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INNOVATION IN MINING

Perspective and new risks

"IF WE DON'T START TO BRING INNOVATION BACK… THE MAJOR DIVERSIFIED (MINING GROUPS) WILL BE SUBSIDIARIES OF GENERAL ELECTRIC OR SOME OTHER CONGLOMERATE THAT HAS STILL GOT INNOVATION IN THEIR VOCABULARY"
– Mark Cutifani, Chief Executive Officer of Anglo American PLC[1]

INTRODUCTION

Mining lies at the foundation of civilization, and has been prominent on the economic landscape since antiquity. But it is often viewed as a traditional and conservative industry, where changes are resisted and innovation is lagging behind.

A miner from the 19th century transported to our modern times would certainly recognize most processes on a mine site, and while he would be amazed by the size and scale of modern equipment, he would be very familiar with the extraction and production techniques in use:

- Access to valuable ore must be secured by digging out overlaying waste material (excavating an open pit) or by developing underground access ways (tunnels, shafts, adits).
- Mineral-bearing rocks are fragmented in order to remove them from their *in-situ* location, most of the time using explosives but also sometimes using physical means (continuous mining or longwall shearing in coal mines).

- "Run of mine" material is then transported from a face (extraction site) to a plant (processing and concentrating site). This task used to be performed by horses, which have now been replaced by trucks, trains, conveyor belts or slurry pipelines.
- Physical processes are used to crush and grind the ore in order to liberate minerals that are subsequently selectively concentrated by physical and/or chemical processes.

There are a number of features behind this apparent resistance to change and general lack of transformational innovation in the mining industry.

- **Extra care and diligence** are required when working in an intrinsically hazardous environment: every change in methods, procedures or equipment must be scrutinized to identify, assess and analyse any potential new risks that it will introduce.
- Most mining operations are located in very **remote places**, away from densely populated areas that foster innovation and have easy access to the latest services and technology.
- With the favourable economic conditions that have prevailed in the first part of the 21st century, miners have focused their attention on **incremental gains and economies of scale** in order to drive unit costs down. High margins have encouraged a technological *status quo* rather than a push in terms of research & development.

[1] taken from a Financial Times article of 26 January 2014.

So the mining industry is not generally perceived as being especially innovative. However, in actual fact the opposite is true.

Mining has always been a source of innovation, consistently striving for better efficiency, safety, and environmental and social integration, often in difficult circumstances.

Mining has allowed many innovative concepts to become reality: for instance the industrial revolution required coal, communication technologies necessitate copper, and mobile phones are dependent on rare earth minerals.

This was famously summarized by the German physicist and Nobel Prize winner Max Planck, who stated that :

> "MINING IS NOT EVERYTHING, BUT WITHOUT MINING EVERYTHING IS NOTHING".

This paper aims to underline recent innovations adopted in the mining industry and to analyse new risks they may introduce. Risk carriers must understand the transformation in progress in the mining and mineral processing industry, in order to offer appropriate risk transfer solutions.

DID YOU KNOW?

INNOVATION FROM THE MINING INDUSTRY THAT CHANGED THE WORLD

Thomas Newcomen designed the first steam engine in 1712 to draw water from tin mines in Cornwall. Its engine was able to raise water from a depth of 50 metres and replaced a team of 500 horses that had previously been used to pump out the mine.

In 1775, James Watt improved the former design and supplied a large steam engine to the Bloomfield Colliery in the West Midlands, England. Steam engines were originally used to pump water out of mines and the first locomotives were then used to transport coal from underground, thus triggering the industrial revolution in the late 18th century.

ECONOMICS

The Euromoney Global Mining Index measures the returns of companies in the metal and mineral extraction industries.

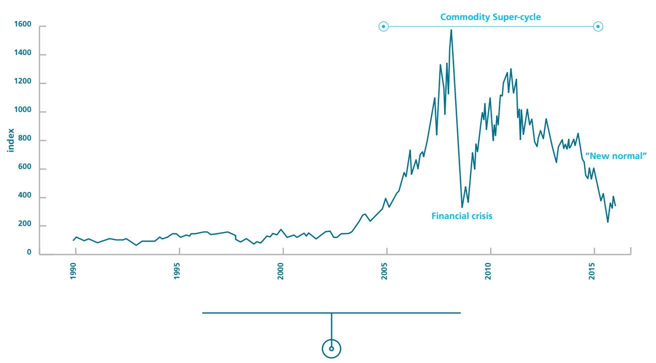


FIGURE 1: ECONOMIC LANDSCAPE

Source: http://www.euromoneyindices.com/indices/euromoney-global-mining-indices/euromoney-global-diversified-mining-inde

The graph shows that the index performed exceptionally well from 2005 until recently, with the exception of a temporary collapse due to the financial crisis in 2008. This period has been dubbed the **commodity super-cycle** by analysts. This super-cycle is generally accepted to have ended around 2012, largely triggered by weakening Chinese GDP growth.

Consequently, mining companies are currently facing an economic downturn: many analysts forecast that commodity prices will remain low in the near future on the back of a persistently oversupplied market, and the past year has seen some heavily indebted mining companies struggling in this depressed commodity environment that is now being called the **"new normal"**.

It may sound like a paradox, but the end of the commodity super-cycle may be a fantastic opportunity for the mining, industry in terms of innovation, because only the fittest

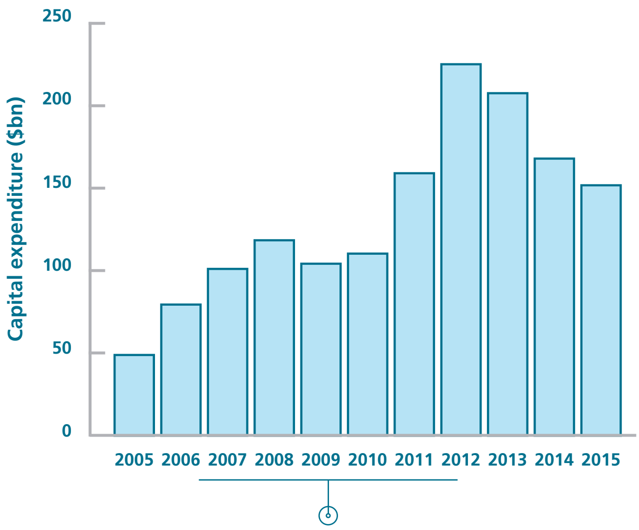


FIGURE 2: MINING INVESTMENT

Source: SNL Metals & Mining

operations will survive, and innovation is a strong driving force for operational efficiency. Mining is a cyclical business, and companies taking actions towards innovation and sustainability during today's tough times are likely to be in an advantageous position in tomorrow's growth markets.

The recent drop in commodity prices, associated with an industry trend of declining ore grades linked to an increase in energy consumption, has pushed the mining industry to switch from capital expenditure to capital efficiency.

According to a recent study[2], the global mining industry's open cut equipment productivity (i.e. annual output/ capacity of input) has declined approximately 20% over the past seven years from its peak in 2006. The mining industry has acknowledged this problem and Productivity Improvement is now ranked the second largest business risk for the mining industry[3]. Until recently, most productivity improvement gains had been realized by exploiting the economies of scale created by continuously adopting larger mining equipment (fixed & mobile, underground & surface, extraction & treatment/processing). Lately, this exercise has proved to have reached its limits. This has led mining companies in recent years to investigate innovative technical solutions and rethink what the mines of the future should be like.

The main objectives to be reached through innovative solutions can be grouped into the following categories:

- Improve safety of personnel.
- Increase productivity.
- Unlock mineral resources that are currently uneconomical to exploit.
- Smarter and longer utilisation of assets.
- Lower environmental impact.
- Better integration in social environment.
- Resilience to external shocks.

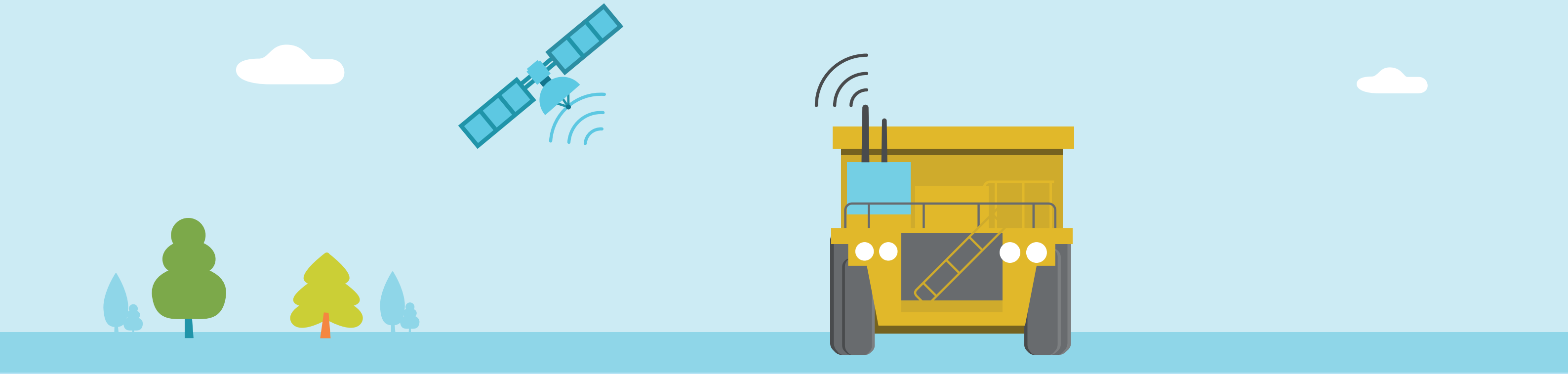
These goals, which were often perceived in the past as mutually exclusive, are now increasingly viewed as the driving force behind the mining industry's move towards sustainable development. For instance, automation serves the dual purpose of increasing productivity and improving safety, by removing humans from hazardous working places.

Investment Category	Country	% of Planned Investments
Fatigue management	Africa	84%
Collision avoidance/ Proximity detection	North America	57%
Mine Management software (scheduling/optimisation)	Asia	54%
Fleet management/ Vehicle monitoring	Europe and FSU	52%
Remote control equipment/ Machine automation	Latin America	50%
Environmental monitoring/ Emissions management	Australia	36%

While the goals of this innovation quest are clear, the path to get there remains unexplored, with all the risks inherent to taking the roads less travelled. Several topical innovations relevant to the mining industry have been selected and are detailed in the following pages of this document. They have been grouped into three main categories:

- Automation, communication and big data.
- Energy efficiency, low emission technologies and sustainable development.
- Innovation in ore extraction, Processing & Treatment, and Marketing.

[2] PWC study - 2014
[3] Ernst & Young - 2015 report Business risks facing mining and metals 2015-2016



AUTOMATION, COMMUNICATION AND BIG DATA

Mining assets are now instrumented and intelligent, reporting their location, status and other key metrics remotely and automatically.

Over the past decade the implementation of data-interpreting technology, in order to automate the mining industry's decision-making processes, has become increasingly popular.

This trend is sent to continue. Automated fleets typically record a 10 to 20% production increase compared to manned vehicles, together with significant savings in maintenance, tyre life and fuel.

In September 2015, the Western Australian government released the world's first code of practice for autonomous mining, which includes robotic mining and exploration.

Developed by the Department of Mines and Petroleum, its purpose is to provide guidance regarding the safe implementation of these technologies. This is a clear sign that such technology is here to stay.

DID YOU KNOW?

MILLS ARE A KEY ELEMENT OF EQUIPMENT IN MINERAL PROCESSING:

they receive run of mine ore and grind or crush it to a fine homogeneous powder that can then be treated by further physical or chemical processes to liberate the valuable metals/minerals inside.

The largest mills can have a diameter in excess of 40 feet (12 m). Powered by a 28 MW (38,000 horse power) engine, they treat 2000 tonnes per hour with 95% availability (17Mtpa), and have a capital cost of around USD 20m.

Some examples of the rapid progress of automation and communication in mining are detailed below:

- **Driverless haul trucks:** the largest concentration of automated driverless trucks operates in Western Australia, in the iron ore rich Pilbara region. Automated trucks respond to GPS directions to deliver their loads of iron ore 24 hours a day, 365 days a year. They are supervised remotely by operators that can be located in a control centre in Perth, thousands of kilometres away[4]. This removes the need to send hundreds of truck drivers to remote locations and improves fleet utilisation.
- **Autonomous trains:** similarly, heavy haul train networks are transitioning to autonomous mode in the Pilbara region.
- **Autonomous drills:** autonomous drill rigs are in operation in several open pit mines (coal, iron ore, metalliferous), and some of the latest models no longer include operator cabins anymore. This means that there is no going back to manual mode. Underground drills are not yet fully autonomous, as an operator is still required to position the drill at the face, but drilling of the whole pattern can then be automated.
- **Remote control of an underground mining fleet** (such as Load-Haul-Dump or LHD equipment) from the surface is already a reality, and an autopilot drive mode for underground trucks has recently been developed that navigates and operates entirely autonomously, both above and below ground. Trucks use sensors, GPS technology, and collision-avoidance lasers to continuously read their surroundings, navigating fixed and movable obstacles while gathering data via their transport system in order to further optimize their route and traffic safety[5].
- **Virtual training,** with simulators replicating the cabins of heavy equipment and using specially designed software.
- **Remote live monitoring and remote diagnostic services provided by suppliers on large semi autogenous (SAG) mills:** in much the same way as aircraft engine manufacturers monitor the health of thousands of engines operating worldwide using on-board sensors and live satellite feeds, large mill manufacturers provide remote condition monitoring services that bring cutting-edge expertise to the most isolated operations on Earth.

[4] E.g. Rio Tinto's remote "Mine of the Future" operating centre
[5] http://news.volvogroup.com/2016/05/09/the-future-of-automation-is-happening-now-at-volvo

- **WIFI for machinery & workers:** wireless networks can now provide total, continuous WIFI coverage to support wearable technology for miners and equipment. WIFI will gradually replace the traditional wired networks and leaky feeders for underground mines.
- **Predictive condition monitoring:** systems using predictive data modelling trigger maintenance orders before equipment failures happen. This forms part of centralized asset management over the entire lifecycle of the equipment.
- **Use of Unmanned Air Vehicles** (UAVs) to obtain easy and safe access to hazardous or inaccessible areas.
- **Slope monitoring radars and alert generation** in case of pit wall instability.
- **Collision avoidance systems,** based on radio, radar or camera technology (or a combination of these), providing advanced warnings and automatic object detection.
- **Fatigue monitoring and alerting systems** (smart glasses or watches ensuring that heavy equipment operators are fit for work).

AUTONOMOUS MACHINERY

In personal motor insurance, it is believed that autonomous driving will eventually reduce accident rates and lower insurance premiums. The same could be true for heavy industrial applications, however a strong database must be established first to compare statistics between man-driven and autonomous machinery. Autonomous machinery also includes a risk of increased severity due to software bugs or crowd effects: whereas a driver could cause an accident that impacts one or two trucks in the event of a collision, autonomous system malfunctions can potentially impact a very large number of trucks. Potential system malfunctions and cyber-attacks bring an accumulation of risks that need to be better understood by insurers.

CONTROL CENTRE

Control centres centralize the monitoring and controlling functions of a large number of physically dispersed operations, and a robust Business Continuity Planning (BCP) must be in place in case of loss of use of these facilities. Disaster recovery services allow a business to continue computer and network operations in the event of a loss, and usually include cold, warm or hot sites:

- **A hot site** is a duplicate of the original site of the organization, with full computer systems as well as near-complete backups of user data. Real time synchronization between the two sites may be used to completely mirror the data environment of the original site, so that following a disruption to the original site, the organization can relocate within a very short recovery time.
- **Warm sites** have hardware and connectivity in place, but require more time to get up and running because back up data must first be recovered.
- **Cold sites** will require even more time before becoming operational and may only include available office space with no hardware.

Big data is generally regarded as a term describing data sets that are so large or complex that traditional data processing applications become inadequate. Capturing, cleansing, analysing, storing, transferring, visualizing, querying and sharing the information can then become problematic.

This has become extremely relevant in the mining sphere with the advent of sensors and real-time information systems: mobile devices, cameras, radio-frequency identification (RFID), wireless sensor networks and wearables all create an enormous amount of data. For instance, the operation centres of large mining companies can collect dozen of terabytes of data per month[6].

But only a small proportion is analysed. Within the mining sector, investments in IT, technology and automation have traditionally lagged behind compared to other sectors because the focus has been on the physical extraction of resources from the ground. However, this is changing fast as miners realize that improved data recording, management and analysis drive decision-making in a more effective manner and lead to greater operational efficiency, cost reductions and reduced risks. For instance a major mining company has recently opened a mobile applications hub in Shanghai, in order to develop applications for mobile devices to help improve communication and productivity across the company.[7]

NEW RISKS CREATED BY BIG DATA

- **Hyper-connectivity**, characterized by an over-dependency on technology and the ever-increasing complexity of human-machine interfaces, poses new risks for mining operations. Fleets of autonomous trucks or drill rigs cannot be easily taken over by operators: personnel may not be available on site, or the equipment may not have been designed with the option of being operated conventionally by a human (some autonomous drill rigs or trucks simply do not have cabins for operators any more).
- **Cyber-attacks** have the potential to bring an entire operation to a halt. All sectors that use industrial control systems are potentially threatened, particularly electrical power, oil & gas, water, transportation, chemical, pharmaceutical and manufacturing industries. Attackers with increasing capabilities have strong financial motivation to go after companies in these highly-competitive industries. Moreover, the hacking of industrial plants for extortion is seldom reported because of reputational damage, so the frequency of these attacks may be underestimated. The energy sector has seen a large number of cyber-attacks over the past few years, and the U.S. Department of Homeland Security says that it is the most attacked industry of all. Additionally, the sector has been impacted by robust state-sponsored cyber espionage campaigns.
- **Suppliers of digital services** are becoming increasingly essential (global positioning systems, data providers, specialised software editors, etc.). Business continuity plans in case of service disruptions must be carefully designed and tested.

[6] https://www.engineersaustralia.org.au/portal/news/rio-re-engineers-future-mining-0
[7] http://www.bhpbilliton.com/investors/news/bhp-billiton-opens-mobile-applications-hub-in-shanghai Bye A (2011) Case Studies

ENERGY EFFICIENCY, LOW EMISSION TECHNOLOGIES AND SUSTAINABLE DEVELOPMENT

It is no surprise that, as time progresses and with the development of exploration techniques, the most easily exploitable mineral deposits (shallow, high grade, with a simple geology, and close to existing infrastructures) have been discovered. The low-hanging fruit has already been picked.

Because of decreasing ore body concentrations, an ever-increasing volume of waste and sterile material must be removed and handled, thus dramatically increasing the energy consumption at mine sites.

For instance, over the last 30 years, the average grade of Australian orebodies being mined has halved, while the waste removed to access the minerals has more than doubled[8].

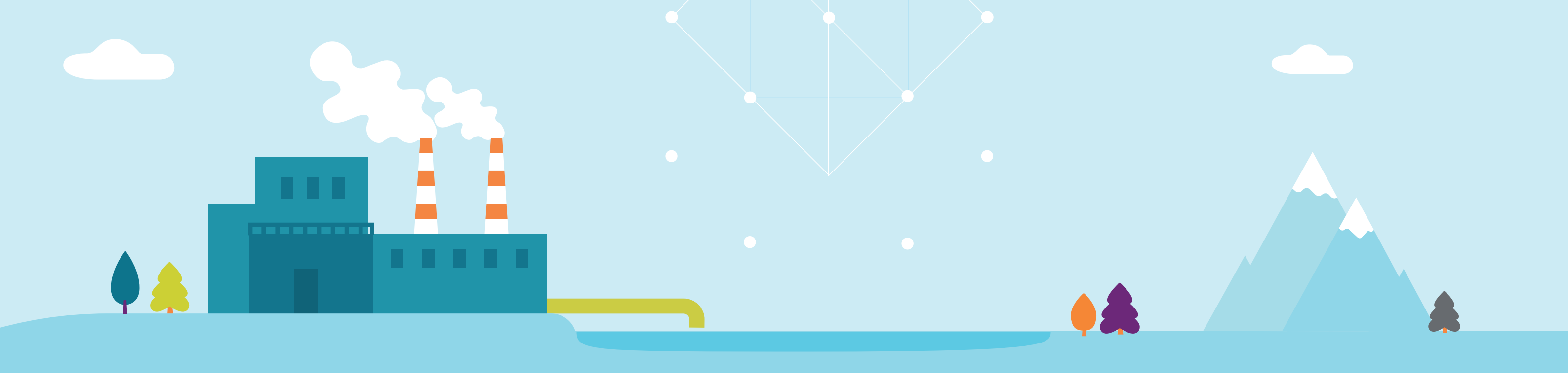
Similarly, remote deposits located away from existing critical infrastructures (roads, rail, ports, access to electricity and water) require more energy. In the last eight years, the industry's energy consumption has increased 70%[9], while multi-factored productivity has fallen 24%. Energy costs constitute a significant proportion of the total mining and mineral processing costs, and a study by the U.S. Department of Energy[10] shows that half the mining industry's energy consumption could be saved by implementing best practices and new advances through R&D. Not surprisingly, the processes where most savings can be gained are the most energy-intensive, namely grinding, transporting materials with diesel equipment, and digging.

ENERGY EFFICIENCY IS THE FIRST STEP TOWARDS A WIDER OBJECTIVE OF SUSTAINABLE DEVELOPMENT IN THE MINERAL EXTRACTION INDUSTRY.

Sustainable development is most commonly defined as development that meets the needs of the present without compromising the ability of future generations to meet their own needs[11].

To become environmentally sustainable, mining must reduce the impact of its operations in terms of energy and water consumption, while minimizing land disturbance, waste production and CO_2 emissions.

[8] Bye A (2011) Case Studies Demonstrating Value from Geometallurgy Initiatives. 1st International Geometallurgy Conference (GeoMet 2011)
[9] Sandu S and Syed A (2008) Trends in Energy Intensity in Australian Industry, ABARE
[10] Mining Industry Energy Bandwidth Study, BCS incorporated, 2007
[11] Mining, Minerals, and Sustainable Development (MMSD) Project, Breaking New Ground: Mining, Minerals, and Sustainable Development, 2002, Earthscan for IIED and WBCSD



REDUCING INPUTS:

◆ Water:

Multiple initiatives have been implemented to optimize water consumption, such as improved water conservation practices, dry tailings, high process water recycling rate, and the use of sea water for ore processing. Mining often becomes controversial when it is competing for resources (electricity, water, land, workforce) with other human activities such as farming or fishing. The use of sea water instead of pumping fresh water from underground aquifers demonstrate that mining can adapt to its environment and act as a responsible neighbour.

◆ Energy:

Both cleaner energy generation and more efficient processes help reduce the energy bills of mining operations:

Renewable energy power production:

- solar power plant (copper mine in Chile)
- wind farm (diamond mine in Canada or a gold mine in Argentina)
- cogeneration plant using waste heat from metallurgical and chemical processes (platinum smelting complex in South Africa)
- hydropower generating facilities (iron ore mine in Brazil)
- geothermal energy (platinum mine in South Africa)
- bio-diesel, ethanol and gas powered industrial engines (iron ore mine in Brazil).

Energy saving solutions for mining processes & infrastructures:

- for some mine sites the energy used by crushing and grinding processes represents up to 70-90% of total energy consumption. Since the 80s SAG mills have got bigger and bigger, making them less flexible. 'Fine crushing' technology could represent an alternative (for some mining operations) that would replace large SAG mills by cone crushers and HPGRs (High Pressure Grinding Rolls) with much better usage of energy[12] .
- High Efficiency Low Emission (HELE), and Ultra Super Critical (USC) coal power stations require less coal per megawatt-hour, leading to lower emissions, higher efficiency and lower fuel costs per megawatt, with efficiencies improving from an average of 33% to 45%.
- Electric-powered mining vehicles (hydrogen fuel-cells, full electric) can generate electricity thanks to the transport of ore downhill by capturing the energy generated from braking down a pit road.
- Batch processes are progressively replaced by continuous methods, which are more energy-efficient (for instance long-distance overland conveyor belts or slurry pipelines replacing fuel-intensive haul trucks).

◆ Land disruption:

Current technology requires ore to be excavated in order to be treated and produce metals, but bio mining (using iron and sulphur oxidizing microorganisms to release occluded copper, gold and uranium from sulphides) could lead the way into an era of *in-situ* mining with minimum land disruption.

[12] http://eex.gov.au/2013/11/crushing-energy-costs-in-the-mining-sector/

MINIMIZING WASTE:

Mining waste represents a huge volume of material that must be disposed of. Mineral content or grade can be as low as a few grams per tonne of rock in the case of gold mining for instance, meaning that millions of tonnes of waste in the form of wet tailings are produced and must be safely stored. A recent accident in Brazil reminded the industry of the enormous environmental, social, economic and reputational risk associated with the storage of tailings in wet dams.

Paste backfill technology: this method consists of adding a high strength rapid setting cement to tailings and pumping it back into underground cavities that have been excavated. It has the advantage of the waste being stored underground, so there is no impact on the landscape, and it also reinforces the strength of the host rock mass, making future exploitation safer.

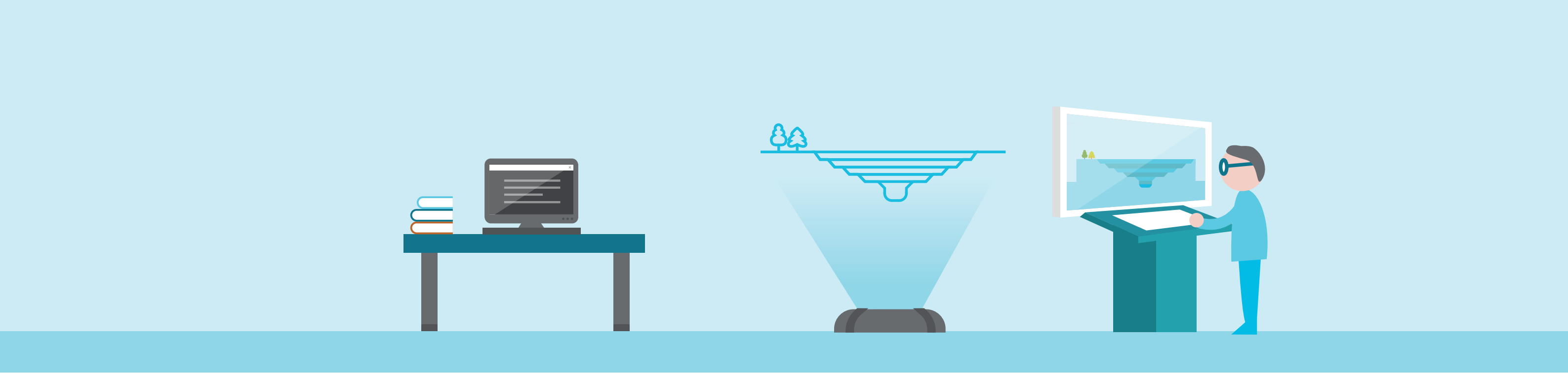
Selective mining: dilution is a permanent issue with narrow or vein orebodies, where waste rock is mixed with mineral-bearing ore in the extraction process, because of the lack of precision of the geological model or of the extraction process (often drill and blast). This creates additional waste and dilutes the product, thus requiring more energy for transport and mineral processing. Selective mining methods are being developed to extract only the metal bearing ore.

Carbon capture and storage solutions: major mining companies partner with electricity providers to accelerate the global development of carbon capture and storage (CCS) technology by sharing knowledge. In the same way that quarries are sometimes used in water diversion schemes, and that old mines are sometimes used as physics laboratories, many mining facilities could be used for CO_2 storage. Some mines already aim to become carbon neutral in the near future.

DID YOU KNOW?
TAILINGS DAMS

Tailings are the solid material and waste water that remain after metals and minerals have been extracted from mined ore. The physical and chemical characteristics of the tailings vary with the nature of the ore, its geological setting and the climate where the tailings are placed. Tailings are most commonly stored in surface ponds which are often dammed due to the high liquid content of the tailings also called Tailings Storage Facility (TSF)[13].

[13] International Council on Mining & Metals (ICMM)



INNOVATION IN ORE EXTRACTION, PROCESSING & TREATMENT, AND MARKETING

Many miners believe that the overarching objective of a mining operation and logistics network is to use the mine, railway system, and port in a way that maximizes production and minimises unit costs.

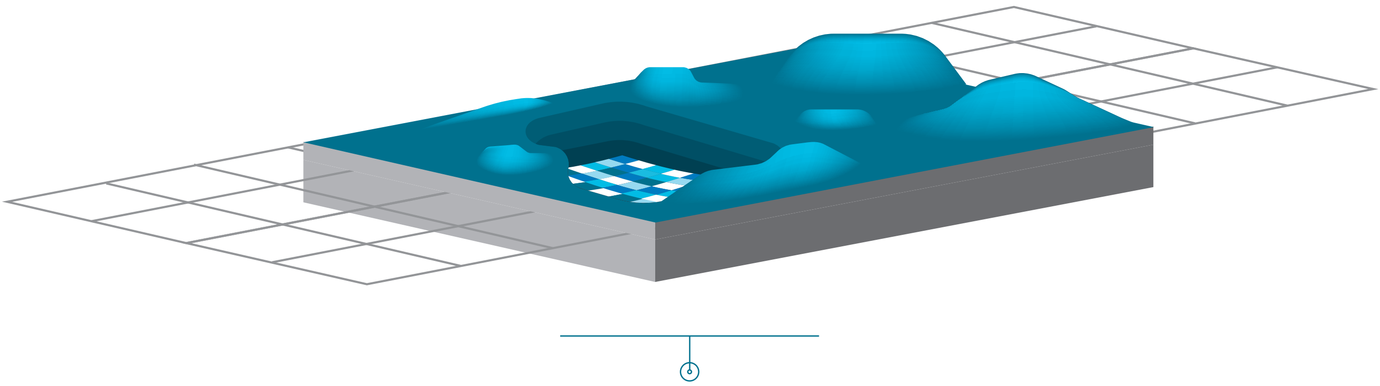
But this belief is evolving as new business models now focus on value, both for the organization and for customers. In economic downturns, mining companies will look to optimize their use of cash and capital and build flexibility. They will have to adapt and lose rigid business models and practices and become fluid, flexible and agile enterprises.

For instance, many gold miners are now focusing on smaller volumes of ore but at higher grades. And producers of bulk commodities can be very successful in blending and marketing their products in order to maximise profits.

"SMARTER RATHER THAN BIGGER"

Innovations that follow this trend of "smart mining" rather than relying solely on economies of scale include:

- **Prototypes of reef boring machines in South Africa:** the idea is to miniaturize tunnel boring machines and adapt them to the extraction of high-grade ore in narrow precious metal vein deposits, thus minimizing the inefficient handling of waste rock.
- **Fine grind & flotation circuit:** new technologies improve ore recoveries from very low grade tailings, and create value from waste.
- **Smart blending of concentrates at the port:** this facilitates marketing and the production of a standard product, thereby simplifying the product range and optimizing value, based on the product specifications preferred by customers.
- **Biomining/bioleaching:** using bacteria and other micro-organisms to leach valuable metals from their *in-situ* location without the need to break and transport the surrounding rock. Moreover these methods do not use toxic chemicals, which have a deleterious effect on the environment.
- **Dry stack tailing dams:** increasing the recycling rate of process water and improving the stability of tailings storage facilities.



3D BLOCK MODEL OF OREBODY

Technological advances also enable miners to look at new territories:

Deep sea mining or sea bed mining:

these terms regroup mining methods that use remote controlled cutters to grind the mineral-rich deep seafloor into a slurry and pump it up to a ship on the surface where it can be processed (technologies already available to the oil & gas offshore production industry can be adapted to this new type of mining). The sector, though small, has been identified by the European Commission of Maritime Affairs as having the potential to generate sustainable growth and jobs for future generations[12]. Although there is no operational production yet and there is a controversy surrounding the potential environmental impact of this method of mining, numerous companies have already begun the race to develop and manufacture equipment, permits for the exploration of minerals in the deep seabed have been granted by several countries, and a couple of companies already commercially explore the seafloor.

Asteroid mining:

this concept used to be considered far-fetched and reserved for Hollywood film makers, but in late 2015 the U.S. Congress passed the Space Act into a law that recognizes the right of U.S. citizens to own asteroid resources they obtain and encourages the commercial exploration and utilization of resources from asteroids. All of a sudden the subject raised some attention, and with space mining companies attracting high-calibre new technology investors (Co-founder of Google Larry Page and Microsoft developer Charles Simonyi), the concept is starting to be taken more seriously.

- **Three main production techniques are being envisaged:**
  - Bring asteroids or pieces of asteroids to Earth for processing (using anchors and spaceships, or solar panels)
  - Process ore on the asteroid and bring back only useful products
  - Transport asteroid to a safe orbit around the moon or Earth
- **Remoteness and distance are the main challenges to overcome, but space mining also brings significant advantages:**
  - Lack of gravity means ore can be moved more efficiently than on Earth
  - Grades of certain minerals (particularly nickel, cobalt, platinum, helium 3) are much higher than on Earth
  - No disturbance to inhabited land

[12] http://ec.europa.eu/maritimeaffairs/policy/seabed_mining/index_en.htm

CONCLUSION

To adapt successfully, the mine of the future must be smarter rather than bigger. It must respond to change faster and be agile and flexible. Innovation plays a key role in this transformation of the industry, and at the same time creates new risks to be covered by insurance.

Transformational leadership coupled with a high degree of resilience will be key requirements for any company willing to embrace this culture of innovation, while navigating through the troubled waters of the current economic downturn.

Moreover the early integration of best practices, preferably at the design stage, will ensure success in the technological implementation of innovative concepts. Thus partnerships with original equipment manufacturers (OEMs) and information technology (IT) companies are critical. Co-operation and collaboration in mining technology are vital to establish a value-adding environment, where best solutions compete with each other.

It is striking to note that uranium, lead, antimony (used in batteries), indium (used in solar panels) zinc, silver, gold (used in electronics) and copper reserves will all be depleted by 2050 at current prices and consumption rates! In an environment of decreasing mineral reserves, only innovative solutions in exploration, mining or mineral processing can unlock new deposits and render them economically viable.

Innovation will be the main force driving the transformation of mining in the 21st century, and will determine the future structure of the industry. Continuous improvement and incremental changes have been the norm for the past few decades, but only innovation has the potential to bring about major changes and improve the general public's perception of the industry. In a world where the famous NIMBY acronym (Not In My Back Yard) has been replaced by BANANA syndrome (Build Absolutely Nothing Anywhere Near Anything) it is up to the mining industry to reverse the trend and take full advantage of the latest technological advances to prosper in the high-tech era.

MINE OF YESTERDAY	MINE OF THE FUTURE
Labour-intensive and low level of mechanization	Extensive use of automated & autonomous machinery & equipment and of remote control systems
High energy cost	Development of energy-efficient solutions and use of renewable energy
High environmental impact	Environmental impact mitigated and no tapping of resources (water, energy) competing with human's needs
Poor ore recovery from complex orebodies (geology and metallurgy)	Use of innovative ore extraction and concentration techniques
Easy access to orebodies and high ore grade	Access constraints to orebodies and declining ore grade trend

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