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Innovation in Mining:

Report to the 2018 International Mines Ministers Summit

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The Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development (IGF) supports more than 60 nations committed to leveraging mining for sustainable development to ensure negative impacts are limited and financial benefits are shared.

We are devoted to optimizing the benefits of mining to achieve poverty reduction, inclusive growth, social development and environmental stewardship.

We are focused on improving resource governance and decision-making by governments working in the sector. We provide a number of services to members including: in-country assessments, capacity building, individual technical assistance and guidance documents. Our flagship event is our Annual General Meeting, which explores best practices and gives members a chance to engage with industry and civil society.

These efforts are largely framed by our Mining Policy Framework, a policy guidance and assessment tool that sets out international best practices in six thematic areas: the legal and policy environment, financial benefit optimization, socioeconomic benefit optimization, environmental management, post-mining transition and artisanal and small-scale mining.

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BACKGROUND

On March 6, 2017, the Prospectors and Developers Association of Canada (PDAC) and the World Economic Forum (WEF) co-hosted the second annual International Mines Ministers Summit (IMMS). The Summit brought together an impressive 25 ministers responsible for mining from around the world, and was an important chance for the global mining community to come together to explore the pressing challenges and opportunities affecting the industry.

The focus of the 2017 Summit was on innovation in the mining industry and the clean innovation agenda. Drawing from the discussions, delegates at the Summit requested that the Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development (IGF) prepare a report on innovation in the mining sector, to be presented to Ministers at the 2018 IMMS. This report, made up of a collection of case studies focusing on those best practices and policies that foster innovation in the sector and developed with help from industry experts and partner organizations, represents the culmination of these efforts.

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INTRODUCTION

Innovation does not come easily to the mining sector. In an already risky and expensive business, true innovation can be hard to justify, with proven technologies a much easier sell to boards and investors than those requiring a leap of faith. A common refrain from mining companies is that, when it comes to innovation, they prefer to be fast followers. They want to be "first to be second."

There is nevertheless a pressing need for innovation in the mining sector. The industry has experienced a 30 per cent decline in productivity over the past decade, according to a 2015 study by McKinsey (Durrant-Whyte, Geraghty, Pujol, & Sellschop, 2015). Commodity price fluctuations are squeezing profit margins or eliminating them altogether; costs, including labour, continue to rise; and deposits are increasingly difficult and expensive to access. Companies must urgently address inefficiencies in their operations to stay competitive, while ensuring they maintain their social licence to operate. The challenges are great, and for many, innovation is the answer.

Innovation, according to Deloitte (2016a), is the creation of a new, viable business offering. For the mining sector, it can take many forms: core innovations that optimize existing assets, products or services; adjacent innovations that incrementally expand a business in new areas; and transformational innovations that represent new breakthroughs and inventions for the industry (Deloitte, 2016a). Innovation is not just continuous improvement, nor is it restricted to technology and changes in the way that companies mine: it also applies to a company's operating structure, management, communications strategies, stakeholder engagement and a number of other areas central to the business. It represents a viable conduit for the mining sector to increasingly develop and implement new approaches, technologies and processes to realize mineral resource opportunities while improving environmental performance and meeting social expectations.

There are a number of drivers of innovation in the mining sector. Above all, companies need to remain competitive: to improve the productivity of their assets; reduce their operational risks; increase the efficiency of deposit discovery; strengthen their mineral recovery rates; recover metals and minerals of higher quality; and drive their own growth. In addition, with recent commodity price declines and reduced profit margins, there is an urgent need for many companies to reduce the costs of developing deposits and operating mines, in terms of labour, capital, energy and other expenses. Also, as new, significant deposits become increasingly remote, deep and difficult to access, new innovative approaches are required—yesterday's technology will not necessarily be able to mine tomorrow's deposits. (Deloitte, 2015, 20016a, 2016b; Delphi, 2017; WEF, 2017).

Junior companies and service providers are particularly innovative—when compared to majors—as they are more nimble, they have become adept at leveraging external partnerships for problem solving, and they benefit most from government incentives (Deloitte, 2015). Mining supply and services companies play a key role in the diffusion of new technologies, particularly through the proving of pre-commercial technologies. Clean technologies, for example, often reach large mining companies after their installation and deployment by engineering, equipment, supply and services companies. Many of these mining suppliers and service providers view themselves as key channels for the diffusion of clean technology in the sector, particularly given the industry's widespread aversion to risk.

Strengthening the business case for innovation, the social and environmental benefits of innovation are also significant, from increased safety on mine sites translating into fewer injuries and less downtime, to reduced environmental footprints and greenhouse gas emissions resulting from the adoption of new technologies and techniques. All could further strengthen a company's social licence to operate.

These changes are, of course, happening within a broader context. The international community has embarked on the most ambitious global development agenda ever conceived, with the adoption of both the 2030 Agenda for Sustainable Development—which defines, through 17 goals and 169 targets, the global development agenda for the next 15 years—and the Paris Agreement on Climate Change. Achieving both ambitions—the Sustainable Development Goals (SDGs) and limiting global warming to 2oC—will require concerted efforts from countries, communities, civil society and the private sector. The mining sector has an important role to play in both agendas (see Columbia Center on Sustainable Investment (CCSI) et al., 2016).

For many resource-rich nations, the role of the mining sector in catalyzing innovation and supporting the achievement of the development agenda is paramount. National governments around the world continue to place emphasis on innovation as a critical path not only to secure their economic goals, but also to ensure social progress and environmental sustainability. This is increasingly relevant, as global trends continue to put pressure on governments to become more forward-looking around critical issues such as globalization, climate change, population growth, emerging economies, environmental stewardship, inequality and social benefits. Innovation can help nations become more competitive, environmentally responsible, and socially inclusive at a time of global economic uncertainties, increasing expectations on sustainable production, and growing sensitivities around local benefits and income disparity.

Despite this, the sector's track record on innovation is not strong, and the barriers are significant (Deloitte, 2016b). Mining is already inherently risky, and investing in innovation and its uncertain outcomes only adds to that risk, a particularly unappealing prospect for a largely conservative industry. Within mining companies there is often a focus on short-term, bottom line improvements, rather than longer-term growth (Deloitte, 2016b). In addition, allocating resources to innovation research is difficult, particularly in periods of depressed prices, as those resources would typically come out of operational budgets. Similarly, cost-cutting during industry downturns hits service providers particularly hard, and they are traditionally home to a significant portion of the sector's innovation. Innovation also thrives in a climate of collaboration; however, competitiveness within the mining sector can inhibit breakthroughs, due to the interoperability of original equipment manufacturer systems and related company fears of jeopardizing the security of their intellectual property (Delphi, 2017; Deloitte, 2016b).

The cumulative impact of limited innovation is significant: the industry's poor reputation on the subject has made it harder for companies to recruit and retain the kinds of staff needed to drive innovation forward, and many companies have been slow to adopt a culture of innovation, believing that it is not fundamental to their business or future competitiveness (Deloitte, 2015, 2016a).

The private sector (operators, but also suppliers, service providers, engineering firms and so on) understandably drives most of the innovation in the industry, but governments, civil society, academia, research organizations and other stakeholders have crucial roles to play. Changes relating to innovation—particularly around automation and digitization—could contribute to reduced greenhouse gas emissions and improved worker health and safety, but they could also have significant impacts on employment levels, skills creation, and local content (Cosbey et al., 2016). As truck driving, drilling and other low-skilled jobs are increasingly lost to automated machines, communities could see declines in economic activity, governments could see reduced revenues and companies could see an erosion of their social licence to operate (Cosbey et al., 2016).

The changes described in the case studies below are coming, and they are coming quickly. Governments must engage with this evolution in the industry. They can do so through the creation of incentive programs for innovation, by directly supporting research and development, and by establishing mining innovation hubs that foster collaboration. Governments should support a culture of communication and coordination among stakeholders that minimizes duplication of efforts and builds trust among innovators (KPMG et al., 2017). They should also leverage existing public innovation funding opportunities, tools, and expertise to support the efficient sharing of resources by mining stakeholders, and to reduce risks for first movers to accelerate the adoption of green technologies (KPMG, 2017). Governments must create stable political and legislative contexts for mining investments, promote the adoption of renewable energy through policies and incentive programs, and ensure that the technological, financial and societal benefits of mining innovation are shared among companies, communities and the state.

Other stakeholders also have important roles to play. Communities and non-governmental organizations must continue to advocate for new, innovative approaches to environmental management, local content provision and financial transparency, approaches that simultaneously promote sustainable development and strengthen social licences to operate mines. Fund managers should target investments into companies that innovate to improve environmental and social performance. And academia, operating without the need to tie research to future profitability, should continue to push mining innovation forward by identifying those trends, challenges and technologies just over the horizon.

In the sections that follow, this report will present a series of case studies looking at mining innovation in its many forms: technological innovation, including automation, digitization and electrification; clean innovation, including energy and technology; business innovation, including financing and business models; and social innovation, including partnerships and engagement. The case studies focus on those best practices and policies that foster innovation in the sector.

It is difficult to say what the future holds for innovation in the mining sector, given the rapid pace of change currently being experienced by those involved in mining. Access to new technologies is rapidly accelerating, the costs of technology are falling dramatically and new approaches to mining are being increasingly tested and adopted. What is clear is that governments, companies and communities must be ready for these changes.

TECHNOLOGICAL INNOVATION

Rapid advances in technological innovation, including through automation, digitization, and electrification, are having a fundamental impact on the mining sector. A sampling of the new technologies currently reshaping the sector would include: autonomous vehicles, including haul trucks, loaders and long-distance haul trains; remote operating centres; automated drilling and tunnel boring systems; GIS/GPS; drones; autonomous equipment monitoring; smart sensors; wearable technology; and machine learning.

The drivers of this shift are many and well known, and the mining cycle is well-suited for the integration of many such technologies. Labour costs are high for many mining companies, with large wage premiums in the sector due to skills shortages and an aging workforce. Automated technologies allow companies to remove staff from dangerous working conditions. Efficiency and productivity gains can be substantial, particularly for those companies operating in remote areas with high fuel costs. The costs of such technology is falling, sometimes rapidly, giving companies further opportunities to reduce and manage their operating costs in the face of volatile commodity markets. And as these technologies are increasingly proven to be commercially viable, the risks associated with their adoption decrease and companies themselves face pressures to compete with technology leaders.

The implications of technological innovation in mining are staggering, and seemingly inevitable. The World Economic Forum (WEF) estimates that autonomous machines will be commonplace by 2025, and that having these machines operating 24 hours a day, every day, at high levels of productivity and with lower personnel costs, could add USD 56 billion in value to the industry (WEF, 2017). In the same study, WEF estimates that the use of smart sensors could create USD 34 billion in value for the mining industry, by facilitating predictive maintenance, improving equipment utilization, reducing downtimes and equipment failures, and lowering the frequency of health and safety incidents (WEF, 2017). Digitization, through improved health and safety, could save an estimated 1,000 lives and avoid 44,000 injuries (WEF, 2017).

Mines are not only getting more geographically remote: they are also getting deeper. As many deposits become more difficult and expensive to access, companies are increasingly looking for opportunities to cut their operating costs through innovation. For deep mines operating with conventional vehicles and generators, the costs of ventilation and refrigeration can be enormous. But without adequate investment in both, working at depth is impossible. Beyond automation and digitization, mining companies are trying to address this challenge through the use of electric vehicles.

The mining industry has typically lagged behind other industrial sectors when it comes to the adoption of electrification. However, with costs plummeting and technology advancing rapidly, the use of electric vehicles in mining is becoming more and more viable, particularly for the unique operating requirements of the sector. Batteries, as a replacement for diesel, can today be charged more rapidly, can be easily replaced, can endure more duty cycles without sacrificing horsepower, and can be charged in a number of ways (including, for example, wirelessly or through regenerative braking) (Delphi, 2017). In addition, battery-operated electric equipment results in less noise, less vibration and reduced emissions within the mine.

As a result of this progress, major companies, including Glencore, Goldcorp, Kirkland Lake, and Hecla Mining, are now testing and implementing new electrified equipment. A key challenge moving forward will be agreeing on charging standards for battery electric vehicles: this will allow mining companies to order machines from multiple manufacturers while avoiding duplication of infrastructure (Ewing, 2016). Collaboration among these equipment providers will be crucial to fast-tracking innovation in electrification and is being promoted by the Canadian Mining Innovation Council and the Global Mining Standards and Guidelines Group.

Governments will have to prepare and respond to the significant shifts in the mining sector resulting from technological innovation. There is an urgent need to ensure that the financial benefits of increased efficiencies and productivity linked to technological innovation are not captured by the company alone; governments and communities must continue to achieve shared value from mining (Cosbey et al., 2016). Shared value may be undermined as automation and artificial intelligence (AI) technologies reduce employment and investment in local communities, allow resource industries to retain a larger share of the value from resource development, and divide jobs into low-paying, low-skilled jobs and high-paying jobs for those individuals who can take advantage of the shift to new technologies. There are concerns associated with a potential "tipping point" that should be avoided as many of the fundamental relationships that underpin the social licence of mining companies to operate become strained or break due to the downward labour pressures associated with automation.

As governments make investments supporting the development of automation and AI technologies, it is critical that they understand and mitigate their potential impacts. For example, when benefits to local communities disappear (e.g., employment, community benefits, community investment and funding for social supports), there is a need for governments to ensure a more equitable approach to technology integration by requiring the benefits of mineral development be more fairly distributed. Governments should explore opportunities for increased, downstream value addition; modified fiscal regimes for improved revenue generation; the transfer of new knowledge and technologies from the private sector to state-run companies; and how mining infrastructure investments can be leveraged to benefit communities and other industries (Cosbey et al., 2016).

RIO TINTO'S PILBARA IRON ORE MINE: WESTERN AUSTRALIA

Launched in 2008, Rio Tinto's Mine of the Future program has achieved significant gains in automation since its establishment. The program was founded to help the company find innovative ways of extracting minerals while reducing environmental impacts and improving worker safety: it has helped the company become the most automated mining operation in the world (Rio Tinto, 2017).

Automation has resulted in a number of important advancements at the company's iron ore mines in the Pilbara region of Western Australia. Rio Tinto is now the world's largest owner and operator of autonomous haulage systems (AHS), and it has 71 automated trucks operating in Pilbara. The AHS trucks, guided by GPS technology, now move approximately 20 per cent of the operations' materials, and this automation has helped ensure that the material can be moved more efficiently and safely. Productivity is improving: the AHS trucks can operate nearly 24 hours per day, every day of the year, no longer stopping for shift changes and employee breaks but only for refuelling and maintenance. In late 2017, the company announced plans to retrofit a further 48 of its trucks with AHS technology, which will increase their fleet of AHS trucks to nearly 130 by the end of 2019.

The cumulative impact has been reduced costs and increased productivity; the cost savings from automation have made the company more resilient to highs and lows in commodity prices, while also helping to make Rio Tinto the lowest-cost iron ore producer in the Pilbara region (Rio Tinto, 2016, 2017). Worker safety has improved: employee exposure to the hazards and risks associated with operating heavy equipment—those related to fatigue, exposure to noise and dust, and soft tissue injuries—has been reduced (Rio Tinto, 2016). Since its adoption, the autonomous fleet has outperformed the manned fleet by an average of 14 per cent, and operating costs have fallen by 13 per cent (Rio Tinto, 2016).

In addition to AHS, in 2016 Rio Tinto began testing the world's first fully-autonomous, heavy haul long-distance railway system, which will help the company meet the demands of increased production without requiring that the company add additional trains (Rio Tinto, 2017). It also operates seven autonomous drill systems (ADS) in its iron ore business, used to drill production blast holes (Rio Tinto, 2016). Since their introduction, the ADS have resulted in 10 per cent less downtime compared to traditionally manned drills, while also reducing staff exposure to blasting and its inherent risks.

Further innovations are being tested through the program. The company is piloting the use of drones to measure stockpiles and to assist with environmental and maintenance activities while reducing risks to personnel (Rio Tinto, 2016). In addition, a new underground visualization tool called RTVis, working like an ultrasound, will help deliver real-time 3D images of ore deposits located far below the surface. Along with AHS, this imaging technology has led to greater ore recovery rates and lower costs (as it enables more accurate drilling and blasting), reduced explosives use, and better waste classification (Rio Tinto, 2016).

All of these automated machines are controlled remotely from an operations centre in Perth. From this single location 1,500 kilometres away, 400 people are able to operate Rio Tinto's Pilbara mines, ports and rail systems. The system incorporates visualization and collaboration tools across the demand chain, which gives operators the real-time information they need to optimize mining, maintenance and logistics across their Western Australia operations (Rio Tinto, 2017).

GOLDCORP'S ÉLÉONORE GOLD MINE: QUEBEC, CANADA

Goldcorp's remote Éléonore gold mine in northern Quebec is using connectivity and smart sensors to change the way that it operates underground. The technology gives the company real-time insights into the performance of its equipment and infrastructure, as well as the location of its personnel, which has helped it cut costs and improve health and safety.

Working with Cisco, Goldcorp has installed a multi-service, secure IP network throughout the mine, enabling full Wi-Fi connectivity underground (Goldcorp, 2017a). All workers, vehicles and other heavy equipment are fitted with radio frequency identification tags, which transmit the person or equipment's unique ID number and location to the operations centre via the Wi-Fi network. Further sensors integrated into the vehicles also send information about the engine's functioning and systems, and issue alerts when action—such as maintenance—is needed (Goldcorp, n.d.a). The network includes voice-over-Internet phones that are used to communicate with staff throughout the mine.

Expanded connectivity has allowed the company to design and implement a new ventilation system that constantly measures air quality to ensure that the right amount of air is sent to where it is needed in the mine, when it is needed (Goldcorp, n.d.a). This ventilation-on-demand system responds to information about where workers are in the mine, and where vehicle engines and other heavy equipment are running (i.e., emission exhaust fumes) or idle. This kind of targeted ventilation has allowed the company to reduce the amount of air they pump into the mine from 1,200,000 cubic feet per minute (cfm) to 650,000 cfm, and has cut the operation's electrical consumption in half, significantly reducing costs (Goldcorp, n.d.a).

Goldcorp is further experimenting with automation at its Red Lake mine in Ontario. In early 2017, the company announced its intention to use artificial intelligence to help extend the life of the Red Lake operation (Els, 2017). Partnering with IBM, Goldcorp will use the company's Watson system and its cognitive analytics to analyze the copious amounts of data available from the mine's core samples, assays, geological models, drillhole data sets, maps, seismic surveys and geological data. This effort will effectively train Watson to "think" like a geologist (Els, 2017). Watson will then synthesize the findings to come up with conclusions on how to extend the mine's life—complementing field knowledge from geologists and engineers to determine the exploration targets most likely to be successful in extending the mine's life.

GLENCORE'S ONAPING MINE: ONTARIO, CANADA

Glencore, an Anglo-Swiss company with headquarters in Switzerland, is currently exploring the use of battery-powered trucks and equipment in its Onaping Depth mine in northern Ontario, Canada. The ultra-deep nickel-copper-platinum group elements deposit is 2,500 m underground, but the deposit is a good one: Glencore representatives have stated that the orebody's grades are double what the company has mined in the area to date (Kelly, 2017).

The depth of the deposit previously made the costs of ventilating the site prohibitive: it would require four new openings to the surface (two intake, two exhaust) to ensure proper ventilation of diesel fumes from the equipment (Ewing, 2016). The economics of the deposit required an innovative solution, and Glencore believes that electrification is the answer: the company hopes that it will be able to reduce its operating costs significantly by electrifying its fleet at the mine site, using battery electric trucks to haul ore to the surface.

By electrifying the underground fleet, the company will be able to design a starkly different—and less expensive—ventilation system. Glencore will not have to design according to vent-per-horsepower particulates regulations, and is looking at new design options for both the recirculation of underground air and smaller cooling plant options (Ewing, 2016). By eliminating diesel and designing the ventilation system for air quality, rather than for removal of diesel emissions, the company will be able to significantly cut the amount of energy required (Kelly, 2017). Ancillary benefits of the vehicles include less noise and less heat, the latter of which also reduces refrigeration requirements. And with electricity significantly cheaper than powering with diesel, the company's energy costs will drop, helping profit margins (Ewing, 2016). In fact, while up-front costs for the equipment will be higher, the company expects to cut its expenditures on ventilation and refrigeration by half over the course of the mine's life (Delphi, 2017).

Glencore is currently working with Caterpillar to test 7-tonne load-haul-dump loaders at the site. The benefits of these vehicles extend beyond reduced operating costs: by using electric haulers, Glencore will be able to improve the health of its workers through reduced underground emissions, while also reducing its environmental footprint and contributing to broader societal goals on climate change. In time, maintenance costs could fall, with reduced shocks to the mechanical portions of the vehicle (Ewing, 2016).

In addition to the electric haulers, the mine plans to install Wi-Fi throughout the mine, extending to the face. This will facilitate the development of a single communications system that integrates equipment and workers (staffed with tablets), allowing for the real-monitoring of operations and the rapid identification of problems as they arise, problems which can be addressed more quickly to boost productivity (Kelly, 2017).

GOLDCORP'S BORDEN MINE: ONTARIO, CANADA

Similarly to Glencore at Onaping, Goldcorp is pursuing full electrification at its Borden Lake deposit. The Canadian mining company plans to make the mine the country's first all-electric operation, and the world's first diesel-free hard rock mine (Ross, 2016). It will do so through the use of a full range of electrified equipment, including load-haul-dump loaders, drills, bolters and personnel carriers (Delphi, 2017).

The company, currently in the exploration phase, plans to design the mine to reflect the equipment it will use, with the ventilation and power systems representing the most dramatic break with a traditional diesel-based mine design. It is undertaking this work with equipment manufacturers like Sandvik Mining and MacLean Engineering, who will ensure that battery-powered underground vehicles can meet all of the company's needs on-site (Goldcorp, 2017b).

Cost is a key driver, and while the electric equipment can be significantly more expensive than comparable diesel equipment, operational savings over time will make it more viable, particularly as the mine goes to deeper depths to access the gold deposits (Delphi, 2017). However, securing and maintaining their social licence to operate is equally important to Goldcorp: the deposit lies within a pristine area, and the company is working to reduce the dust, noise, emissions and general environmental footprint of the mine to ensure that its impact on area residents—including local First Nations communities—is minimized (Ross, 2016).

The new technology will help Goldcorp meet climate change mitigation targets—a key SDG—at the mine. It will do this by eliminating all greenhouse gases (GHG) associated with the movement of ore and waste rock, a 70 per cent reduction in annual GHG emissions over a baseline mine, and the use of significantly less energy (almost two million litres of diesel fuel, over one million litres of propane and 32,000 MWh of energy) (Goldcorp, 2017b). Reducing operating costs and waste generation through innovation will help the company achieve its targets of a 20 per cent increase in production across its operations by 2021.

CLEAN INNOVATION

The scale of energy used in the mining sector is significant. In Australia, for example, the mining sector consumes 500 petajoules of energy per year, which amounts to approximately 10 per cent of the country's total energy use (SunSHIFT, 2017). Most of this energy is supplied by diesel (41 per cent) and natural gas (33 per cent), and the total amount of energy used annually in Australia is growing with increasing mining volumes (SunSHIFT, 2017). The energy mix in Australian mining is changing: diesel use is declining in favour of natural gas and grid electricity, in response to price fluctuations and improved infrastructure.

While the environmental case for the mining sector's adoption of renewable energy sources—solar, wind, geothermal and other—is easily made, the business case is also increasingly persuasive. Advances in technology coupled with reductions in cost make renewables more and more likely to be integrated into a mining company's energy mix. For example, the cost per kilowatt hour for solar energy dropped from USD 30 in 1984 to USD 0.14 in 2014, while onshore wind costs have fallen by 50 per cent since 2009 (WEF, 2017; SunSHIFT, 2017). These costs continue to fall with advances in turbines and photovoltaic panels, ramped up production and easier installation. This trend also allows smaller, more nimble mining companies to increasingly take advantage of renewables.

A number of companies are already using renewables to partly power their sites. Newcrest's Lihir gold mine in Papua New Guinea draws a significant portion of its energy from geothermal sources. IAMGOLD's Rosebel gold mine in Suriname has installed a solar grid on site, which will be transferred to local communities to meet their energy needs once the mine closes. Glencore's Raglan nickel mine in Quebec and Rio Tinto's Diavik diamond mine in Northwest Territories—both in Canada—have installed on-site wind turbines to offset some of their reliance on diesel.

In another innovation, microgrids are being used with greater regularity in the mining sector due to improvements in renewable technologies and their decreasing costs. Microgrids are smaller versions of the traditional power grid, and they provide closer proximity between power generation and power use, resulting in efficiency increases and transmission loss reductions. They can also integrate with renewable energy sources such as solar, wind power, small hydro, geothermal, waste-to-energy, and combined heat and power (CHP) systems. A number of renewable energy companies now provide portable microgrids that can be shipped and installed (and moved) very quickly. This in turn reduces both dependence on diesel and greenhouse gas emissions.

While energy needs at mine sites will vary according to the operation's location, substance, mining type and processing type, and renewables are unlikely—in the near term—to meet a mine's full energy needs, the sector is increasingly looking to renewables as a viable and important part of a mine's energy mix. This trend toward hybrid energy systems mixing renewable and fossil fuel sources will continue as costs fall and there are further advances in fuel cells and battery technologies. The latter give the operator the possibility of storing renewable energy and address the variability of supply inherent in many renewables. This shift also reflects the fact that fossil fuel price volatility and logistics can have a significant impact on the viability of a mine, but are outside of the control of most mining companies (SunSHIFT, 2017).

While renewable energy represents a significant area of clean innovation for the mining sector, the broad range of environmental impacts from mining necessitates that the sector continue to explore new, innovative technologies and techniques across a range of areas of operation, including mine site design, production, closure, and chemical and water use.

Research into genomic mining is looking at how bacteria can be used to extract minerals in situ, and how bio- and phytoremediation processes using natural enzymes and plants can be used to clean sites and soils contaminated by metal leaching and drainage (Deloitte, 2016b). At Barrick's Goldstrike mine in Nevada, the company is using thiosulfate processing to eliminate the use of cyanide in its gold processing, while at its Jabal Sayid mine in Saudi Arabia, it is producing copper concentrate using only recycled wastewater. The closed Prosper-Haniel hard coal mine in Germany is being converted into a large, 200 MW pumped storage hydroelectric reservoir, effectively turning it into a battery for storing excess solar and wind energy (Parkin, 2017). And Newmont is implementing leading water treatment technologies in its operations, including the use of algae for nitrogen compounds; trona (a sodium carbonate compound) in pit lake applications; and microbes and advanced biological treatments for metals and nitrogen compounds.

B2GOLD IN NAMIBIA

For mining companies operating in Namibia, the world's second-sunniest country, offsetting fossil fuels with solar energy makes economic sense, particularly given the volatility of the former's prices (Mining Weekly, 2017).

The Canadian mining company B2Gold has recently completed construction of a 7 MW solar power plant at its Otjikoto mine, with the twin goals of reducing the site's reliance on heavy fuel oil and improving its social licence to operate. The company is working with Caterpillar on the project, using that company's photovoltaic solar modules and micro-grid technology to generate and distribute the power (Mining.com, 2017). The system itself is pre-engineered and scalable for rapid installation. Once complete it will contribute to a hybrid energy model: a connection to the traditional grid would allow for electricity use at off-peak nighttime tariffs, while solar and heavy fuel oil will power the site during the day (Mining Weekly, 2017).

The system also allows for the real-time collection and communication of performance data that can be monitored and analyzed remotely, allowing for the quick identification of problems and rapid responses (Mining.com, 2017). Improvements in battery storage in the near future are expected to further help B2Gold reduce its dependence on non-renewables.

Beyond a reduction in energy costs and greenhouse gas emissions, B2Gold is exploring ways the project can provide power to local communities after the mine closes to further contribute to the company's social licence. It is also looking at how it can use the proceeds from the solar project to support the creation and management of a new national park, as well as fund other local development initiatives (Mining Weekly, 2017).

B2Gold represents a growing trend for mining companies to embrace renewable energy in their operations. As another example, Sandfire invested AUD 40 million in an integrated off-grid solar and battery storage facility for its DeGrussa Copper-Gold Mine in June 2016 (Sandfire, 2016). This project covers a total area of 20 hectares, comprises over 34,000 photovoltaic panels mounted on a tracking system that follows the sun, and is supported by a 6 MW lithium-ion battery storage facility. It is expected to supply 20 per cent of the mine's annual power requirements, and will cut carbon dioxide emissions by 12,000 tonnes per year (Sandfire, 2016). In addition to exploring the viability of solar energy at its operations in Australia, Newmont measures, reports on and verifies its energy consumption and greenhouse gas emissions at these operations. It has also established a forestry project to offset its carbon dioxide emissions. This project has planted 800,000 seedlings in New South Wales and Western Australia, which is expected to capture 300,000 tonnes of carbon over a 30- to 50-year period while also contributing to improving soil quality and biodiversity (Newmont, n.d.).

ANGLO AMERICAN PLATINUM'S FUEL CELL ELECTRIC VEHICLES

Anglo American Platinum, the British-South African mining company, is working with partners to promote the use of hydrogen powered fuel cell electric vehicles (FCEVs). Driving the investment is a hope that—once deemed economical—the widespread adoption of the technology would represent a new market for platinum, one of the company's key products (Anglo American is the world's largest supplier of the metal). Supporting this new clean energy is risky; however, given the growing popularity of battery-powered electric vehicles it could prove transformative for the company.

Platinum-containing FCEVs emit no greenhouse gases and run off hydrogen, an nearly unlimited fuel source (Anglo American, n.d.). The company began testing prototypes of five fuel cell-powered locomotives at its mining operations in South Africa in 2012 (Jamasmie, 2012). The test aimed to prove the viability of the technology, while also improving energy efficiency at the mine site and offering a safer, more environmentally friendly means of underground transport. The move was also part of a broader strategy by the company to establish a South African fuel cell industry, and in doing so support job creation and help meet the country's energy challenges (Jamasmie, 2012).

Anglo American has invested USD 110 million in encouraging technologies that use platinum, including partnerships with key innovators, and has lobbied governments to establish more infrastructure for hydrogen FCEVs (Lewis, 2017). Despite competing (and growing) demand for battery-powered electric vehicles, demand for FCEVs could be substantial if the technology proves viable. China has set a target of 1 million hydrogen FCEVs by 2030, and Britain has committed to expanding its own network of refuelling stations (Lewis, 2017). Anglo American has also joined with automotive, chemical and oil industry partners to create the Hydrogen Council lobbying group, and is working with car companies, including Toyota and Hyundai, to explore further prototype options. FCEVs have greater range and faster refuelling than battery electric vehicles, which is seen by some as an advantage in the sector.

CO-DISPOSAL TO TAILINGS AND WASTE ROCK

Mining companies continue to struggle with the two biggest problems associated with conventional mine waste disposal: acid rock drainage (ARD) from waste rock, and the catastrophic failure of tailings impoundments (Wickland & Wilson, 2005). Waste rock piles are porous, which promotes the development of acid rock drainage and presents mining companies with a problem that is expensive to monitor and prevent—and even more expensive to clean up. Tailings impoundments, on the other hand, can fail due to liquefaction, and must be constantly monitored and managed to prevent erosion and failure. The costs and liabilities of both are significant and long-lasting, while the potential human and environmental costs of failure can be disastrous.

In response, researchers are exploring co-disposal: the mixing of waste rock and tailings to improve the stability of tailings impoundments while also reducing the exposure of waste rock to oxygen (Wickland & Wilson, 2005). Co-disposal is being tested in a number of forms (Wickland & Wilson, 2005):

- Un-mixed disposal: waste rock and tailings are not mixed, but both dumped into opposite ends of an open pit.
- Layered co-mingling: waste rock and tailings are placed in alternating layers.
- Pumped co-disposal: coarse and fine materials are slurried together and pumped to an impoundment.
- Homogeneous mixtures: waste rock and tailings are thoroughly blended or mixed.

Pumped co-disposal is the most tested method, and more effectively reduces the risks of oxidation and subsequent acid rock drainage. It also reduces total disposal costs and storage volumes.

The viability of co-disposal depends, of course, on the geotechnical properties of the mine site; the technique will not be applicable to all mine sites. But by mixing waste rock and tailings, and reducing the flow of oxygen within the mass, co-disposal can inhibit ARD, while the frictional resistance among the waste rock can in turn reduce the risk of liquefaction failure for tailings impoundments (Wickland & Wilson, 2005). Co-disposal can also reduce the mine operator's long-term, post-closure risks and costs, while also decreasing the mine's environmental footprint.

GOLDCORP: TOWARD ZERO WATER

Linked explicitly to the Sustainable Development Goals and the UN Global Compact initiative, Goldcorp's Towards Zero Water (H2Zero) strategy represents an attempt by the company to significantly reduce its use of fresh water in mining operations. The strategy, launched in 2016, aims to drastically reduce freshwater consumption and to completely eliminate the use of traditional slurry tailings (Goldcorp, 2016b). This will help the company improve its environmental performance. Specifically, the strategy aims to: reduce the company's overall water consumption; eliminate the use of traditional slurry tailings at all new operations; halve water consumption at all new sites (compared to current use rates); move at least half of all existing operations to water reuse/recycle rates of more than 80 per cent; and use substantially less fresh water in milling operations (Goldcorp, n.d.b).

In addition to its environmental impacts, the strategy is expected to help Goldcorp cut operating costs. By reducing freshwater use, the company hopes to decrease the amount of infrastructure, energy and labour required to extract, pump and transport it around a mine site; to lower maintenance costs for water infrastructure; and to minimize the costs of water storage, treatment and discharge (Goldcorp, n.d.b). One of the H2Zero strategy's primary objectives is to ensure that the gains achieved by the company can be replicated by other mining companies. Goldcorp is hoping to achieve this by sharing of information and best practices with other companies in the sector through the Canadian Mining Innovation Council and the Canadian Mining Association (Goldcorp, 2016).

At the company's Porcupine Gold Mine, Goldcorp has been able to reduce its reliance on water from nearby Porcupine Lake by increasing its reuse of processed water. Traditionally, 22 per cent of the water used for processing ore at the mine's Dome Mill had been pumped from the lake (Goldcorp, 2017c). In 2012, the mill team proposed a goal of using 100 per cent reclaimed water for ore processing, which would have the added benefit of reducing the need to treat and discharge water from the effluent treatment plan (Goldcorp, 2017c). A multidisciplinary team from within the company developed a model for the project, which was then successfully piloted and implemented following permanent modifications to the mill's infrastructure. For an initial investment of CAD 170,000 (for mill modifications), the project now yields savings of more than 100,000 cubic metres of water per month and CAD 500,000 in reduced water treatment expenses per year (Goldcorp, 2017c). In addition, with less water stored in the mine's tailings pond, one less dam lift was required, saving Goldcorp an estimated CAD 7.5 million. Overall, since the reclaimed water project was implemented, freshwater use from the lake per ounce of gold recovered has declined from 5.86 cubic metres in 2012 to 0.09 cubic metres in 2016 (Goldcorp, 2017c).

BUSINESS MODEL INNOVATION

Innovation is not limited to the physical work of mining operations. Stakeholders from across the sector are also exploring new ways of structuring their business and financing their operations, in recognition of the fact that innovation should not be restricted to technology, but should also apply to the way that a company does its work. This includes innovations in the company's profit model, value chain, structure, employment, processes, brand, and stakeholder and customer engagement (Deloitte, 2016b). In some cases, it can involve a complete rethinking of the kind of business the company is pursuing (see the Alcoa example below). Many of these business innovations are by necessity; technological change, including automation and digitization, is poised to transform entire systems of production, management and governance in the mining sector, and stakeholders must respond accordingly (WEF, 2016).

Fostering business innovation at the organizational level will often require a significant change in corporate culture. Companies must develop a systematized approach to innovation, including the definition of an innovation strategy and the active management of an innovation pipeline. Innovation must be made a priority among the leadership, and systems should be in place to empower innovative decision making throughout the company. Innovation must be adequately funded and should not be defunded during market downturns. Mechanisms should be actively in place for connecting with external partners. And innovation should be measurable, monitored and rewarded (Deloitte, 2016a).

Business innovation includes a commitment to ensuring gender diversity within an organization, in a sector that has often struggled to recruit and retain female talent. Goldcorp's Creating Choices initiative, for example, focuses on training, development and mentorship for women across the company. It aims to strengthen the ability of women within the company to understand their opportunities for personal and professional growth, to develop their self-confidence and courage, to build partnerships with fellow employees and communities where Goldcorp operates, to gain access to mentoring, and to ensure they receive recognition for their contributions to the company (Goldcorp, 2016a). Since its inception in 2010, 1,700 women have graduated from the program.

Business innovation also involves new ways of thinking about project financing, including public-private partnerships, joint ventures and crowdfunding (explored in detail below). For example, Atlas Iron, responding to the collapse in iron ore prices in 2015, developed a new profit model that linked the company's service providers to its productivity, cash flow and net operating profit, effectively giving them equity in the company and tying these supply chain service providers to Atlas Iron's performance (Deloitte, 2016b). IAMGOLD has recently entered into a power purchase agreement with two partners in Burkina Faso to provide renewable solar energy to its Essakane gold mine. Locking in a reliable source of renewable energy at an agreed upon price will help the company reduce its reliance on diesel fuel, improve its carbon and social footprint, and hedge again oil price volatility (Slavin, 2017).

BHP BILLITON CHILE: THE WORLD-CLASS SUPPLIER PROGRAM

Launched in Chile in 2008, BHP Billiton's World-Class Supplier Program (WCSP) represents an innovative approach compared to the traditional mining business model, one in which suppliers and service providers are much more formally integrated into the company's problem-solving processes. The result is not only an improved system for addressing mining challenges in Chile, but also significant capacity building among local and national suppliers and service providers, elevating their global competitiveness and catalyzing sustainable development within the country (BHP, 2014).

The WCSP was launched in response to rising industry costs, increased water scarcity in the Atacama Desert, and a growing shortage of skilled labour (ICMM, n.d.). It aims to develop new solutions to the operational and environmental challenges faced by BHP's Chilean business. Five areas were identified as priorities for the program: water; energy; health, safety, environment and community; human capital; and operational efficiency (BHP, 2014).

For problems that lack a satisfactory market solution, BHP works with local suppliers to come up with innovative solutions to their problems rather than attempting to solve the challenges themselves. The system turns the traditional procurement model around: local suppliers submit tenders on problems or challenges, rather than on solutions that have been developed by BHP Billiton at the operational level. The proposed supplier solutions are then tested in real-time (ICMM, n.d.). BHP Billiton provides suppliers with consultancy support as they come up with the solutions, focusing on management, corporate governance, strategic planning and marketing (BHP, 2014).

The hope is that, in addition to solving BHP Billiton's operational challenges, the program will increase the ability of Chilean suppliers to compete and succeed in the global marketplace. It aims to develop 250 world-class, Chilean industry suppliers by 2020 (BHP, 2015). Since its inception, the WCSP has developed more than 70 projects, and some of the suppliers have begun to export the resulting solutions to new clients outside of Chile (BHP, 2015). Initial projects under the program have resulted in an estimated USD 121 million in cost savings for BHP Billiton (ICMM, n.d.). Examples include (BHP, 2014):

- Tesra and Sixth Sense Processware: Developed an automatic scanning system for detecting shorts and helping operators fix them, which reduced electricity consumption by two per cent per tonne of copper produced.
- Prodinsa: Developed a system to increase the useful life of cables on electromechanical shovels by 40 per cent. Exports now account for 50 per cent of Prodinsa's sales.

Since its launch, the WCSP has also been adopted by the Chilean state copper producer, Codelco (in 2011). The expanding adoption of the approach will help create a more sophisticated and export-driven economy in Chile, while also increasing efficiency and cost savings within the domestic mining sector (ICMM, n.d.). Similar initiatives are being considered in Peru, Colombia and Mexico (ICMM, n.d.)

Crowdfunding Exploration

Crowdfunding is a means of raising capital from the general public via Internet-based platforms. Through crowdfunding, companies or individuals can raise funding for projects by soliciting relatively small amounts of financing from a large number of investors. It can be seen as a tool to expand the investor pool for mineral investments, as it enables the participation of all individuals in the purchase of shares or stakes. Minerals exploration is costly and risky; for companies operating in this space, it can be easier to solicit a number of smaller investments from a variety of stakeholders through crowdfunding than to raise money through larger investments from a more limited pool of investors.

Crowdfunding originated in the non-profit sector, where funding was predominantly donation-based, but is now employed by a number of sectors, including—to a limited extent—the mineral exploration sector. For mining, there are high administrative costs and requirements related to establishing and maintaining a public listing, and crowdfunding allows companies to access public funding while bypassing these costs and requirements. These platforms bundle investment information online and play the role of a typical brokerage firm, enabling broader community access to retail investment. There are limits, however: crowdfunding lacks legislative protections for investors, and investors are limited by the allowable size of their investment (depending on the jurisdiction), which typically results in the raising of relatively small amounts of capital.

In Canada, available crowdfunding exemptions come attached with various conditions used to protect both the investor and the company. In 2015, several provinces adopted a harmonized registration and prospectus exemption, known together as the "start-up crowdfunding exemption." This exemption permits non-reporting issuers to issue eligible securities, subject to a number of conditions. An Internet-based portal can be either registered or unregistered. If the portal decides to take advantage of the prospectus exemption, it must be a registered dealer that meets the obligations under the securities legislation. Alternatively, a portal can take advantage of the combined start-up crowdfunding exemption, in which case it is unregistered via the registration exemption. Under this exemption, funding portals are prohibited from providing advice to the purchaser on the merits of the investment and from receiving a commission or fee from the purchaser of eligible securities. The start-up crowdfunding exemption includes a cap of CAD 250,000 on the size of a distribution (and an annual limit of two distributions) and limits investors to a maximum CAD 1,500 investment per distribution.

The Ontario government has also approved several new prospectus exemptions that are designed to facilitate capital formation and job creation. These include a new crowdfunding prospectus exemption regime, which took effect in 2016, and allows businesses, particularly those in the early stages of development, to raise up to CAD 1.5M annually by distributing securities on a prospectus-exempt basis through a registered Internet funding portal. Issuers can only distribute their securities through a single registered funding portal unrelated to the issuer. Investors utilizing these portals are subject to limitations. Non-accredited investors are limited to CAD 2,500 per investment and an annual limit of CAD 10,000. Accredited investors are permitted to invest CAD 25,000 per investment with an annual limit of CAD 50,000. There are no limits for permitted clients such as institutional investors.

Ontario-based Red Cloud Klondike Strike was the first platform to launch in Canada that is specific to the mining sector and uses an online issuance of securities; however, it does not use the combined crowdfunding exemption. Rather, this company is registered as an exempt dealer with the securities regulator and offers an online issuance of securities on behalf of issuing companies. Red Pine Exploration Inc. was listed on the platform on May 26, 2016, to raise CAD 2 million. On June 3, 2016, Red Pine announced that it had closed the brokered private placement financing with total gross proceeds of CAD 2,158,008. Similarly, Vested, another Canadian crowdfunding platform, helped Kal Minerals Corporation become the first ever fully online crowdfunding mineral development company.

3D METAL PRINTING

Rapid advances in 3D printing will have dramatic impacts on the mining sector. As it becomes more economical, efficient and scalable, 3D printing will influence the entire mining value chain, from equipment, maintenance and procurement to customer demand and reach (WEF, 2017). This could transform the sector by condensing, or even eliminating, complex supply chains and the associated costs of managing them (Deloitte, 2016b).

3D metal printing remains expensive, and lacks the speed and scale needed for mass production (WEF, 2017). However, once these hurdles are overcome and the technology becomes more broadly available and applicable, its potential for internal part production could drastically change on-site maintenance of vehicles and equipment, and consequently improve productivity. Mining companies, particularly those operating in harsh or remote environments, could simply print, immediately and on-site, the parts needed to repair their trucks, drills, bolters and other equipment. They could thus minimize or eliminate any interruptions to production caused by traditional maintenance delays. Required parts can be produced in their entirety with minimal materials, eliminating the need for complex component assembly and reducing transport, shipping and energy requirements. 3D printing could as a consequence also significantly reduce greenhouse gas emissions for the sector (WEF, 2017).

New markets will also emerge for the sector. In the near future, metals companies could sell input materials directly to 3D metals-printing customers, or become integrated mining and 3D printing firms (WEF, 2017). Alcoa, the U.S.-based industrial corporation and aluminum producer, has been working on 3D printing innovation for two decades (Millsaps, 2016). The company—the world's sixth largest aluminum producer—recently opened a USD 60 million 3D printing metal powder production facility at the Alcoa Technology Center in Pittsburgh. The facility will be devoted to producing the proprietary titanium, nickel and aluminum powders needed for 3D printed parts for the aerospace industry (Millsaps, 2016). Alcoa's investment illustrates two trends outlined above: progress in the technology required for the on-site printing of parts for equipment, as well as being a leader in the mining sector using 3D printing to at least partially shift its business focus to reach new customers.

Advances in 3D printing also carry significant risks. As the broader technology continues to improve, it is likely that metal products will increasingly be substituted by plastics and other non-metal materials. The World Economic Forum (WEF) estimates that this kind of plastics-for-metals demand substitution, facilitated by 3D printing, could lead to losses of up to USD 195 million for the sector. Whether these losses will be offset by the efficiency gains and new customers described above remains to be seen.

SOCIAL INNOVATION

Mining companies are also increasingly innovating when it comes their engagement with governments, competitors, communities, and other stakeholders, and in their approach to partnerships. This social innovation is often crucial to maintaining and strengthening a mining company's social licence to operate, and to ensuring that value from the mine is shared across stakeholders. It is also important for the future of the industry; engaging with the broader public in an innovative way will help to attract new talent to an industry struggling with an aging work force.

Innovation thrives in a context of collaboration, and collaborative ecosystems designed around engagement are proliferating (Deloitte, 2016b). Hackathons, which are increasingly popular and are described in detail below, bring together a large number of people—often young, energetic students and software developers—to engage in intense, collaborative problem solving around a specific problem. Similarly, Open Industry Forums give companies the opportunity to present a challenge they are facing to suppliers and other members of the mining community, who then brainstorm to solve it. Mining innovation hubs also provide a platform through which multiple stakeholders can connect and collaborate, often engaging technology start-ups, businesses and industry leaders in finding creative solutions to resource challenges (Deloitte, 2016b).

Companies are also rethinking how they engage with communities, both while they operate and after they close. In its operations in Ghana, Golden Star has integrated its open pits into the local hydrology, so that they act like natural lakes that fill and drain after rainfall. The lakes are stocked with fish that the community can raise and harvest long after mine closure. In addition, local farmers can manage and harvest palm oil from plantations established on the company's decommissioned tailings facilities. In Ecuador, Lundin Gold is aligning its community investment programs with the UN's SDG8 (Decent Work and Economic Growth) through the Fruta del Norte gold project: local agricultural producers have been integrated in the mine's catering supply chain, boosting local employment and economic activity. And Antofagasta Minerals in Chile broadcasts videos of its meetings with Transparency International on its website and through social media platforms to ensure that affected stakeholders, including local communities, are well informed as to their work.

SUNMINE: KIMBERLEY, BRITISH COLUMBIA

When faced with the question of what to do with a fully reclaimed mine concentrator site on the outskirts of the city of Kimberley in western Canada, the municipality worked with a mix of partners to come up with an innovative solution. They decided to convert the site into a large-scale, commercial solar power station, called SunMine. The project, which began production in 2015, is not only the province of British Columbia's largest solar field, but also the country's largest solar tracking facility.

Working in the city's favour is not only the fact that it had a large site available for development, but also that Kimberley is Canada's highest municipality, at 1,120 m. This makes it particularly suitable for solar energy generation, given the high number of sunny days it experiences throughout the year. The site, part of the former Sullivan zinc-lead-iron mine complex, now hosts 4,032 solar-cell modules mounted on 96 solar trackers that follow the sun's movement to maximize exposure (SunMine, 2017). The energy produced on-site contributes directly to the province's energy grid. While the site currently produces 1 MW of power, the municipality is looking for investors to expand the site to increase production to at least 15 MW (Watson, 2016).

Beyond the innovation of converting a rehabilitated mine site into a solar energy project, SunMine also represents a significant collaboration between a number of stakeholders. Teck Resources, the Canadian mining company that was the former owner of the site, provided the land and site infrastructure, as well as CAD 2 million toward the project. The province, through its Innovation Clean Energy Fund program, contributed CAD 1 million through the EcoSmart Foundation, a non-profit foundation promoting public-private projects. BC Hydro purchases the power that goes into the grid, and both the Columbia Basin Trust and the Southern Interior Development Initiative Trust contributed additional funding and assistance. The project has the full support of the local community, and helps develop local skills in engineering and renewables that could be applied elsewhere (SunMine, 2017).

HACKATHONS: CROWDSOURCED PROBLEM SOLVING

Growing in popularity, hackathons are increasingly being used in the mining sector to rapidly solve specific problems through intense, open source collaboration between industry and a broad set of stakeholders. These relatively inexpensive brainstorming events bring together a number of stakeholders—including software developers, designers, engineers, students and industry members—for multi-day sessions where participants aim to develop solutions to resource sector challenges. Participants typically compete in teams for cash prizes and retain the intellectual property rights to their solutions. While not every hackathon will produce ideas and prototypes that are funded or developed, many of them have in the past (Bechtold, 2017).

Unearthed, an Australian company, hosted a number of hackathons in 2017, in Canada, Australia, the United States and Argentina. In Brisbane, Origin used the assembled talent to think through how to optimize their drilling through real-time performance feedback. In Vancouver, SSR Mining wanted to improve their ability to predict haul truck and shovel failure, while Teck was looking to improve haul truck performance. Barrick hosted hackathons in Toronto, Buenos Aires and Denver focused on a number of challenges: finding new ways to detect, track and optimize maintenance work at their mines; developing new tools to consolidate exploration data from multiple sources; predicting agitator failures; and using 3D visualization tools to better identify gold and increase recovery rates in processing. Also in 2017, the Canada Mining Innovation Council (CMIC) hosted #HackMining in Toronto, a three-day hackathon focused on two challenges: transporting ore and waste from difficult-to-access areas, and reducing the volume of mine tailings (CMIC, 2017).

One of the great benefits of hackathons is their ability to bring in new, innovative thinking to old mining problems. This thinking often comes from outside of the sector, from participants with limited knowledge of the industry but also none of the biases that might come with a history in the sector. This allows for the generation of solutions which may not have been considered by those entrenched in the mining field, and can also serve to attract young, innovative professionals to the sector.

TECK RESOURCES: SMART SENSORS FOR COMMUNITY ENGAGEMENT

Teck Resources, a Canadian mining company, is using smart sensors at a mine site in Chile to generate data on the impacts of its operations on the local environment (WEF, 2017). The company then shares this data to affected stakeholders. By promoting transparency and engagement with the community, the company holds itself to a high level of environmental performance and hopes to strengthen its social licence to operate.

At the Carmen de Andacollo copper mine in central Chile, Teck is using a number of practices to improve air quality. Given the proximity of the mine to the community (Andacollo is within walking distance of the mine), managing air quality is extremely important; crushing, blasting and transportation can produce significant amounts of dust, which can in turn affect community health if unmitigated (Teck, 2017).

Teck's action on air quality is in response to an Atmospheric Decontamination Plan established by Chile's central government to address air quality concerns in the region. The goal of the plan was to reduce dust emissions by 65 per cent by 2017, compared to 2010 levels (Teck, 2017). Teck attempted to achieve this objective through practices including using weather vanes to inform and plan blasting practices; improving blasting techniques to reduce dust; using sweeper truck to clean roads; spraying foam to reduce dust in the crushing process; and covering concentrate trucks (Teck, 2017).

In addition, the company has started to use sensors with frequent data feeds to measure its performance in watershed management and dust generation. With the adoption of the new technology, it can now identify slight variations in quality for both, variations it was not previously able to measure through daily sampling (WEF, 2017). Data on water and dust are then shared with local communities to help them understand the impact of the mine on the local environment, and to ensure that they feel safe. The sensors have also improved the operator's ability to analyze environmental data and to report on its performance to governments (WEF, 2017).

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