Case Studies of Innovations in Mining

**Bottom Line:** Despite its reputation as a slow-moving industry, the Metals & Mining sector is currently enjoying a resurgence in research and development work to improve processes throughout the mining cycle. Some “blue-sky” innovations are farther from implementation and others, such as the four case studies presented in this report, will have real opportunity for adoption in the nearer term.

**Key Points**

Last week, BMO hosted Kamran Esmaieli, Associate Professor at the University of Toronto, Department of Civil & Mineral Engineering for a ThinkSeries presentation “Recent innovations in real-time mining data acquisition and decision making.” Professor Esmaieli presented his academic research, which has important applications to the mining industry.

A replay of the ThinkSeries event will continue to be available for a limited time. Canada dial-in 1-800-408-3053; international dial-in numbers available at this website: https://www.confsolutions.ca/ILT?oss=4P45R8004083053; passcode 4072248#. The replay will be available until June 14, 2019.

**Case studies in Mining Innovation.** In the spirit of the ThinkSeries presentation, we are highlighting some of the innovations within the mining industry – including research published by Professor Esmaieli and his colleagues, and innovative projects underway by two companies in our coverage universe, Teck Resources (TECK.B, C$27.66; Outperform rating, C$47.00 per share one-year target price) and First Quantum Minerals (FM, C$11; Outperform rating, C$16.00 per share one-year target price).

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- Saturated rock fill, Teck Resources (page 4)
- Sulfide leaching, First Quantum Minerals (page 6)

The impact of these projects is impossible to quantify. The projects discussed in this report are early stage, ranging from scale-level models to prototype. The probabilities for success of the projects is difficult to estimate. It’s also difficult to quantify an economic impact from the potential success of these projects; success could take many forms including improved workplace safety and environmental cleanup in addition to efficiency improvements or cost savings.

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If our research has been helpful, we appreciate your consideration.

Learn more

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**Aerial Surveying for Blast Monitoring**

**Problem:** Accurately quantifying initial blast design parameters is important in a mining process to ensure proper fragmentation, which improves the cost and efficiency of downstream operations. It also minimizes or controls blast-induced rock movement, which is important to reduce ore loss and dilution. University of Toronto researchers noted in a paper that accurately quantifying blast design parameters to achieve blasting outcomes (fragmentation and movement) has always remained a challenge due to the complex interaction between explosives and rock mass.

**Making best use of drone technology.** Data collection has been a highly manual, time-consuming, and sometimes dangerous activity. Drones, or unmanned aerial vehicles (UAVs) are increasingly cost effective, useful, and prevalent in mining for aerial surveying and process monitoring. With drone technology, data can be collected more safely and more quickly; however, the data has limited value until it is interpreted and used to subsequently improve the process in some way. A key aspect of the research presented last week centred around collection and interpretation of the visual images captured by drones.

**Exhibit 1: UAE Data Collection at McEwen Mining’s El Gallo Mine**

![UAE Data Collection at McEwen Mining’s El Gallo Mine](source: University of Toronto)

**Data collection is facilitated by drones (UAVs).** The researchers’ preliminary analysis showed that data collection by UAV was five times faster, on average. Using machine learning techniques, the UAV system can also analyze images more quickly. Faster sampling will allow for more data to be collected which improves the statistical reliability of measurements and reduces sampling error.

**Data analysis still requires work.** One of the papers published by Professor Esmaeili and his colleagues found that automated estimation of the rock size distribution using UAV image analysis predicted the rock size distribution within 17% of the “benchmark” sieving measurement. The UAV-based rock size distribution prediction was within 6% of conventional image analysis method for measuring rock fragmentation, which the authors consider to be a very accurate prediction. Another paper published by the group found that relatively large errors can occur when measuring the fragmentation size distribution due to overlapping rock particles and misinterpretation of their shapes.
Machine learning could help. Machine learning uses algorithms that iteratively learn from data, building analytical models from empirical relationships. Professor Esmaieli and his colleagues partnered with Detour Gold’s (C$12.02/share; Brian Quast, Outperform rating, C$16.00/share one-year target price) Detour Lake mine to train a machine learning system on data from more than 500 production blasts. This technique showed that rock mass characteristics are the most important influential outcomes on blast-induced outcomes. The researchers note that the accuracy of the developed predictive models can be enhanced by incorporating new records with different blast design parameters for variability in the data used to ‘train’ the machine learning algorithms.

Exhibit 2: Image Collected by UAV for Rock Size Distribution Analysis
Exhibit 3: Delineated Image for Data Analysis

Source: University of Toronto

Application: More efficient milling. Measuring real-time rock fragmentation would help improve the blast design over time towards production of an optimal rock size to maximize the efficiency of downstream mining and milling.

Monitoring rock size at McEwen Mining. University of Toronto has partnered with McEwen Mining (not rated) to conduct UAV experiments at the El Gallo mine. This includes the collection of images at an area of the pit wall identified as a geotechnical concern. Pit wall mapping was done to measure the structural complexity of the rock mass and to predict the in-situ rock size distribution before a blast, then again after the blast. The actual measured size distribution of blasted rock was compared with the predictions to assess the efficiency of blasting parameters in practice.

Future Work

- Further imaging tools for rock fragmentation analysis, e.g. a 3D imaging technique, to better differentiate particles, which are overlapping
- Implementation in an active mining environment

Digitized Core Logging

Problem: Conventional manual logging of drill core can be time-consuming, subjective, inconsistent, and difficult to audit. Further, Professor Esmaieli noted at the ThinkSeries presentation that core logging typically does not collect information that may subsequently be required, e.g. for metallurgical testing.

Prototype logging facility can improve data collected. A portable core logger includes a small table on which core is rotated so that multiple sensors can scan the full surface of the core. The prototype was
fitted with sensors to test for hardness, rock discontinuities, ultrasound pulse velocity (UPV), and presence of specific elements through x-ray fluorescence. The core logging facility is faster and more efficient, and objective data is more consistent.

**Exhibit 4: “Unrolled” Core Image and Sensor Log**

![Exhibit 4: “Unrolled” Core Image and Sensor Log](image)

Source: University of Toronto

**Application: Improved data collection allows correlations to be drawn.** Studies at the Kinross Gold (US$3.14/share, Andrew Kaip, Market Perform rating, US$3.75/share one-year target) Paracutu Mine have employed an extensive data set and sophisticated statistical analysis to link rock properties (e.g. Mineralogy, texture, geochemistry) to processing behaviour.

**Saturated Rock Fill**

**Problem: Active water treatment is more expensive and less effective.** Teck is required to treat water at its Elk Valley coal operations to remove selenium. This typically is achieved through “active” water treatment, such as the plant Teck built at Line Creek (as shown in Exhibit 5). However, active treatment plants not optimal in terms of cost and efficacy.

A solution to the high-cost water treatment process is Saturated Rock Fill. As was noted at Teck’s April 3, 2019 investor day, Saturated Rock Fill (SRF) is a simple process, which would cost only ~20% the capex and ~50% the opex of conventional water treatment.
Teck is an innovator of Saturated Rock Fill technology. Saturated Rock Fill is a larger-scale application of similarly designed gravel bed bioreactors (GBB). In both cases, the treatment involves a depression (in the case of SRF, a depleted open pit and in the case of GBB, a smaller trench). The rock-filled depression is saturated with water and the naturally occurring biological process to remove selenium and nitrates takes place within the facility. Consumables, including methanol and phosphoric acid, are added to the saturated rock to increase the rate of the process.

Teck has operated a successful trial for the past year, which treats 10,000m³/day at Elkview. The company has applied to increase throughput to 20,000m³/day, which is the total amount of water that the company had committed to treat at the site at this time. Teck is currently awaiting regulatory review and approval for the expansion by the British Columbia Minister for the Environment. After operating the SRF at the higher 20,000m³/day rate for one to two years, Teck believes it should have collected enough evidence to satisfy the government that the process is viable.

Once demonstrated, SRF technology could be rolled out to other sites beyond Elkview, and potentially even beyond Teck. Suitable sites will have a depleted pit and available backfill material. Each site would require separate permitting, but the permitting process will likely be shorter once proof-of-concept is established.
**Sulfide Leaching**

**Problem:** Sulfide ores require more extensive processing at higher capital cost. Sulfides don’t respond well to the lower-cost heap leaching technology that can be used to produce copper from oxide ores. Instead of leaching, sulfides are typically treated by a conventional crush/grind/float circuit, which generally requires larger processing facilities and higher up-front costs as compared with a leaching process. Polymetallic orebodies in Spain have other specific challenges – namely, floatation doesn’t recover copper, zinc, or lead well (typical recoveries between 50% and 60%).

**Atmospheric leaching of primary sulfides.** First Quantum, along with partners such as Outotec, has developed an atmospheric leach, to effectively liberate copper from the sulfide ores and to produce a solution suitable for SX-EW refining. The pilot plant has been producing for over a year and has yielded good results, though First Quantum continues to make refinements to improve the plant recoveries.
After the code is cracked, technology could be rolled out to other applications. The atmospheric leach technology could eventually be applied to assets not currently owned by First Quantum, although its applicability would not be known for certain until the process and the ores are tested. This could be a significant source of low-cost feed to Las Cruces, if the mine possesses the only low-cost (capital / operating) facility for processing the ores. The technology could also potentially be applied in other parts of the world. First Quantum has tested ores from some of its other operations through the Las Cruces pilot plant as well, including ores that are not primarily copper ores. Other miners, including Antofagasta (£8.46/share, Edward Sterck, Outperform rating, £12.00/share one-year target), have also invested in the development of a sulfides leaching technology, although no other technology is currently as far advanced as First Quantum’s process, to our knowledge.

Permitting, mine planning are the main bottlenecks. The permitting process to convert the current open pit mine to a larger underground operation is ongoing. Permitting in Spain is a well-defined process, although it can be lengthy. The company expects permits could be received by mid-2020.

A comfortable resource has been outlined through surface and underground exploration, although work continues to optimize the mine plan. This includes studies to reduce costs of underground mining at Las Cruces to ensure economic viability of the sulfides project. First Quantum is investigating the use of an electric truck fleet (which reduces ventilation costs), conveyance, and other alternatives.
References

Copies of these academic research papers are available on request


7 Mahadi Bhuiyan, Kamran Esmaieli, Juan C. Ordonez-Calderon “Application of Data Analytics Techniques to Establish Geometallurgical Relationships to Bond Work Index at the Paracatu Mine, Minas Gerais, Brazil”, Minerals, 2019, 9, 302.
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Disclosure 16: A research analyst has extensively viewed the material operations of Kinross Gold.

Disclosure 17: Kinross Gold has paid or reimbursed some or all of the research analyst's travel expenses.

Disclosure 22: Teck Resources has a security with subordinate voting shares.

Methodology and Risks to Target Price/Valuation for Antofagasta (ANTO-LSE)

Methodology: Antofagasta’s target price is based upon 1.3x NPV, estimated at a 10% discount rate.

Risks: Antofagasta’s earnings are highly levered to the prices of copper and gold, which can be very volatile. The company is subject to foreign exchange risk and country risk, as the company reports in U.S. dollars but its primary operations are located in Chile with operating costs peso denominated. The company is subject to environmental liability and changing environmental legislation.

Methodology and Risks to Target Price/Valuation for Detour Gold (DGC-TSX)

Methodology: Target prices for mid-tier gold producers covered by BMO Research are based on 50% weighting given to the P/NPV (5% discount rate, BMO metal price assumptions) and a 50% weighting given to a CFPS multiple.

Risks: Risks to the BMO Research target price include commodity/currency, technical/operating, and litigation/political risks inherent to mining operations, as well as feasibility, permitting and financing risks related to development of growth projects.

Methodology and Risks to Target Price/Valuation for First Quantum Minerals (FM-TSX)

Methodology: The target price is derived using a blend of NAV and EV/EBITDA multiples.

Risks: Risks to our target price include a material difference of actual commodity prices or FX compared to our price assumptions, future revisions to tax/mining codes in countries in which FM operates, and any potential significant delays ramping up the Cobre Panama mine.

Methodology and Risks to Target Price/Valuation for Kinross Gold (KGC-NYSE)

Methodology: Target prices for senior and intermediate gold producers covered by BMO Research are based on a weighted blend of P/NPV adjusted for market capitalization and P/CF adjusted for growth.

Risks: Key risks for KGC centre on negotiations with the Mauritanian government and the development and execution of brownfield growth projects at Tasiast, Round Mountain, and Fort Knox. If these risks are greater than we expect, the stock could have difficulty achieving our target price. Likewise, if these risks are less than we expect, the stock could trade above our target price.

Methodology and Risks to Target Price/Valuation for Teck Resources (TECK.B-TSX)

Methodology: The target price is derived using a blend of NAV and EV/EBITDA multiples.

Risks: Risks to our target price include a material difference of actual commodity prices or FX compared with our price assumptions, future revisions to tax/mining codes in countries in which Teck operates, and any potential significant delays in developing the QB2 project.

Distribution of Ratings (May 21, 2019)

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