2nd Annual Mining Value from Waste

CanmetMINING held the 2nd Annual Mining Value from Waste workshop on December 6th in Toronto. The objective of the workshop was to continue the development of a collaborative Canadian approach to reprocessing and repurposing mine waste. The agenda (Appendix 1) included a variety of talks to provide updates on existing and new projects in this space, and to highlight other considerations. This was followed by discussion topics aimed at getting feedback on developing the path forward. More than 40 participants from across the mining sector attended the workshop (Appendix 2).

Bryan Tisch opened the workshop by welcoming participants and thanking Mandeep Rayat, Vlad Papangelakis and the University of Toronto for hosting the workshops. He provided opening remarks and presented logistical details. He noted that this is the second Mining Value from Waste event, and that it is now time to start developing the path forward.

Magdi Habib provided opening remarks, noting the work of CanmetMINING and the Green Mining Innovation division. He also mentioned NRCan's Assistant to Mining Innovation (AMI) which is helping to foster a Canadian Green Mining Innovation Network, and the recent announcement from Energy and Mines Ministers Conference (EMMC) recommending the creation of a Mining Value from Waste program.

Janice Zinck highlighted CanmetMINING's rationale and approach for Mining Value from Waste, including the ongoing demand for metals, the accelerating green economy, public and corporate concerns, associated liabilities, and supply risks (Appendix 3). She discussed how the program contributes to the advancement of a circular (Figure 1) and low carbon economy for the mining industry, reiterated the program common objective and gave a brief overview of the scope of projects in progress at CanmetMINING, including linkages to several projects submitted under the Clean Growth Fund. In response to the EMMC recommendation noted above, CanmetMINING is in the process of establishing a Mining Value from Waste research group (program). It was suggested that recycling of metal components should also be part of the program.

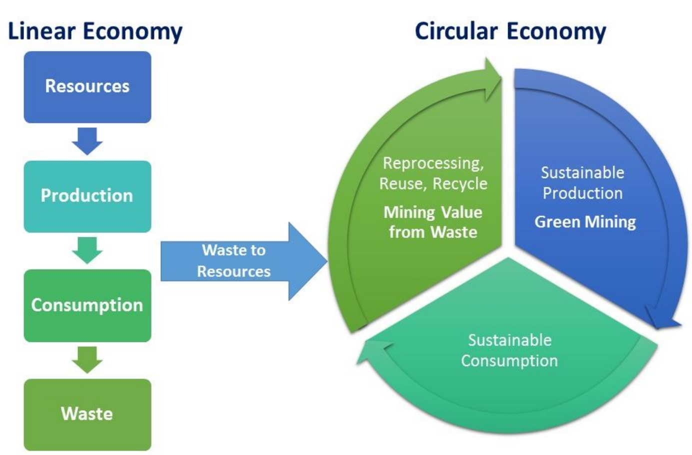

Figure 1: Transforming Mining from a Linear to a Circular Economy.

Dawne Skinner (Dillion Consulting) presented an overview of the circular economy as it relates to mining (Appendix 4). A circular economy is "*one that is restorative and regenerative by design, and which aims to keep products, components and materials at their highest utility and value at all times*…." (Ellen Macarthur Foundation). It incorporates best practices and four key principles: 1) waste equals food, 2) building resilience through diversity 3) powered with renewables, 4) requires whole systems thinking. The "Butterfly" approach provides for maximum recycling/reuse, and includes four aspects of value creation in the circular economy. System enablers include tax incentives, recognizing negative externalities as a cost, appropriate legislation and technology. Increased demand of resources, with difficulty to supply are drivers for a circular economy. The current successfully-applied linear model (Figure 2) of take, make and dispose, based on fossil fuel use, may be coming to an end. A circular economy operates on the basis of rethinking the throughput model and asking whether there is a better or more effective way to use the abundance of materials, resources and energy that we are squandering.

Mining generates 3.7 Gt/year of waste rock and tailings. Technologies such as ore sorting and other sensors can be used to improve efficiencies, reduce costs and maintenance, and will lengthen asset life. Waste heat recovery and use of renewables can help to reduce energy inputs. Designing products for disassembly can improve the likelihood of component recycling. Comments suggested that tax incentives can be used to encourage waste reprocessing, repurposing, and re-use, and that companies must look into tax mechanisms to establish the true cost for the circular economy. For example, could remove taxes from labour as a circular economy is labour-intensive i.e. tax what you want less of. Incentivize the reuse of wastes through taxation. Policies and regulations, along with taxes, are the driving factors. What is the lifetime of metals? Metals are the most recycled item, once they are extracted and can be reused indefinitely, though there is some degradation.

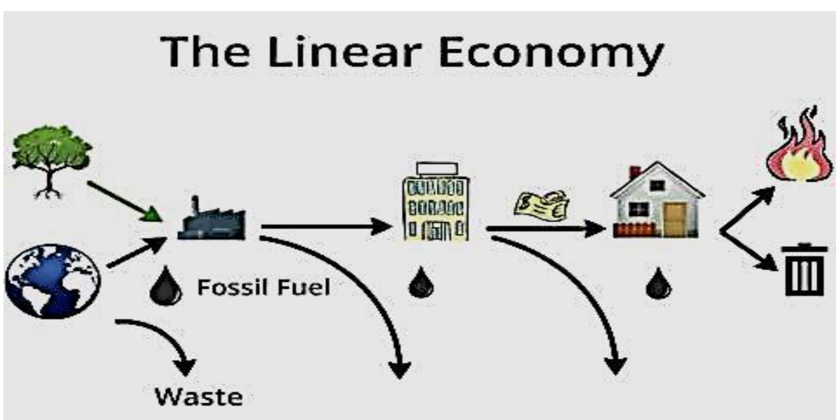

Figure 2: The linear take, make, dispose economy, powered by fossil fuels, has been hugely successful for the developed world, but there is growing evidence to indicate that the conditions underpinning these successes may be changing and perhaps drawing to an end.

Vladimiros Papangelakis presented on the work that the University of Toronto is undertaking on pyrrhotite tailings reprocessing to recover nickel (Appendix 5). One of the challenges is the large amount of sulphur present in these tailings, as it is highly reactive and produces acidic drainage. If assume 80% of the nickel can be recovered the in the value of Ni is in the Sudbury tailings is estimated at ~$9 billion. UoT's approach (Figure 3) is to form elemental sulphur instead of sulphate during the nickel recovery process using a two stage (abiotic ferric attack, followed by bio-catalyzed ferric regeneration). Liming kills the economics of any process that results in the oxidation of sulphur to sulphate. After recovery of the sulphur and nickel, a benign residue will be left. This project is part of the Elements of Bio-Mining program, which is a collaboration between University of Toronto, Laurentian and University of British Columbia examining bioleaching mechanisms relating to the sulphur and selenium cycles.

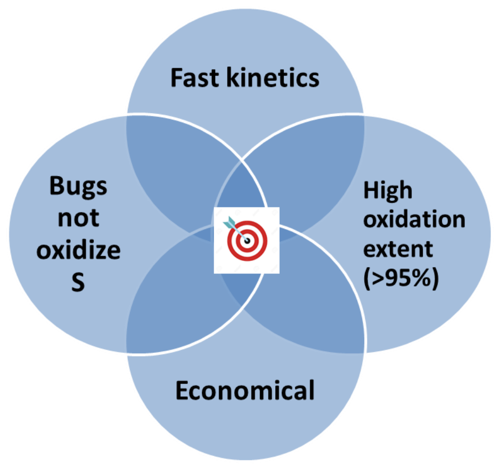

Figure 3: The objective is to identify the best reagent and conditions to regenerate ferric iron

Nadia Mykytczuk from Laurentian University spoke on the optimization of gold recovery through bio-oxidation of arsenopyrite concentrates (Appendix 6). The microorganisms present on the waste will strongly influence the bioleaching performance, and it is important to better understand how existing flora adapted to a particular environment perform compared to "superbugs" typically used for bioleaching. She noted the need to optimize aeration and mixing in order to maximize gold recovery, and that it is important to liberate the arsenic (Figure 4) so that it can be stabilized as ferric arsenate or scorodite. Nadia also spoke about the proposed Centre of Mine Waste Biotechnology at Laurentian University, including potential partners and funding opportunities. There is need for this because universities typically do not have capacity to scale-up and there is currently no cohesive entity to optimize technologies as you move from bench to pilot scale.

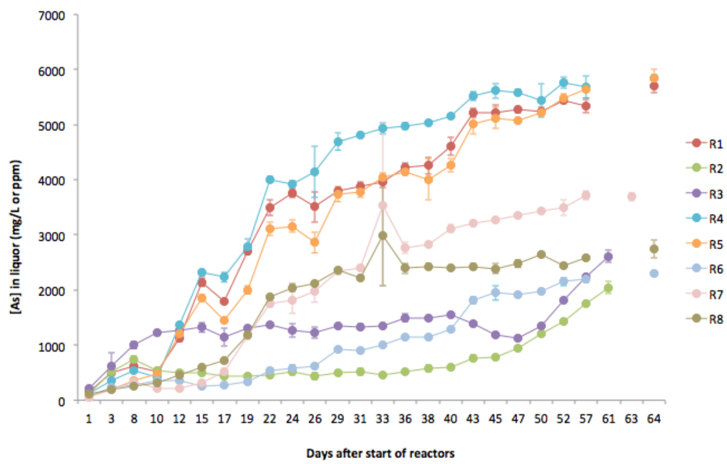

Figure 4: Optimizing the bioleaching performance for the removal of arsenic, which will be precipitated as scorodite.

The gold tailings reprocessing research at CanmetMINING was presented by Terry Cheng (Appendix 7). He reiterated the importance of the economics and the business case for reprocessing. His work is focussed on tailings from the Timmins camp and from Montague, Nova Scotia. He provided a holistic approach to repurposing, recovery of the pay metals and reduction of the liabilities. In one of the samples examined, 88% of the gold was free milling, leading to roughly 85% recovery by cyanidation and also from thiosulphate leaching. For the other tailings sample 95% of the gold was recovered from oxidative chloride leaching. His work found agglomeration of the tailings was common, and passivation was not an issue. Terry also indicated that deleterious substances can be removed on the basis of particle size (Figure 5). The next steps for his research are focussed on desulphurization, immobilization or arsenic and gold recovery.

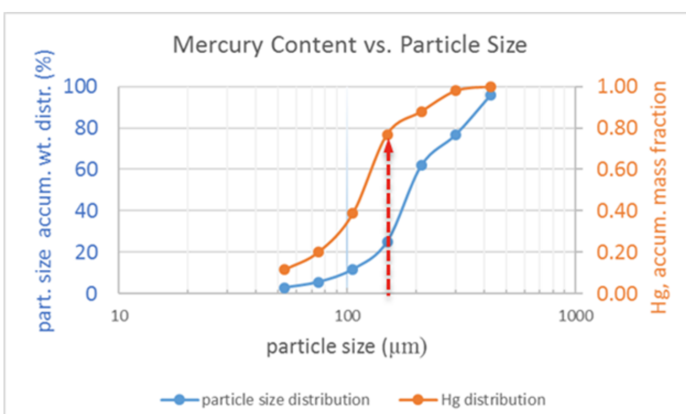

Figure 5: By collecting particles smaller than 150 µm (i.e. 25% of the mass), 80% of Hg can be captured from gold-bearing tailings during reprocessing.

Stephanie Downing (SGS) presented on determining metal value from waste using mineralogical characterization (Appendix 8). Gold processing mineralogy is often completed by combining different tools/approaches. For example, invisible gold can be identified using microscopic methods. Refractory gold is invisible under optical microscopy and requires other methods. Gold exposure is a critical key parameter because it indicates whether the mineral is available for cyanidation (Figure 6). She highlighted results for Black and Green slag, which contain gold and platinum group metals. It is critical to obtain a representative sample for characterization and ultimately process development.

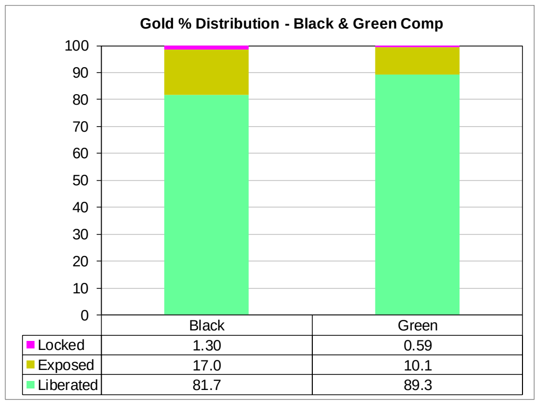

Figure 6: Gold % distribution as a function of surface area and % gold for black and green slag.

Allan Cramm provided industrially applied examples of Anaconda Gold's '*Total Waste Utilization*' efforts (Appendix 9). Specifically, he highlighted that their tailings contain approximately 0.32 g/t gold worth approximately $30 million, and they are working with RPC to develop methods to extract this residual gold economically. One of their significant achievements has been repurposing their coarse mine waste as an aggregate. Anaconda is currently shipping their mine waste to North Carolina to be used as amour stone. Marine shipping is a key to their success, as it provides access to a large market (Figure 7).

Figure 7: Economically feasible bulk international shipping of mine waste for commercial applications.

In addition, Anaconda is repurposing their tailings sand as a soil amendment, since deleterious substances in waste rock and tailings are below detectable limits. The next step for their Total Waste Utilization program is to consider using their rock dust for carbon sequestration, and to reuse their open pit for tailings as a stable landform.

The next talk was co-presented by Hendrik Falck (NWT government) and Heather Jamieson (Queen's University) on the reprocessing potential of the Cantung tailings (Appendix 10). The Cantung site is located in Northwest Territories near the border with Yukon and 310 km from the nearest town. The site has been worked since 1962, and operated until the mid 1980's. It was restarted in 2002 and has operated sporadically since. The initial tailings were deposited in the river. Remediation cost of the tailings on surface has been estimated at $30M. Scheelite is the main ore mineral, with pyrrhotite, chalcopyrite and minor Au, Ag, Bi, Cu and Te also present. Over milling has been an issue, resulting in scheelite fines. Mineral resources are defined as a WO_3 cut off grade of 0.5%. Production history from 1962-2015 was 7.68MT ore @ 1.4% WO_3. There are approximately 6.5 Mt of tailings contained in five tailings ponds, with most considered acid generating. The carbonate content appears to have delayed acid generation. Queen's University has used automated mineralogy to examine 50 tailings samples (Figure 8). The W content in the tailings ranges from 0.1 to 0.65%, comparable to viable W deposits. Agglomeration of the tailings is an issue, and the particle size distribution is bimodal. Queens U. is also undertaking a study on the mobility of W in surface, river and pore waters.

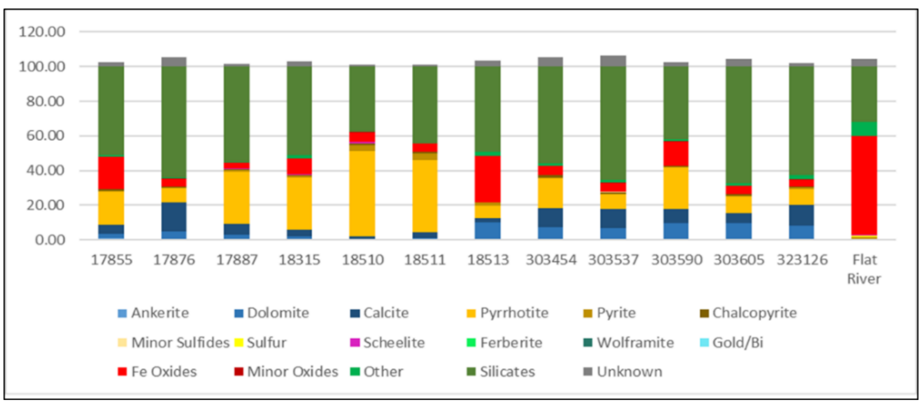

Figure 8: Modal mineralogy of the Cantung tailings.

Siavash Farhangi (Golder Associates) presented geotechnical and hydrotechnical aspects to be considered during tailings reprocessing (Appendix 11). There are different methods to move the tailings, such as excavate and truck, dredge, slurry and pump and hydraulic mining (Figure 9). Some of the challenges regarding tailings reprocessing from a geotechnical perspective can include dewatering (especially fine grained tailings), debris, stability and access, chemistry, discharge, makeup water, requirements for a new tailings facility, increased footprint (initially) and disturbing an established cover. He noted the need for an inventory of tailings ponds in Canada, with information including location, quantity, logistics, and chemical and physical stabilities. There is also need to document case studies where tailings have been reprocessed. He emphasized the need for changes in regulations and guidelines, and suggested that there is an opportunity to produce designer wastes.

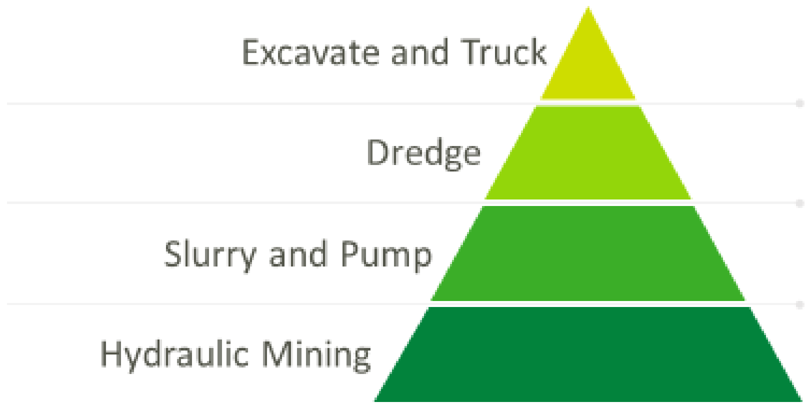

Figure 9: Methods of moving tailings for reprocessing.

Larry Smith (L.D. Smith and Associates) presented on the aspect of closure plans and their implications for tailings reprocessing (Appendix 12). He introduced the concept of "HABU" – highest and best use of the land, and that companies should consider segregating mines wastes (Figure 10). Larry recommended that Canada should move away from full site decommissioning upon closure, and instead maintain the site infrastructure to support future brownfield development. In addition, he stressed the importance of integrating fluctuating commodity prices in business models. The opportunity really comes from reducing closure and care/maintenance costs.

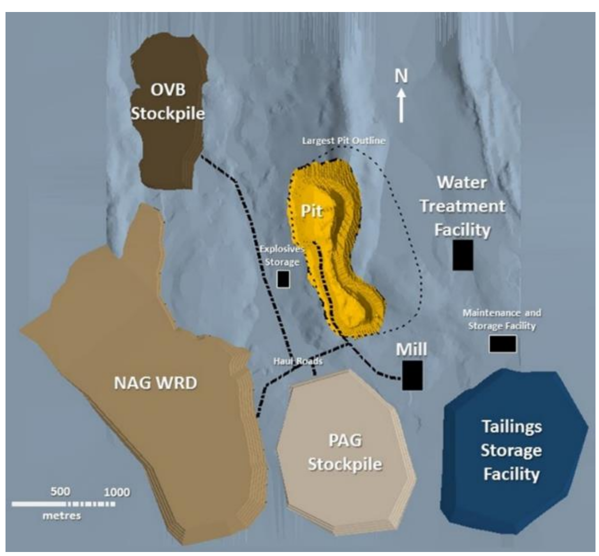

Figure 10: Schematic showing potential to segregate mine wastes to allow for more focussed rehabilitation or reuse options.

Ljiljana Josic (SNC Lavalin) presented on a waste classification program (Appendix 13). There are several types of wastes generated through mining, including topsoil, overburden, waste rock, tailings, slag, and sludge. The best mine waste management approaches start with waste reuse, while disposal is the least attractive mine waste management option. Only 20% of the tailings volume is deemed hazardous, most is actually benign material. Currently the mining industry does not classify the waste, but there are a variety of benefits that could be realized from utilizing the wastes. Some of the aspects to consider in waste classification are acid generating potential, penalty elements, and processing chemicals. The proposed program separates waste into level 0 – neutral, level 1 – low risk, level 2 - intermediate risk, level 3 – high risk (Figure 11). Geophysical risk could also be included.

CATEGORY / ITEM	WASTE CODE			
	0 NEUTRAL	1 LOW RISK	2 INTERMEDIATE RISK	3 HIGH RISK
ARD	Non-acid generating	NPR > 2	NPR = 1-2	NPR < 1
PENALTY ELEMENTS	No Penalty Elements present	No Penalty Element exceeds threshold limit	One or more exceeds threshold in the low concentration	One or more exceeds threshold in high concentration
PROCESSING CHEMICALS	No Processing Chemicals present	No Processing Chemical exceeds threshold limit	One or more exceeds threshold in the low concentration	One or more exceeds threshold in high concentration
COMMENTS	*May have some commercial value*	*Threshold Limits will vary by jurisdiction*	*QP determines "low" concentration limit*	*QP determines "high" concentration limit*

QP decision

ARD = Acid generating waste; can be mined rock or processing waste
NPR = Neutralization Potential Ratio (NPR 2 based on NP/AP>2
Penalty Elements can include: Ag, As, Ba, Be, Cd, Co, Cr Cu, Hg, Ni, Pb, Sb, Se, Sn, Te, Tl, U, V Zn, asbestos, etc.
Processing Chemicals can include: cyanide, phenols, mercury, flotation agents

Figure 11: Proposed Mine Waste Classification system.

Melanie Nash (Environment and Climate Change Canada) provided the final presentation, which was on Metal and Diamond Mining Effluent Regulations (Appendix 14). She outlined relevant subsections under Section 36 of the Fisheries Act. The definition of milling captures the reprocessing of tailings. These regulations apply to any site discharging more than 50 m^3 per day of effluent containing a deleterious substance to waters frequented by fish or to a place where it may enter such waters

Question/Discussion Period

Workshop participants raised the points below during a discussion period following the talks:

- Define the end land use and involve communities in land use discussion;
- Public much more aware of issues now as evidenced by time required for permit approval;
- Program should be policy and stakeholder driven;
- Tourism and historic value of old sites are important considerations;
- Geotechnical stability aspects of tailings reprocessing must be strongly considered;
- Turn to insurance industry for help, as they understand long term "in perpetuity" risk;

- Need a geological model or NI-43-101 definitions/best practices to define tailings as a resource;
- Access historic records to find out what is in tailings;
- Use reprocessing projects to evaluate new technologies and future tailings management methods;
- Capture the impact of tailings management issues on stock price; e.g. Imperial Metals lost $550M in market share in one day following the Mount Polley tailings dam failure;
- Develop better regulatory practices to overcome tailings management challenges;
- Managing solids is likely more effective than managing water, in certain scenarios;
- Need to look at the overall cost of waste management / site remediation's on the society.

Breakout Group Discussions

Following the presentations, four breakout groups were assembled and tasked with the following questions.

1) **Advancing our Agenda** – how can we best move this initiative further?
2) **Working Groups** - define them/define role/who should participate?/frequency of meetings?/reporting requirements?/technical meetings?
3) **Repurposing Options** – how do we approach repurposing?
4) **Regulatory Constraints** - what are they?/define implications?/how do we begin to address?

Despite the somewhat limited time constraint, a tremendous variety of comments were put forth through these discussions and are summarized below for each.

Advancing our Agenda

It is necessary to continue to build momentum and take every opportunity to highlight this program and its goals through a variety of means, including workshops, webinars, conferences, social media, meetings and word of mouth. It is equally important to take action quickly to achieve early successes, especially at a demonstration scale as this will lead to increased visibility and credibility. Non-conventional stakeholders such as lenders and insurance should be engaged in the program as well, as they are experts in assessing risk. The program must clearly distinguish between reprocessing, repurposing and mine closure.

Efforts to obtain funding and to encourage collaborative projects with relevant stakeholders should continue as much as possible. Regulators should be engaged early in projects to ensure maximum relevance and applicability.

The scope, milestones and deliverables must be clearly defined, both for the overall program and subprojects. Consideration should also be given to taxation implications/options and the inclusion of post-consumer waste recycling as part of the circular economy.

An inventory of wastes, expertise, mines and potential market opportunities should be developed in the short term. Existing industry examples of reprocessing should be shared amongst stakeholders.

Lastly, there is need to create a governing body such as a steering committee that would oversee and provide guidance on the activities of the working groups.

Working Groups

The general consensus was that working groups should be established and should meet quarterly, with an oversight meeting (all groups represented) annually. An annual program report should be produced. The objectives and deliverables for each group must be clearly defined, terms of reference developed and group leaders assigned. A coordinator role should be considered as well i.e. someone to organize the various activities. The initial focus should be on topics that can be relatively easily achieved (low hanging fruit) to get some quick wins.

There was no clear consensus on defining what the working groups should be, but it was clear that a broad range of expertise is required, and should encompass policy, research and investment communities, industry, and end users. One suggestion was that there be only two main groups, those being a profitability focussed group and a liability focussed group (presumably with a variety of subprojects within those). Other suggestions were that the groups should be developed around specific technical challenges, or specific commodity types and that regulatory constraints should have its own working group.

Facilities with specific expertise, such as mineral characterization and mineral processing, should be involved and emphasis should be placed on linking related expertise. Lifecycle and techno-economic analyses should be incorporated wherever practical. It was suggested that early priorities for the working groups should be technology roadmaps and sources of financing to move towards value generation. A follow-up survey is needed to better define the working groups and potential leaders.

Repurposing Options

There was general consensus that the first step in this area is to develop a clearer understanding of what is actually available from tailings and waste rock e.g. silica/sand and to define the potential market (through market studies) and demand. It was noted that these would be residue-specific, and that data-mining from historical operations could likely be used to generate sufficient information for a first cut. Required specifications (by the end user) can also be compared against the specifications from materials generated from tailings, so as to provide the end user with confidence in the product. This information can then be used to determine the value contained in the entire ore body. The characteristics of the remaining non-value material, including deleterious substances, can then be evaluated in the context of safe storage.

It was suggested that two or three sites could be chosen for more detailed study (case studies) or that data for ten sites could be supplied by provinces, in order to develop case studies. It was further noted that closure plans are thought to exist for the reprocessing of some tailings in Ontario (e.g. Castle, Gowganda, Cobalt, Hoyle).

It was felt that mine/mill infrastructure should be retained following mine closure to facilitate use for other purposes (potentially even repurposing). However, this clearly lands in the regulatory constraints section as well, since there are both regulatory and financial assurance implications.

Lastly, there was a suggestion that the program reach should go beyond conventional mining technology circles to include innovation hubs (e.g. MARS & Communitech), innovation platforms (e.g. Ennomotive) and hackathons to encourage development of out of the box solutions for repurposing mine wastes.

Regulatory Constraints

Most of the discussion and comments in this area focussed on constraints, rather than solutions.

The Ontario Mining Act was last updated in 1990 and may not adequately address how mining has evolved since then (e.g. new technologies, reprocessing, land tenure, financial assurance, closure plans). Further, the Mining Act is also bound by other legislation e.g. Environmental Protection Act, Lakes and Rivers Improvement Act, Species at Risk, Metal and Diamond Mine Effluent Regulations, which must also be considered.

Reprocessing, is deemed '*mining*' and as such, is subject to all existing mining acts and regulations. Currently, there are no exceptions. Voluntary rehabilitation, such as reprocessing, triggers closure plan and financial assurance requirements. These factors are all compounded by the lack of a single-window approach to permitting and approvals.

The transfer of liability is a key regulatory constraint, which needs to be addressed. It is also not clear whether, in the case of reprocessing, permitting applications would be considered as re-mining or remediating, and what differences exist between the two.

All of the above items highlight that there are clearly many barriers to implementing reprocessing practices, and that the pace of policy development will be slow, and will depend on proof of performance for new technologies/approaches (as there are many examples of failed "sure things"). However, reprocessing is gaining traction, as evidenced by recent announcements surrounding the reprocessing of asbestos tailings (for magnesium) in Quebec. This may offer an excellent case study to better understand permitting and operational issues, which could be utilized to assist in updating regulations in other jurisdictions. Efforts should be made to eliminate these barriers and offer incentives to address waste management challenges through reprocessing. Invoking financial or other penalties for waste production and considering tax incentives for reprocessing or reducing the generation of waste materials are longer-term options that could be considered in updating regulations. For now, ongoing discussion with regulators combined with the development of sound science for new technologies and in-field demonstration of proof of concept are the most meaningful means to address this topic.

Actions/Next Steps/Recommendations

CanmetMINING will continue to utilize information garnered through these workshops and work with program stakeholders to further develop a program for Mining Value from Waste. This includes ongoing reporting to the Energy and Mines Ministers.

An advisory committee consisting of industry, academia and government representatives will be formed to provide more focussed guidance and promote better collaboration amongst stakeholders.

Several draft Working Group scenarios will be developed by CanmetMINING for review by the advisory committee.

It is anticipated that a Mining Value from Waste technical presentation will be made at the CIM conference in Montreal April 28 – May 1, 2019, to further promote the program. In addition, a technical meeting will be held in association with the conference to continue discussions and to finalize selection of the committee members and working groups.