THOUGHT LEADERSHIP
RESEARCH

MINING FOR INNOVATION

Innovations within the mining industry and the historical challenges to innovation that companies are finally overcoming.

MASSIF CAPITAL

In this report, we examine the role of technological innovation in the mining sector. Specifically, why it is imperative that miners focus on innovation now, the challenges mining management teams face in attempting to innovate, and a review of several promising innovations by industry leaders. The Bottom Line: Long-term metals demand growth when paired with decreasing ore grades, more challenging ore bodies and an increasing investor focus on cash-on-cash returns mean mining firms need to do more than cut costs if they are to deliver meaningful shareholder returns.

Overview

AS WE HAVE SAID BEFORE, AND WILL UNDOUBTEDLY SAY AGAIN, AGGREGATE FINANCIAL STATEMENTS ARE IMPORTANT, BUT MEANINGFUL RETURNS ARE GENERATED BY UNDERSTANDING THE DETAILS OF HOW A COMPANY MAKES THEIR MONEY, NOT JUST IN KNOWING WHETHER THEY MAKE MONEY.

At Massif Capital, our research is focused on the operations of the companies we invest in. As we have said before, and will undoubtedly say again, aggregate financial statements are important, but meaningful returns are generated by understanding the details of how a company makes their money, not just in knowing whether they make money, the only thing one can learn from aggregate financials. A keen eye towards operations is especially important for capital-intensive, project-focused businesses that operate in the real asset world which makes up our investment universe.[1]

Real asset companies often hold long-lived assets on their balance sheet that have high upfront capital costs and low unit operating costs relative to unit revenue. The result is that daily operational execution is paramount to ensuring a steady flow of cash over the life of an asset. The capital requirements and years required to earn a return on those assets mean that management decisions have long-term consequences. Once made, a degree of path dependency is created that makes it difficult to change course.

Given this operating paradigm, the hesitancy of management teams in real asset businesses to deploy untested technologies or methodologies is understandable. One might go so far as to say that management teams in real asset industries are averse to innovation, a critique that would not be wholly out of place if leveled against the mining industry. Mining is often viewed as a low technology, backward-looking industry of the past, with declining profitability and few positive spillovers to the economy and society.[2] This outlook stems not only from the reticence with which mining companies deploy new technology but also from the common mischaracterization of mining as a simple process in which valuable resources are easily pulled from the earth and redeployed into cell phones, electric cars, and the many other devices that power our modern lives. Unless the value-added process of mining occurs, potential mineral resources in the earth have no value.

To prosper in the coming year’s miners, need to reassess tried and true methods and innovate new approaches to old problems, least the challenges of growing demand, lower ore grades, and increasingly far-flung locations overwhelm. Increasingly successful mining operations will be about the integration of new technology and ideas into an industry that has roots as old as any.

Reserve Replacement Challenges And Declining Grades

How challenging is it to find a new economic ore body?

According to the Hard Rock Miners Handbook it takes 25,000 stacked claims to find 500 deposits worth drilling, of which only 1 will likely become a mine. From the time a miner decides to focus on a single discovery out of the 25,000 staked to the moment the mine begins production is generally between 7 to 10 years.

The State of Ore Grades

- For the 10 years prior to 2016, the amount of gold discovered declined by 85%, while reserves have fallen by 40% since 2011.
- In the period from 2006 to 2016 the average ore grade at copper mines has decreased by approximately 25%.
- Although production of copper during the same period increased by 30%, that increase required a 45% increase in energy consumption.

At an Inflection Point: Why Miners Must Innovate Now

Few within the mining industry would argue that the business of mining is becoming more difficult. Despite mineral demand being at or near all-time highs and projected to continue growing for some time, ore body replacement rates are falling, new mine development times are increasing, and fundamental cost drivers are rising.[3] These factors combine to create industry-wide struggles that threaten the ongoing viability of the current mining industry business model and call for management teams to innovate.

The most pressing challenge for mining firms at present is economically meeting societal demand for metals. The primary complicating factor is the declining rate of significant, new, economic mineral discoveries. Not only have most of the significant deposits globally with surface expression and/or ready accessibility been found, which is especially true of well-developed mining countries such as Australia and Canada, but when discoveries are made they are increasingly more challenging with lower ore grades, deeper ore bodies and in more complex locations that have a combination of limited infrastructure and greater local community expectations.[4]

How difficult is it becoming to find new deposits? In the case of a leading mining jurisdiction such as Australia, it is becoming significantly more difficult. Zero tier 1 deposits have been found in the last twelve years while ten were found in the six years prior.[5] Furthermore, since 2007, the average cost per discovery globally has tripled, and the value to expenditure ratio has fallen to 0.47.[6]

Commodity-specific data tells a similar story. The average ore grade of a copper mine has decreased 25% between 2006 and 2016. Total energy consumption at those mines increased 46% over the same period, while production only rose by 30%. The depth of deposits is also increasing, adding further operational challenges. From 2002 to 2007, the depth drilled by mining firms to find new deposits increased by 64%, a trend that has continued to this day but at a slower rate.[7] New deposits are increasingly difficult to find, are of lower grade, and are harder to extract.

This bleak resource outlook comes after a period of significant production growth and price appreciation for a range of commodities. Strong demand from emerging economies, in particular, China, have driven increased global demand and improved pricing across the board. One would expect equity valuations and investor appetite to thrive in a rallying commodity environment; however, most firms have created very little value. As an example, since 2010 cumulative impairments by gold miners have totaled 85 billion dollars' [8] while the price of gold is largely unchanged since 2010.

Why did this occur? During the most recent commodity boom, mining firms adopted a volume strategy rather than a value strategy. The result was significant growth in additional production inputs that outstripped growth in output.[9] More trucks and more shovels, bigger trucks and bigger shovels, but little thought to the operational efficiency of those trucks and shovels. Growth in volume was the priority, and little attention was paid to the return on a truck or shovel load.

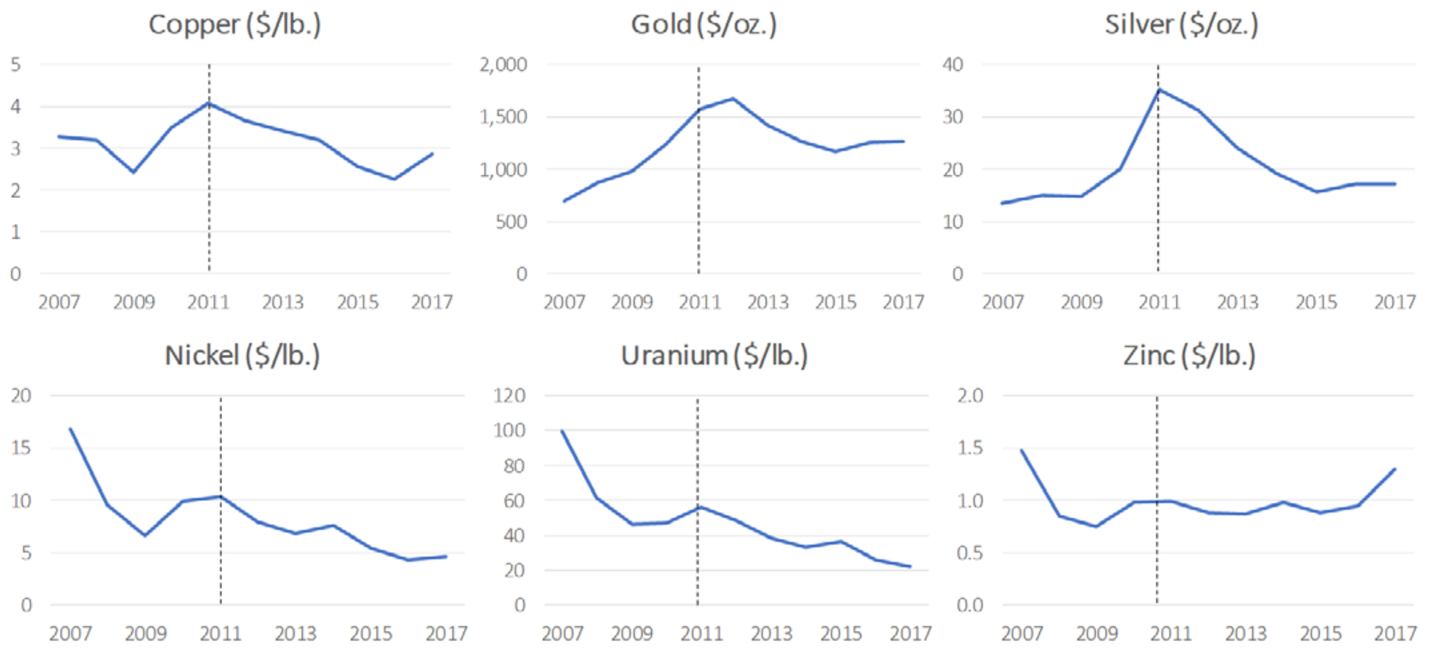


Figure 1: Select Commodity Prices (2007-2017), Real Dollars

2011-2012 was the most recent peak in commodity prices, and on an inflation-adjusted basis commodity prices are still well below their recent cyclical highs (See Figure 1). The failures of the period from 2000 to 2012 to grow the mining business in a value-conscious way is clear by looking at the posted price crash results of most miners. Despite growth in absolute volume, the industry in 2015 was producing poor margins with prices for individual commodities still 2-4x the lows experienced in 2000.[10] Assuming population growth forecasts are reasonably accurate, the global population will reach 9.7 billion by 2050. In this case, there is little question about the general direction of demand and likely prices for most metals over the long-term, but investors should not be satisfied with mining firms that are bailed out by demographically juiced commodity prices, or with businesses that cannot capitalize on price appreciation of their product.

What is clear is that business, as usual, is not sufficient for mining firms and certainly not sufficient for investors. If mining firms want to grow value and attract capital, they are confronted with a stark choice between static efficiency, with a focus on maximizing the return from their current assets, or dynamic efficiency, in which the implementation of innovative approaches potentially impacts near-term return from existing assets, but long-term value increases as a result of being well positioned for a future that includes greater demand from lower quality assets.

Why Mining Firms Struggle to Innovate

Although the mining industry needs to innovate, we cannot assume they are blithely ignorant of the situation. The industry has several characteristics that make innovation particularly challenging[11]:

- The finite resource base underlying each investment
- The high capital intensity of even the smallest projects
- The very long capital cycles (typically 10+ years) vs. comparably short business cycles
- The high fixed costs are relative to revenues which are highly sensitive to price movements in highly volatile commodity prices.

These factors combine to create an industry that has an exceedingly high cost of failure. The result is that conventional approaches to well-understood problems are often favored over new and untested solutions. Furthermore, because of these industry characteristics, innovation in mining must not be the traditional creative destruction of Silicon Valley, it must be creative preservation.[12] Mining capital expenditures are long cycle investments, not short cycle investments. As such, firms need smarter ways to extend the life and utility of assets at lower costs, not innovations that upend existing operations and create shorter cycles of capital replacement.

Beyond industry characteristics that make innovation a challenge, project, and company-specific barriers to innovation exist. What follows is a limited discussion of some of these challenges:

Technical Risk: An investment in a new mine or mine expansion is based on limited and patchy information about a mineral deposit that is hundreds to thousands of meters beneath the surface. Furthermore, most deposits have a disseminated quality, meaning what the ore miners are looking for is fine-grained and scattered throughout the otherwise useless rock. Models of ore deposits are the best guesses of geologists based on statistical inference and drilling results, hence "models of ore deposits." Ore bodies are estimated, and the size delineated without ever actually seeing what the ore body looks like.

Adding to the technical risk is the significant commodity price risk. Given decisions about whether to move forward or not with a mining project are usually based on a net present value estimate of the potential ore recoverable from a hypothetical model of an ore body hundreds of meters below the surface. Delays or mistakes in accurately forecasting the timing, volume and price of ore sold from a project can significantly affect the final return on investment of mine.[13] Layering innovation risk on top of an already risky venture simple means adding unknown risks to substantial known risks. As such, it is understandable that management teams are hesitant to deploy innovative approaches to mining.

Integration Risk: The mining value chain has a significant overlooked complication. A simplified mining value chain would include exploration, planning, operations, processing, maintenance, support functions, and logistics. Each aspect of the value chain can operate in series or sequence over multiple time horizons, multiple geographies and are subject to different fluctuating value drivers. Very rarely does one aspect of the value chain operate in a vacuum. If operational changes alter the mix of ore that must be processed, the entire processing stage of the value chain may need to be reworked. Alterations to processing may mean new logistical and support functions as new chemicals or machinery might be necessary. Furthermore, the value chain is subject to significant alteration due to changes in mined material, a variable completely out of control of mining firms as they can only take what the earth gives them.[14]

According to mining management teams, for every $1 spent on an innovative product, a firm must generally spend $8 to $9 integrating the new product into the existing mine process and workflow.[15] That means the breakeven return on invested capital is 800% higher than the cost of the new product itself. The complication and cost of integration are easier to understand when one sees the process and workflow of mine, for example, Figure 2 below, which is the process flow sheet for one of Barrick Gold's (ABX) smaller mines in Canada. All things considered, it is a relatively simple process flow for a mine. The Hemlo mine produces on average 200 to 250 thousand ounces of gold a year; Barrick has several mines that produce between 500 thousand and million ounces a year. As scale increases, operational complications increase accordingly.

Different stages of the workflow require chemicals, many of which require special handling. Each stage involves moving machinery that must be maintained and replaced on a regular basis as mines are harsh operating environments and

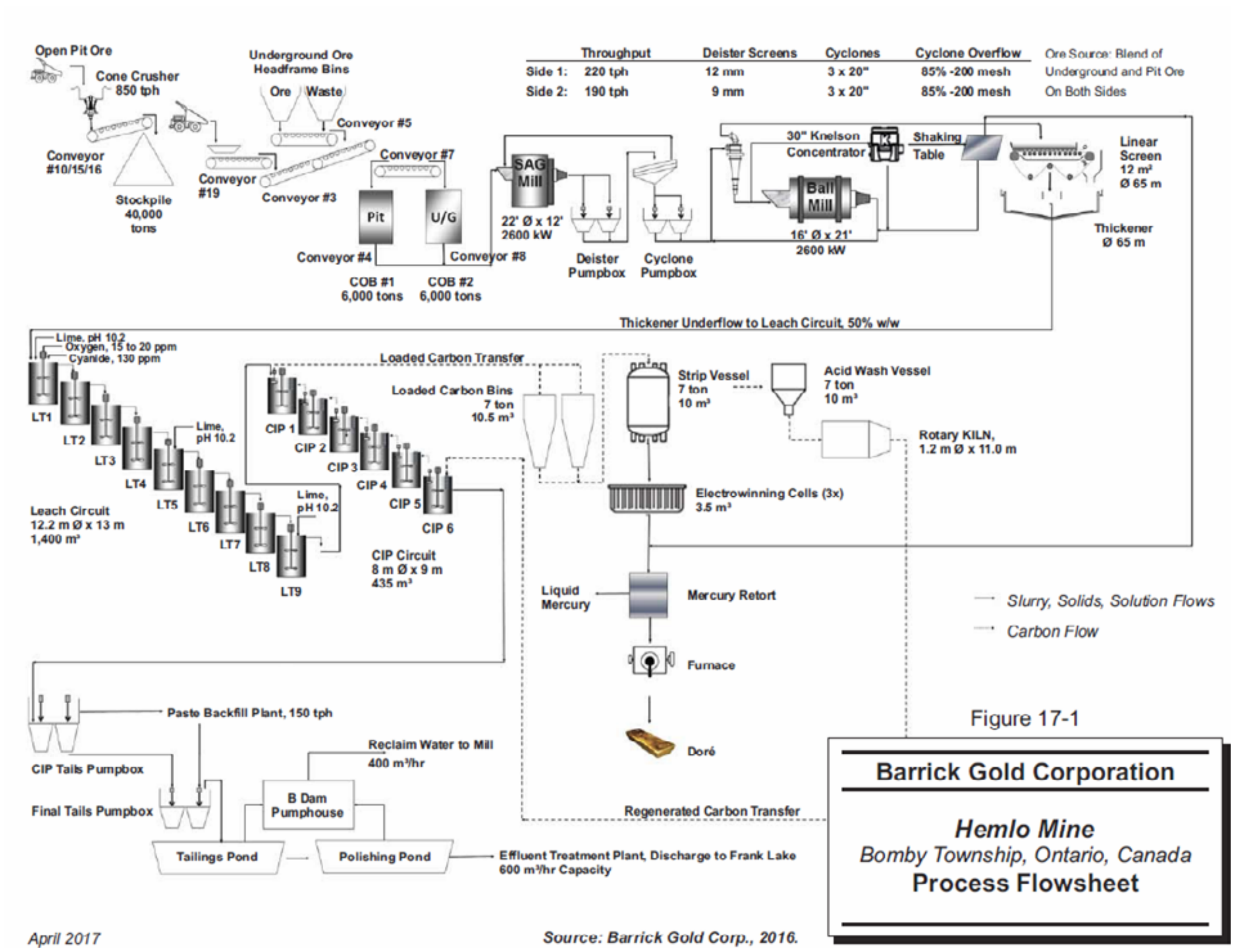


Figure 2: Processing Workflow, Hemlo Mine Barrick

require significant energy. At each stage, there is different equipment from different manufacturers of different ages that all must work together seamlessly. Integration challenges are probably the most misunderstood by investors and outsiders as each mine is different, and although general process flow for two mines is generally similar, they are rarely ever the same, much of which has to do with the fact that not two ore bodies are the same or have the same composition.

Information Challenges: Although the discussion of technical risks above touched upon the most obvious source of information risk in mining, the literal lack of knowledge about what will be dug up, there are several other areas of information challenge. One of the most pressing current information challenges is the utilization of volumes' amounts of data generated at a mine to produce useful insight. Mines are data rich environments that are insight or information poor. Every vehicle, machine, and worker produce data, but no one is in charge of taking all that data and synthesizing it to produce knowledge. Significant operational silos exist, and there are too few people responsible for, or even capable of, understanding the mine as a single system. The nature of this situation is perhaps best characterized by an organization such as Rio Tinto.

Rio Tinto tracks a vehicle fleet comprised of 4,000 vehicles spread across 40 countries 24/7 in real time. That fleet generates more than 30 million geo-position data points a day. Assessing whether those vehicles are in the right place at the right time and got there in the most efficient manner is a daunting challenge. When one focuses on specific subsets of the fleet, the data challenge becomes even more significant. The haul trucks Rio Tinto uses, which are a subset of the vehicle fleet but perhaps the most important vehicle at a mine, each have 45 electronic tags on them. Each tag reports data to a central location every few seconds. In total, each haul truck creates 200 megabytes of data per day or 73 gigabytes of data a year. Rio Tinto's Iron Ore operations in the Pilbara region of Australia utilize 370 haul trucks, of which 95 are currently autonomous. This means that the trucks operating at the 16 mines that Rio Tinto operates in the Pilbara create a staggering 27 terabytes of data a year.[16] The data includes everything from engine feedback and tire pressure to information about how ore is spread through the bed of the truck and whether or not that ore was dumped into the truck in a way that best utilizes space to maximize carrying the load. Combing through this volume of data to generate insight is likely a full-time job for a team of people.

Another area of significant information challenge for miners is the challenge of measuring how much material has been mined. Unlike oil and natural gas companies, which benefit from the fact that volumes of liquids and gases are relatively easily measured, measuring a continues flow of solids that has a highly variable composition of particles of varying size, ore grade and chemical composition (all of which change over time and based on where in a mine the material comes from) is exceedingly challenging. The result is that mining firms operate based on averages of averages. Ore qualities are measured at one place over time and then another, and then another, and then averaged together, and then averages are averaged together, and slowly over time a picture of what the ore coming out of the mine looks like begins to develop. Unfortunately, this approach means that miners never actually know where or how much value is being lost between mine and final commodity sale as they never really know how much metal there is in the first place.

Promising Mining Innovation Efforts

Despite the challenges discussed above, the struggles to replace ore bodies, declining ore grades and increasing demand are driving some firms to innovate. Below we present a few examples of current innovation efforts. Most of the innovations discussed are step changes that improve production efficiency; some though are platform changes that would fundamentally alter the entire mining process. Both types of innovation will be necessary to meet the challenges mining firms will face in the future. These examples should give investors an idea of what to be on the lookout for when examining mining firms, especially given the general industry preference for being the first to copy rather than the first to innovate.

Automation: Of the handful of innovations within the mining industry that are either on the cusp of widespread adoption or nearing a point at which widespread adoption is possible, automation is the leading candidate. The industry leader in this regard appears to be Rio Tinto. The firm has not only pushed further into automation than most but has also taken advantage of benefits of automation to centralize command and control of mines, ports and rail systems at a single location for the firm's massive iron ore operations in Australia. Management hopes that by centralizing command and control of mines and automation at a central location (in this case in Perth) that further opportunities arising from shared data and real-time oversight will emerge.

At the center of Rio's automation efforts is the AutoHaul Initiative which is focused on automating the trains that Rio uses to transport iron ore from mines to ports. AutoHaul is also the world's first fully automated long-distance railway system. The system operates on 1,700 kilometers of track that connect 16 Pilbara Iron Ore mines to four port terminals. According to Rio Tinto, more than 60% of all kilometers traversed by their trains are now completed by trains operating in autonomous mode. The AutoHaul system will be complete this year, and despite not being fully operational yet, autonomous operation of trains has already produced a 6% improvement in speed.

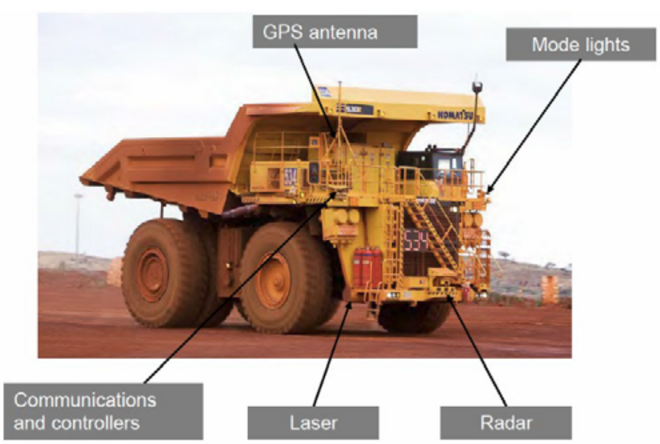


Figure 1: Autonomous Haulage System (AHS) Setup

Rio Tinto has also worked to automate their mine haulage systems, the trucks that take away ore. Currently, the Auto Haulage System[17] in the Pilbara includes 90 autonomous trucks and will expand to 140 by the end of 2019. In 2017, on average the autonomous haulage fleet operated an additional 700 hours relative to a similar sized manned fleet, with 15% lower load and haul costs. Between 2015 and year-end 2017, haul truck utilization has increased by 8% and maintenance costs have decreased by 28%, with much of the improvement coming from the automated part of the truck fleet and the rest from enhanced data collection geared towards informing truck maintenance procedures. In total Rio Tinto expects efforts at automation and data utilization will result in incremental operating efficiency improvements that will increase cash flow by the US $1.5 billion by 2021.

SEVERAL LARGE MINING OPERATORS HAVE INDICATED THAT AS MUCH AS 10% OF HAUL TRUCKLOADS END UP GOING TO THE WRONG PLACE DESPITE BEING DISPATCHED CORRECTLY.

It is worth noting that the autonomous haulage systems also reduce some of the information challenges associated with dealing with solid materials discussed above. Several large mining operators have indicated that as much as 10% of haul truckloads end up going to the wrong place despite being dispatched correctly. What this means is that roughly 10% of waste haulage ends up being placed with ore for processing and 10% of ore ends up placed with waste. This translates to 10% of ore being lost and the increased processing of useless material, a large enough number to significantly impact the average measures of solid flows at a mine. Autonomous haulage significantly reduces this as vehicles are dispatched to do specific tasks from which they cannot deviate, as opposed to human drivers who make judgment calls about where their loads should go.[18]

Data Usage: One of the core uses by mining firms of emerging technology is becoming leaner, resulting in mining higher value tons vs. more tons (value over volume). Anglo American is one of the leaders in the mining world regarding utilizing advances in data science geared towards streamlining mine processes to create simpler and less resource intensive mines. Anglo-American is testing platform innovations that will fundamentally change how they mine. Anglo American's primary initiative is called FutureSmart Mining[19] and focuses on four data-driven concepts to achieve improved mine yield. The four core concepts are "the intelligent mine," "the modern mine," the waterless mine," and the concentrated mine." In total Anglo American expects innovations arising from these four efforts to produces 1 billion dollars in cost savings by 2022.

<u>The Intelligent Mine:</u> Utilizing real-time data and machine learning the intelligent mine initiative aims to optimize excavation at the mine via improved drilling and geological modeling. Additionally, the intelligent mining initiative deploys learning algorithms to improve operations at ore processing plants. The end goal, as is the case with several data focused mining efforts, is the ability to digitally twin the operation of a mine allowing for real-time testing of operational changes on a digital mine model before deployment in the real world, reducing unknown risks and speeding up the deployment of incremental process improvements.

<u>The Modern Mine:</u> The modern mine initiative aims to use automation and robotics to improve underground ore extraction. At the core of the effort is a joint venture between Atlas Copco, a mining equipment firm, and Anglo American called the Rapid Mine Development System which utilizes low-cost modular mining robots and continues rock cutting vehicles to excavate low profile tunnels in hard rock. The robot fleet would reduce safety risks and operate with higher precision than human miners and reduce the need for explosive blasting. The modern mine initiative flips many traditional mining concepts on their head by focusing on increasing production via more precise smaller scale mining, rather than

increasing production by scaling up capacity (bigger trucks, bigger shovels, bigger mines, etc.). In short, the modern mine initiative aims to mine less waste and more ore with fewer people in more complex or difficult ore bodies.

The Waterless Mine: All mining is highly water intensive, which is a frequent source of tension with local communities and a source of long-term environmental concern. The waterless mine initiative aims to eliminate the need for fresh water use in the mining process, specifically in the separation and transportation of ore and waste. At the current time, this concept is the furthest developed, with two-thirds of Anglo American water requirements met using a closed loop system that greatly diminishes the use of fresh water. The goal is to use zero fresh water, but this has not yet been accomplished. One area ripe for significant operational improvement that will immediately and directly impact the bottom line is evaporation of water from storage dams, which costs Anglo American roughly $200 million annually to replace.

The Concentrated Mine: As mine grades continue to decline miners must increasingly focus on maximizing return per ton of ore processed. The concentrated mine initiative aims at utilizing data to optimize the processing of ore via three enabling technologies that Anglo American is currently testing at a pilot plant in Chile. The three enabling technologies are advanced fragmentation, an approach to blasting design that increases fine ore fragmentation with fewer explosives, bulk sorting which utilizes sensors to sort worthless rock from ore-bearing rock and Coarse Particle Recovery, a method of further separating waste rock from ore during flotation processing. All enabling technologies aim to reduce water and energy usage in ore processing by reducing the amount of waste rock processed along with increasing the concentration of ore-bearing material being processed.

A Sustainable Approach to Mining

It will become increasingly important for mining firms to innovate. The steady growing demand for resources combined with the trend towards lower grade more complex deposits in increasingly difficult locations necessitates efforts to creatively preserve existing deposits and improve the efficiency and process of operations at new deposits. Absent innovation, the challenges will make mining increasingly uneconomic and unappealing for shareholders. This is not a call for a dramatic change in strategy, but rather a recognition of the need for a gradual shift in process at every step of the mining value chain: exploration, investment, development, and operations, with a view to future technologies.

Efforts must be made to test and assess step-changes on a small scale at every point in the value chain. It will also require recognition that just as few exploration targets become mines, few innovations will warrant full integration into operations, and the failures will outnumber the successes. Furthermore, timeframes to commercial deployment will be longer than hoped for or expected, but the efforts must be sustained and will yield tangible returns.[20] Management teams that recognize the need for innovation in their communication with shareholders and follow the talk up with action will reward shareholders with value creation.

Going forward, successful investing in the often-volatile mining sector will be predicated on more than just an understanding of a particular resource base or past cash flow generation. Understanding the changing nature of operations will take on increasing importance. Historically, being a low-cost producer was the result of economies of scale and geology - investors needed to know little more. The challenges of geology and limitations of economies of scale mean that being the low-cost producer now will be a function of the value a firm can create via the innovating mining of a resource and the creative preservation/extension of the life of existing capital investments. In short, investors should be on the lookout for management teams that utilize technology and innovation to reduce the capital intensity of mining in the long run.

Footnotes

[1]We can provide interested readers with a more complete list of our investing universe. In general, we focus on the following industries: Basic Materials, Energy, Utilities, Industrial Firms and Infrastructure. Further details are available on our website.

[2]How About the METS? Leveraging Australia's Mining Equipment, Technology and Services Sector (Don Scott-Kemmis, March 2013, Mineral Council of Australia).

[3]It has been suggested by Richard Schodde, a mining industry consultant whose research focuses on the evolution of metals demand and global discovery trends, that in the next 25 years the world will demand and mine more copper then has been mined in all of history.

[4]Rediscovering its Swagger (Core Magazine, Fall 2014).

[5]There is no commonly excepted definition of what qualifies as a tier one deposit, every mining firms seems to have a slightly different understanding. Some firms define tier 1 based on the size of the mineral endowment, for example more than 3 million ounces of gold or more than 2 million tons of copper, other firms define it based on the NPV of the mine. Either way the importance of tier one deposits (via either definition) is significant. Regarding base metal deposits the top 14% of mines ranked by NPV contain 32% of the metal tons and 67% of the total NPV for the base metals mining industry, for gold the numbers are similar, with the top 12% of gold mines ranked by NPV containing 30% of the total metal and 53% of the total NPV globally.

[6]Crisis in Discovery: Improving the business paradigm for Mineral Exploration (Robert Schafer, May 2018, Mining Engineering Magazine).

[7]The deeper the mine the more complicated initial construction is, the costlier ongoing operations and the thinner the margins. Energy and water related costs increase significantly as mines go deeper. Productivity and Innovation in the Mining Industry (Anna Matysek and Brian Fisher, 2016, BAE Research Report).

[8]Gold Equities: Myths, Dreams and Reality (Marcelo Kim, September 2017, Paulson & Company Inc).

[9]Mining for Efficiency (August 2014, PWC).

[10]The Case for Innovation in the Mining Industry (Peter Bryant, 2015, Clareo).

[11]Michael Hollitt, Managing Director of Process Effectiveness group at Rio Tinto.

[12]Innovation and Growth – Keeping Pace in A Virtuous Cycle (Michael Hollitt, International Mineral Process Congress, 2012).

[13]What does this mean? If we assume a mine with a productive life of 10 years with a two year ramp up and two year ramp down and that the mine produces $3 million in free cash flow for 6 years during the core operating life and has a ramp up and ramp down free cash flow of $3 million spread across 2 years ($1 million in FCF in year 1 and $2 million in Year 2, and $2 million in year 9 and $1 million in year 10) the mine has a value of $14.6 million assuming a 10% discount. If all variables remain the same except it take an extra year to ramp (an extra year of $1 million FCF with the lost $1 million recouped in year 10) the mine has value of $13.8 million or 5% less. So, a 1-year timing miscalculation costs 5% of the projects value.

[14]Mineral ores have many different elements in them, some are desirable, and some are not, complex ores require significant processing to obtain clean metal concentrates. Various undesirable elements, for example sulfur, must be removed via chemical or physical treatment.

[15]Mining Innovations: Barriers and Imperatives (Kane Usher and Ian Dover, 2018).

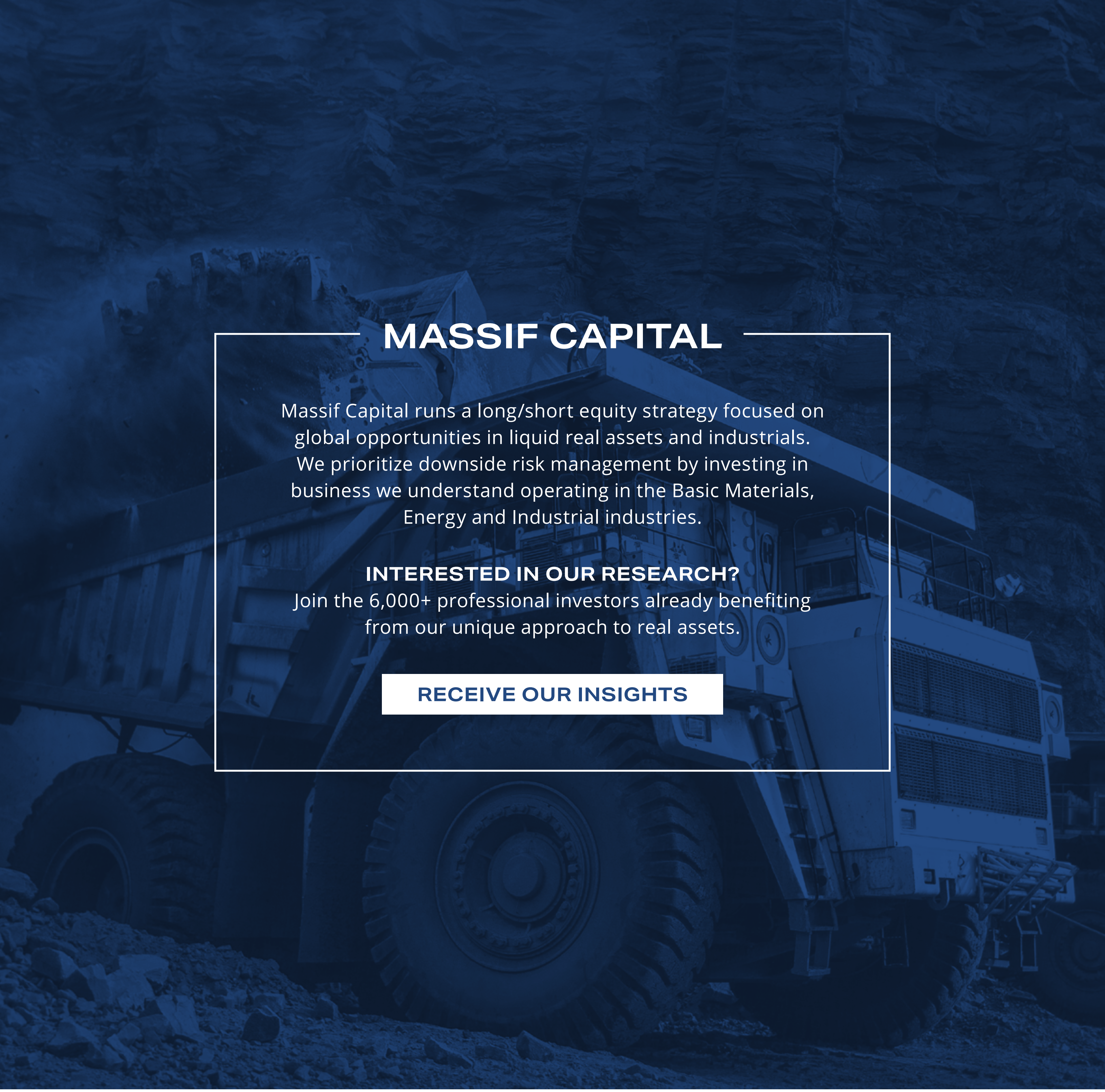
[16]Rio Tinto Presentations: Iron Ore- Delivering Value from Flexibility and Optionality (18 June 2018) & Breaking From Tradition – The Mine of the Future (14 May 2018).

[17]The truck in Figure 4 is an example of an automated haulage vehicle used by Rio Tinto, in this case a Komatsu 930E. The 930E is the bestselling "ultra-class" haul truck in the work and has a payload capacity of 290 tons. It has a 2,701-horse power engine with a top speed of 40 mph. The newest version of the truck, introduced by Komatsu in 2016, is fully automated and does not have a cabin.

[18]The same large mining firms that suggest 10% of haul truck loads end up in the wrong place have also noted that upwards of 70% of the time Fleet Management Systems used at their mines, designed to reduce the incorrect placement of haul loads because of human error are turned off. Extracting Innovations: Mining, Energy and Technological Change in the Digital Age (Martin J. Clifford, CRC Press, 2018).

[19]A more detailed discussion of AngloAmerican FutureSmart Mining Initiatives is available on their website.

[20]How long innovation will take to cross from small scale testing to commercial development is difficult to forecast. Step change and refinement of process via but understanding of operating environments as a result of data analysis will be quicker than new operating platforms. Although we recommend mining firms focus first on the low hanging fruit of digital integration for improved situational awareness, proper R&D into new production platforms should not be overlooked but is more time and cost intensive. By way of example, the first small heap leaching operations for copper occurred in 1968 but large scale commercial deployment took a further 15 years. Modern block cave mining for underground mass mining was first demonstrated in 1976 but it was not until the 2000s that it really came into its own as a frequently deployed methodology. Innovation and Growth – Keeping Pace in A Virtuous Cycle (Mike Hollitt, 2012, International Mineral Processing Congress).



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