically over the last century. Since the 1960s, the volume of tailings produced per day has increased 20-fold. More than two decades ago, daily production of waste rock by the Canadian mineral industry was estimated at 1,000,000 tonnes, and daily production of tailings at 950,000 tonnes, which was more than 20 times the combined amount of municipal solid waste generated by all homes, industries, commercial properties and institutions in Canada (Government of Canada, 1991). In recent years, while reported levels of tailings and waste rock were relatively constant from 2006 and 2009, levels increased by 23% between 2009 and 2010 and by 27% between 2010 and 2011. Some mines are now producing more than 200,000 tonnes of tailings per day (Earthworks and MiningWatch Canada). Moreover, according to IntierraRMG, ore grades of the ten largest gold operations in the world are less than a quarter of what they were 14 years ago, generating higher volumes of waste that require safe storage.

In addition to the problem of declining ore grades, mining companies face growing pressures to improve their environmental performance. Federal and provincial regulations and the future amendments to the Metal Mining Effluent Regulations (MMER) require the industry to reduce or mitigate their impacts. Managing these waste streams and minimizing associated environmental impacts present significant engineering, environmental and safety challenges. The problem is compounded by the fact that while mine operations have a finite life cycle, waste management does not. The costs of storing and managing waste rock and tailings persist long past the end of mining operations and product sales, leaving significant asset retirement obligations on mining companies and governments. Environmental impacts associated with tailings can also lead to fines or mine shut-down in the case of non-compliance. Finding cost-effective solutions to this issue is an industry-threatening challenge – big and getting bigger.

Furthermore, as shown in the recent Mount Polley incident accidental failure of tailings containment has severe negative impacts, not only on the stock value of the company, but also

on the brand and image of the entire industry. Steven G. Vick, member of The Mount Polley Independent Expert Engineering Investigation and Review Panel, publically recognizes that the mining industry cannot continue business as usual and must move away from storing mine waste under water behind earthen dams, a technology that is fundamentally 100 years old. The industry needs a new approach and a clear path to implementation before the sought-after results of reduced impacts, cost and liability can be realized. This requires integration across multiple participants in innovation cycles. Fortunately, Canada can count on strong enabling conditions for innovation across business sectors, including in natural resource industries.

This paper reviews the current state of research and development (R&D) to increase environmental performance in the Canadian mining sector. In particular, the sources of funding, governmental support, the key players in R&D and future opportunities are examined.

2 ADDRESSING ENVIRONMENTAL CHALLENGES THROUGH R&D

Tailings management is among the environmental challenges that will always face operations in Canada and abroad. In this context, the mining industry needs to develop environmentally sound and economically efficient solutions to deal with its huge and always increasing volume of waste. An improved selection of best available technologies (BAT) for managing environmental impact at the planning stage will later facilitate and speed-up permitting as well as gaining and maintaining social licence to operate, in Canada and abroad. More efficient technologies to reduce mine waste will also lower requirements for financial guarantees (reclamation bonds) and residual liability at the closure stage. However, as suggested by the indicators in Table 1, waste and tailings management from 2006-2011 showed limited improvement.

Table 1. Indicators of environmental performance.

Indicator	Trend
Waste and tailings management (2006-2011)	●
Water quality (2003-2011)	○
Air emissions (1998-2011)	○
GHG emissions (1998-2011)	○
Energy consumption and efficiency (1998-2011)	●
Environmental expenditures (1998-2010)	○
Improved Performance ○	Limited Improvement ●

Adapted from: Mining Sector Performance: 1998-2012 (2013)

Mining companies have made and continue to make important investments in R&D to modernize past practices. However, as a whole Canada's private sector has historically scored low compared to other countries. Canada's ratio of Business Expenditure on Research and Development (BERD) to Gross Domestic Product (GDP) was of 0.93% in 2010, which is well below the OECD average of 1.6%. In Canada, in 2014, business expenditures on R&D by the minerals and metals sector were about $500 million. While significant, these expenditures have been on a downward trend and data show that R&D intensity (BERD as a percentage of GDP) of extractive industries has been lagging behind that of the business sector as a whole (Energy and Mines Ministers' Conference 2014). In comparison, mining is a major contributor to investment in R&D in Australia. In 2011-12, global mining R&D expenditure was $4.1 billion (22% of total BERD), the second largest industry share behind manufacturing. Mining's share of total Australian business R&D has more than doubled in the last decade (Mineral Council of Australia).

On the other hand, R&D spending touching the environmental aspects of mining was more significant. For example in 2012, Canadian industrial R&D spending on environmental engineering was $745 million, and $280 million was spent on earth and related environmental

sciences. Of this, the mining, oil and gas extraction sector performed 77% ($577 million) of all R&D spending in environmental engineering and 64% ($178 million) of the spending for earth and related environmental sciences (Statistics Canada).

Most countries recognize the importance of investing in innovation to stimulate private-sector spending on the development and adoption of new technologies. Canadian mining sector R&D is supported by a range of governmental initiatives, from tax incentives and regulations to direct funding programs, with the responsible development of natural resources and environmental protection being common areas of focus.

3 OVERVIEW OF SOME R&D FINANCIAL SUPPORT AVAILABLE FROM THE CANADIAN GOVERNMENT

Canada's Scientific Research and Experimental Development (SR&ED) tax incentive program is the single largest federal program supporting businesses that engage in research, development and commercialization. Related work that qualifies for SR&ED tax credits includes experimental development to achieve technological advancement to create new processes or improve existing ones, as well as applied research to advance scientific knowledge for a specific application. Over the years, the SR&ED tax credit program has supported the mining industry for R&D in environmental areas such as metal contamination and improved tailings management. However, the mining sector is a relatively minor user of the program. Data collected in 2007 indicated that the extraction segment of the mining industry accounted for ~0.5% of the total credits earned under the program.

The Natural Sciences and Engineering Research Council (NSERC) is a governmental funding agency that promotes innovation by financially supporting postsecondary students and postdoctoral fellows and funding research conducted by postsecondary professors. NSERC's programs gives the opportunity for members of the Canadian mining supply chain to collaborate with a research team from a university or college to address an immediate challenge or a longer-term innovation need. The mining industry has not traditionally been a large recipient of NSERC funding but this is nevertheless an important source. A successful example was the OCE-CEMI-NSERC Mining funding Initiative, a partnership of the Ontario Centres of Excellence (OCE) and the Centre for Excellence in Mining Innovation (CEMI), with the mining industry and NSERC, to fund $2 million in university- and industry-based transformative R&D, which included projects for mine water and waste. Two NSERC Industrial Research Chairs related to mine-impacted water and tailings are currently held by Yukon College and by Université du Québec en Abitibi-Temiscamingue (UQAT)/École Polytechnique de Montréal. The Research Chair in Yukon College (Industrial Research Chair in Mine Life Cycle) was created to address northern-specific challenges associated with mine-influenced water and terrestrial reclamation practices. The Research Institute in Mines and Environment (RIME) at UQAT-Polytechnique is supported by several mining companies (~$10 million over 7 years) and addresses technical challenges associated with mining ore deposits and mine site reclamation.

Small and medium-sized enterprises (500 or fewer full-time equivalent employees) are eligible for financial and technology assistance from the NRC-Industrial Research Assistance Program (NRC-IRAP). IRAP helps Canadian enterprises in understanding the technology issues and opportunities and provides linkages to the best expertise for the development and commercialization of innovative technologies, processes, products and services. One example of NRC-IRAP support was the non-repayable contribution of up to $295,000 to BioteQ Environmental Technologies, for technologies that can treat wastewater produced from the Canadian oil sands.

Since innovation is never risk-free, entrepreneurs with innovative technologies often find it difficult to attract investment. This lack of financing explains why many promising innovations never make it from the lab to the market, dying instead at the capital-intensive development and

demonstration phase. Sustainable Development Technologies Canada (SDTC) is an initiative of the Government of Canada that operates as an arm's-length not-for-profit corporation. It aims at increasing access to market and the rate of market entry for the commercialization of innovative clean technologies to achieve Canada's environmental and economic goals. This includes technologies in mine waste management. A remarkable example of support the Canadian mining supply chain is the funding (~$4.4 million) attributed to a consortium led a B.C.-based company (MineSense Technologies Ltd.) for a ground-breaking sorting technology that increases metal recovery from low-grade ore and decreases environmental impact.

Environment Canada manages Canada's Environmental Technology Verification (ETV) program. ETV provides verification and validation, by qualified and impartial third parties, of the performance claims for innovative environmental technologies ready for commercialization. The goal is to allow faster and more widespread adoption of environmental technologies, both nationally and internationally, and to reduce risk for buyers and end users.

To some extent, the industry finds that government research funding mechanisms are not coordinated and do not provide support commensurate with the industry's innovation needs, priorities and contributions. As pointed out by the Mining Association of Canada (MAC) in its 2015 report: first, the government (through NSERC) primarily funds academic institutions, often pursuing more fundamental research which does not necessarily have bearing on industry-generated innovation needs and priorities. This "push versus pull" scenario does not always provide relevant innovation. Second, Canada's minerals sector innovation continuum is fragmented due to a lack of national scale coordination of government and industry funding. As well, the sector faces challenges in effectively networking and focusing Canada's R&D community to integrate service providers into its innovation continuum. In response to these challenges, the mining industry has banded together through non-governmental associations, such as the Canada Mining Innovation Council (CMIC), to coordinate and leverage funding for industry-defined R&D priorities.

These developments represent a subtle but key shift in focus, away from how to spend available funding and budgets and towards developing innovative solutions and outcomes. The emphasis moves off metrics around total dollars spent on R&D and starts to fall on innovation outcomes and direct business benefits. The planning conversation must now emphasize the business case for investment, not just the budget for R&D spending. The rationale is that if the return on investment is clear, funding decisions will follow. The role of government support then also shifts away from simple R&D support towards providing risk mitigation and risk sharing arrangements with the investors and the ultimate beneficiaries of innovation, the industry. In addition to technical risk management, R&D agencies become the stewards of strategic expertise and facilities, guided by industry needs. These changes are accompanied by changes in the relationships between R&D providers and the participants in the mining supply chain – an idea that is explored more fully in Section 5 of this paper.

4 KEY PLAYERS FOR ENVIRONMENTAL R&D AND INNOVATION

With the magnitude and complexity of the problems, and the increasing need for an interdisciplinary approach in the development of innovative technologies, it has become nearly impossible for mining companies to meet their technology needs by in-house R&D: only a few of the largest companies currently maintain internal research centres and it is by no means clear that this remains the best way to approach R&D. Table 2 reviews the strength and weaknesses of some key players involved in environmental R&D and innovation for the mining sector.

Table 2. Overview of the key players in environmental R&D and innovation for the mining sector.

Entities	Leaders	Strengths	Weaknesses
Universities	A few examples are Polytechnique Montreal/UQAT – Program RIME; Laurentian University - Goodman School of Mines; UBC – Dept. of Mining Engineering; Yukon College; Laval; Many others.	Generally more focused on fundamental and academic research, targeting an increased understanding of basic concepts and developing future work. Strong focus on HQP, where industry is at risk. Able to secure NSERC funding, which is still seen as attractive by industry.	Limited pool of trained personnel, work generally conducted by research staff (students) with a high rate of turnover. Students have limited industrial experience.
RTOs	Canada National Research Council (CNRC); COREM; Saskatchewan Research Council (SRC); CRIQ, CEMI.	Long-standing relationships with mining industry. Aware of environmental issues related to the mining sector. Development of relevant expertise.	Mandates of some RTOs are in scope to specific geographical or technical areas. Depth of capabilities varies. Limited supply chain engagement. Focus on funding pressures.
Federal Agencies	CanmetMINING	Science and technology dedicated to the mining sector, but only partially dedicated to technologies to reduce environmental impacts. Some long-standing programs (e.g. MEND) and facilities. Local presence in mining regions.	Specific areas of expertise and programs that cannot cover all industry needs. Collaboration initiatives are being developed.
Environmental Services Providers	Engineering firms, less than 50 of various sizes.	Well-established business model, strong awareness of cost. A few are exploring greater technology role.	Appetite for innovation often constrained by commercial arrangements that stifle appetite for technology risk. Generally have limited R&D capabilities (there are exceptions).
Associations	Mining Association of Canada (MAC); Canada Mining Innovation Council (CMIC); CAMESE, provincial associations e.g. MABC, MSABC.	Sharing of knowledge and tools leading to rapid adoption of 'industry-standard' way of operating, creates a system encouraging companies to contribute.	Tend to be less effective beyond the pre-competitive stage when membership become less inclined to collaborate. Required competencies or research capabilities may not be available from member organizations.

Technology Suppliers	Supplier companies ranging from global MNEs to SMEs, from technology-specific vendors through consultancies to large EPCM firms.	Play key role in optimizing and developing innovative technologies and ideas. Often active in other industrial sectors (opportunity to acquire technologies developed for other industries). Offer key integration services.	Often constrained by end user specification of proven technology. Not necessarily proactive in environmental solutions but rather work to find specific solutions that meet client specifications at lowest cost. Limited appetite for applying advances from adjacent industries.
Original equipment manufacturers (OEM)	Also range from global MNEs to SMEs.	Progressively shifted focus to provide greener machinery and techniques, for unit operations – for example increased efficiency and reduced effluents and waste.	Responding to user specifications, proven equipment at lowest cost. Traditional OEM-centric business models. Often prefer to adapt existing systems rather than redesign. Few head-office in Canada; sector relies largely on imported technology.

National non-governmental organizations are emerging as major enablers of a more effective R&D system. CMIC, a national non-profit organization with representatives from industry, academia and government, was formed with the aim of investing mining industry R&D dollars more strategically. CMIC discusses with government agencies how best to support the industry's innovation priorities, including in the areas of tailings management. The organization also seeks federal government funding for projects that more fully reflect the industry's needs. CMIC working groups in its Environmental Stewardship Initiative (ESI) have developed roadmaps to address the environmental needs of the mining industry; a Tailings Working Group is currently being re-established after a hiatus. Towards Sustainable Mining (TSM) is MAC's commitment to responsible mining. It is a set of tools and indicators to drive performance and ensure that key mining risks are managed responsibly. One of the priority areas of TSM is tailings management. The protocols and management system-based indicators that back the TSM guiding principles describe the industry's current environmental performance and what can be improved, and therefore help to define R&D priorities.

In response to the ongoing challenges faced by the mining industry to reduce its environmental footprint, Natural Resources Canada (NRCan) established, in 2009, the Green Mining Initiative (GMI). The objectives are to accelerate R&D and deployment of green mining technologies and practices, to enhance innovation and improve environmental performance of the Canadian mining industry. GMI works in close partnership with provincial/territorial governments, industry, academia, non-governmental organizations (NGOs) and other interested stakeholders such as the Canada Mining Innovation Council (CMIC). One of the research and innovation pillars is 'Footprint Reduction' and comprises activities to minimize the quantity of waste. NRCan also administers the Mine Environment Neutral Drainage (MEND) Program and the National Orphaned/Abandoned Mines Initiative (NOAMI). CanmetMINING, a division of NRCan, is involved in the development and deployment of green mining science and technologies. Much of CanmetMINING's research is done in partnership with industry, provincial governments, other federal departments, universities and even international agencies. They operate by doing in-house research and contracting-out on a cost-shared, task-shared or cost-recovery basis.

Traditionally, academic institutions were mainly involved in fundamental research that did not necessarily meet the needs of the industry. Over the years, collaborations with the industry have led to more applied and aligned projects that significantly contribute to innovation. NSERC grants requiring industry co-investment allow universities to offer research services at low cost, but their major impact remains on the development of knowledge and the training of highly qualified personnel.

Engineering firms provide environmental services though the whole mine life cycle, for environmental compliance (permitting, environmental assessments, environmental impact study, and site closure plan) and conception, implementation and monitoring of treatment and environmental solutions through feasibility/mine planning to mine closure/rehabilitation. Owner risk aversion drives commercial arrangements that discourage these engineering firms from recommending innovative solutions. These arrangements generally fail to define mechanisms for managing technical risk associated with new technologies, so they tend to work on optimization rather than on the development of new technologies. Engineering firms do perform R&D to keep their expertise up-to-date, but typically such R&D is limited to meet a specific need at a specific site during the course of a project. They commonly use tax credits to support their R&D activities, which allow the companies to occupy their personnel off-season while maintaining the intellectual capital of the company.

Environmental technology suppliers, ranging from multinational enterprises (MNEs) to small and medium-sized enterprises (SMEs), play a key role in the development of environmental technologies. A company is generally active in a range of industrial sectors and thus can provide mining companies with technologies that were proved successful in other industries, without having to invest in R&D. They generally have few contacts with the mining companies and are often constrained by end user requirements for proven technology. The same applies to the original equipment manufacturers (OEMs). OEMs often supply a ‘standard duty box’ to fit all industries, without providing a custom solution for a specific application. It the current traditional model, it is difficult for smaller innovative companies to get visibility and commercialize their products and services.

Finally, Research and Technology Organizations (RTOs) are industry-driven organizations whose primary role is to develop and deploy technologies. They play a crucial role in overcoming national innovation difficulties by acting as links in the innovation system, stimulating business investment in R&D, adding value to research investment, reducing risks and developing market-focused technologies. Some of Canada’s RTO have long-standing relationships with the mining sector and are well-aware of its environmental issues. However, they are typically regional in scope and have traditionally focused on working with end-user companies with limited supply chain engagement.

5 FUTURE: NEW WAYS, NEW OPPORTUNITIES

A question remains: what can we do to boost innovation in the mining sector and find solutions for tailings and other environmental issues? Business innovation in Canada has continued to fade despite billions of dollars invested in R&D over two decades. Relying only on R&D is not enough.

Part of the better way of doing things is to allow innovation to flourish in the hands of those best placed to realize its benefits. Somewhat counterintuitively this is not necessarily the end user mining operator. In many cases, it is the service or equipment supplier. For example, improvements to mineral processing flow diagram or equipment unit operations are implemented by the process consultant and process equipment supplier. But because commercial arrangements between such suppliers and the mining operator do not currently transfer either risk or benefit of improved performance to the supplier, there is little incentive for innovation. The industry should recognize that it is not only technical innovation that is required. Business innovation is an equally important part of the puzzle. These issues have been

recognized by other, more-technology-based and innovation-driven industries including the automotive and aerospace industries. Engineering and commercial systems have been developed by these sectors to facilitate appropriate transfer of technical and performance risks with their costs and benefits, in a way that incentivizes innovation by the supply chain. The mining industry is just starting to recognize that these approaches can also be applied to the entire mining lifecycle – including approaches to tailings management, disposal and remediation.

In this context, Canada National Research Council (CNRC) has re-structured its approach to meeting industry needs in general, including those of the Canadian mining industry. CNRC is the primary national research and technology organization (RTO) of the Government of Canada, and has a clear mandate to work with clients and partners to provide innovation support, strategic research, scientific and technical services in order to develop and deploy solutions to meet Canada's current and future industrial and societal needs. CNRC's program High Efficiency Mining (HEM), launched in November 2013, is a multi-year R&D program that establishes co-investment opportunities for stakeholders along Canada's mining value chain. Prior to launching the program, CNRC engaged with industry and worked with CMIC, which had already identified a set of industry priorities. Targeted projects will help optimize mining processes, improve equipment durability, and reduce the risk of technology adoption and integration across mining operations. These collaborative activities are expected to result in practical technology solutions to save companies hundreds of millions of dollars in operating and maintenance costs, while generating sustainable economic benefits to Canada. Another CNRC program, fully dedicated to generate environmental advances in mining, is currently in development. The program's main objectives are 1) to decrease environmental CAPEX, OPEX and liability cost in mining and 2) to reduce risk associated with adoption of innovative solutions, providing Canadian mining companies and Canadian suppliers (technology and services) economic and environmental competitive advantages on the global stage. The future program will be positioned to work with technology suppliers to deliver solutions to environmental problems experienced by mining end-users conducting development, operations and remediation. This approach should allow costs and risks of increasing environmental challenges to be brought under control. The current stage of the commodity cycle would be an ideal time to launch a program such as this: all industry eyes are on efficiency and productivity, providing fertile ground for a business case approach.

6 CONCLUSION

Canada's mining sector has the tools and capacities to position itself as the global leader in environmental mining technologies and practices. However, international competition is a major threat to the Canadian supply chain because other countries' R&D capacity for this sector can support their own suppliers and service providers to develop and export new technologies. Industrialized and emerging economies around the world continue to invest heavily in science and technology. International programs, initiatives and associations that support or perform R&D for environmental advances in mining exist at the government or industry level in resource-based economies similar to Canada's. As competitors increase in both number and quality, the Canadian industry must continue to leverage its strengths and be ready to make fundamental and dramatic changes in the way of driving innovation into Canada's mining supply chains.

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