Mining Value from Waste Initiative: Towards a Low Carbon and Circular Economy

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Abstract The concept of tailings reprocessing is not new. However, due to the complexities ranging from S&T to material handling to policy and regulations, reprocessing successes have been limited. Several factors have been identified by stakeholders as requirements for success, such as economic considerations, engineering challenges, and policy and regulatory implications. Innovation underlies each of these factors. One of the biggest challenges is to reduce the environmental liabilities associated with mining waste, for which the financial securities may not be sufficient to ensure adequate protection. The recovery of metal values from tailings is potentially attractive and economically viable, particularly when combined with a concomitant reduction in environmental liabilities. Recently, Natural Resources Canada embarked on a pan-Canadian effort entitled 'Mining Value from Waste' to develop tools, technologies, and policies to de-risk and accelerate demonstration and full-scale waste reprocessing/repurposing projects with the goal to reduce mine waste liability and environmental impact, while providing local and national value.

Keywords Reprocessing · Repurposing · Tailings · Recovery · By-products · Liability · Bioleaching

Introduction

It is estimated that the liability for managing mine wastes in Canada and the US exceeds $50 billion [16]. These wastes represent a huge liability for both mining companies and governments. The liability associated with the management of tailings impoundment areas (TIA) alone is significant. Specifically, the cost of remediation for TIA failures worldwide is estimated to be US$ 6 billion in this decade alone [2]. In 2016, Mining Watch Canada analysed Auditor General for Canada reports from three mining jurisdictions, British Columbia, Quebec and Ontario, and stated

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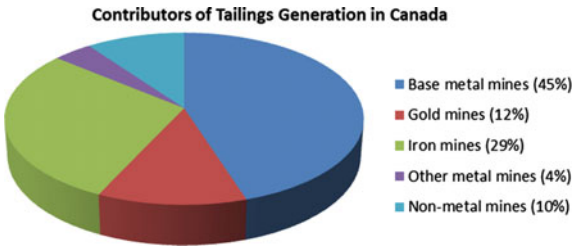

Fig. 1 Tailings types in Canada by weight (6 billion total tonnes)

that the total environmental liability for mine site clean-up was estimated to be over C$7 billion; of which C$4 billion was unsecured by financial securities held by the provinces [9].

The Kam Kotia mine site near Timmins, Ontario, Canada was considered to be one of the worst contaminated sites in Ontario. Beginning around 2000, the Ontario government spent in excess of C$135 million in care, maintenance and remediation to address this site [17]. Most of this cost was associated with stabilization of the tailings impoundment and treatment of acidic tailings seepage water.

The Canadian Federal Contaminated Sites Action Plan (FCSAP) is a 15-year/$4.54 billion programme that was established in 2005 by the Government of Canada to address the risks that these sites pose to human health and the environment, and to reduce the associated financial liability. Many of the sites included in this programme are from mining and contain tailings. Under FCSAP, the estimated cost to remediate just one site in the Yukon, the Faro Mine, exceeds $1B.

In addition to government liabilities, tailings and other mine wastes pose a long-term liability to mine operators. Besides holding long-term insurance bonds, mine operators are actively engaged in developing best practices in tailings management [8, 11–14] to mitigate the risks associated with these wastes. Furthermore, mine waste management efforts and objectives are typically formulated around reclamation and mine closure, not targeted at reaping potential economic benefits through waste reprocessing and repurposing.

In general, tailings represent over 95% of the rock mass mined and because of the diversity of ore bodies and technologies employed to process them, the resulting tailings are very much site-specific. The rate of tailings generated at Canadian mines is on the order of 200–250 million tonnes per annum, with the cumulative sum of the tailings from the last three decades amounting to over 6 billion tonnes [1]. Records indicated that over 6 billion tonnes of tailings were generated in Canada over the last 30 years; of which 90% originated from metal mines with base metals, iron and gold mines as the major contributors (Fig. 1) [1]. The typical tonnage of tailings generated in each commodity industry varies largely depending on the primary metal mined. For example, about 400 tonnes of tailings are generated per kg of gold produced, 125 tonnes per tonne of copper produced, and 2 tonnes per tonne of iron produced. These ratios will continue to climb as high-grade ores become scarce, while the continuous advancement of technologies will allow the industry to process lower grade ores [6].

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

Program Rationale

By coupling the high liabilities associated with mine waste management areas and the decline in easy to access, high-grade ore deposits, the option to reprocess 'older' tailings becomes an attractive and potentially economically viable alternative to a new mine development. With a growing global middle class, it is likely that there may be a supply risk for some minerals and metals that will increase in the coming years. In addition, finding high-grade ores in politically stable regions is more difficult and permitting time for new projects is lengthening [10], while many historic tailings contain metal grades higher than currently mined today.

Cheng et al. [6] conservatively estimated that the total metal value in Canadian gold tailings is on the order of $US10 billion. Eighty per cent of this could be easily recoverable. Despite the significant metal value contained in mine waste, reprocessing of these wastes is unconventional. In general, the remaining metal value present in tailings is considered a process loss that does not warrant any further effort to recover. This is mostly due to economics, environmental liabilities and regulation or technological deficiencies.

The development of a cash-flow model, which will become part of the prefeasibility study tools to provide techno-economic analysis of the selected process options for a particular tailings site, is underway at CanmetMINING (Natural Resources Canada). The preliminary model depicts a hypothetical tailings reprocessing project with 50 million tonnes of gold tailings and an average gold grade of 0.5 g/t. Assuming the mine life of this tailings reprocessing project to be 8 years, with 80% gold recovery at a gold price of US$700 per ounce, the discounted cash flow rate of return (DC-ROR) is estimated to be 17%. It is important to note that the cash flow analysis shows DC-ROR is highly sensitive to gold price, gold grade of the tailings and gold recovery, and is moderately sensitive to reprocessing (operating) cost and least sensitive to capital investment.

Mining Value from Waste Program

Launched in August 2018 at the Canadian Energy and Mines Ministers Conference (EMMC), the Mining Value from Waste programme (Fig. 2) is a pan-Canadian initiative focused on reducing the environmental, social and economic footprint of mine wastes, such as tailings, and examining options to obtain value from these wastes, both by recovering valuable metals and by using the wastes as resources in other applications. The objective of the project is to develop tools, technologies and policies to de-risk and accelerate demonstration and full-scale waste reprocessing and repurposing projects, with the goal of reducing mine waste liability and providing value (cleaner environment, jobs, resources, etc.).

While the concept of tailings reprocessing is not new, successes to date have been limited in Canada and elsewhere due to complexities related to science and technology, materials handling, as well as policy and regulations. Mining Value from Waste stakeholders recognize that to achieve the goal of developing onsite process demonstrations (and eventually full tailings reprocessing) will require addressing several factors including: economic considerations such as reducing capital and operating costs; engineering challenges related to processing a complex and variable low-grade feed at a high throughput; and policy and regulatory factors. To address these factors in an integrated way, and to move from concept to reality, and to a circular and low carbon economy, requires a multi-disciplinary and multi-stakeholder approach.

In advance of the program launch, a stakeholder workshop was held [17] to discuss current projects being undertaken in the area of waste reprocessing/repurposing and define areas of collaboration and future work. It was recommended that a holistic approach be taken, which would include the following:

- Waste reprocessing
- Repurposing options
- Novel materials from waste components
- Processing to eliminate tails and other waste

Fig. 2 Mining value from waste programme concept

- Tailings and mine waste lifecycle
- Mine waste management options to facilitate reprocessing at a later date
- Policy and regulatory reviews

The program has identified three types of tailings, which pose high risks to the environment and/or contain high economic values that make them commercially attractive. These are: (i) reactive sulphide tailings prone to acid mine drainage, (ii) gold tailings with low sulphide content and (iii) tailings that pose high liability to the environment (Table 1).

CanmetMINING is already undertaking several projects under the Mining Value from Waste Programme. These are detailed below.

Reprocessing of pyrrhotite rich tailings [3, 4]: Large quantities of pyrrhotite are produced during physical separation of nickel ore. The pyrrhotite contains nickel and cobalt and is highly reactive, producing significant acidic drainage. Reprocessing of this material will result in lower treatment cost and significant revenue generation.

Achievements include:

- Completion of stirred-tank bioleaching experiments to examine the effect of chemical additives and flotation on sample beneficiation.
- Preliminary techno-economic evaluation (TEA) and genomic characterization

Rare earth elements and scandium from coal ash [5]: Coal and coal ash contain significant quantities of rare earths and other critical elements. The rare earths and scandium are relatively readily extractable and could provide a secure source of critical metals from a waste source.

Achievements:

- Several coal ash sources examined
- Scandium is 70–90% of the contained value and able to leach 30–50% with dilute sulphuric acid
- Residue can be used in supplementary cementing materials for civil engineering.

Iron removal using biomass-based technologies to produce a saleable product: This project emphasizes the removal of iron from base metal mine wastes. Considering that the base metal tailings can contain high levels of iron oxides that could be economically exploited upon the development of an efficient iron recovery technology. This project focusses on the coupling of biomass-based technologies to facilitate iron removal by magnetization. The magnetic iron produced may be suitable as a saleable product, but also as an important sink for trace metal contaminants in tailings.

Achievements include:

- Successful magnetization of relevant ferric oxide (hematite), hydroxide (goethite), and sulphate (jarosite) as well as oxidized pyrrhotite tailings in the presence of biomass at low temperature.
- Detailed characterization of the reactive process during phase transformation.

Table 1 Tailings types for consideration (From Cheng et al. [6])

Tailings type	Economic driver	Environmental benefit	Technical merit
Reactive sulphide tailings (e.g. pyrrhotite-rich tailings)	High Reactive sulphide tailings, especially those generated several decades ago, often contain base metals/ precious metals/strategic metals with metal grades comparable to new exploration projects	High Reactive sulphide tailings require perpetual containment in costly engineered cover systems to avoid AMD generation. Tailings reprocessing can eliminate/reduce the volume of the reactive tailings by converting part of them to benign residues	High
Gold tailings with low sulphide content	High Tailings with gold grade as low as 0.2–0.3 g/t can be commercially attractive provided that the operating cost of the novel reprocessing technology is significantly reduced. (less than $10 per tonne)	High Through reprocessing of the tailings and recovery of the gold values, the resulting residues have great potential to become benign tailings, which can be repurposed for backfill or construction use	High
High liability tailings (e.g. high arsenic tailings)	High The liability cost and the future remediation cost are very high for contaminated tailings sites	High Bio-mineralization can be used to stabilize deleterious elements such as arsenic. Microbial transformation of arsenic in the subsurface can provide a long-term arsenic stabilization solution, thereby protecting the environment	High

Demonstration and optimization of the alternative binder technology: This technology could be used to place enormous quantities of tailings and slag back underground, thereby decreasing surface liabilities. Further, the alternative binder 'recipe' results in significant greenhouse gas reduction and cost savings for the mining industry, due to the replacement of Portland cement.

Achievements include:

- Recipe development for various waste types
- Slag characterization
- Binder strength on par if not greater than Portland cement

Recovery of metal values from gold tailings [7]: The focus of the project is to develop novel processes to recover metal values, particularly gold from historic gold mine tailings and to reduce the environmental liabilities associated with these wastes. The project focusses on the development and deployment of innovative tailings reprocessing solutions, specifically in the areas of reactivation of sulphide minerals, recovery of metal values, and removal of contaminants.

Achievements:

- Process flow sheet developed
- Successful gold recovery (>80%) without the use of cyanide

Bioenergy production from mine waste areas [15]: This project examines the opportunity to use municipal waste and other residues on mines sites to reclaim mining lands and grow energy crops. It employs the strategy of utilizing one waste to reclaim another with the aim of generating bioenergy from these sites.

Achievements:

- Successful field trials employing hybrid willows, canola and corn
- Data suggest oilseed production on mine tailings could generate approximately 3600 litres per hectare, and a gross profit of approximately $900 per hectare per year
- A preliminary bioenergy feasibility study showed a combustion option to be the best, and that <400 ha of hybrid willow could provide enough electricity to power a typical water treatment plant.

Conclusion

The Mining Value from Waste program has the potential to be a game changer in the way we look at mining. The approach strives for green extraction of metals with the goal being value generation, along with associated liability and environment impact reduction. As we look to transition to a low carbon and circular economy, we need to examine novel approaches to secure mineral and metal resources. Considering the volume and variety of mine waste available, the opportunity for reprocessing and repurposing is real and potentially immense. Through collaboration, existing technical, engineering and regulatory challenges can be overcome to achieve 'mining value from waste'.

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