# Au-some

## John Chadwick reports on some innovative mining and processing methods likely to see more widespread use soon

Let us start this year's examination of better ways to extract gold by reviewing some of the innovative ore extraction techniques and how these are advancing.

**AngloGold Ashanti i**s making progress with its innovative reef-boring system. One MK IV proto type machine has been deployed at TauTona mine test site in South Africa. It extracts only the gold ore before backfilling. The backfill is not conventional but a specially developed ultra-high strength backfill (UHSB) to fill the void.

AngloGold Ashanti CEO Srinivasan Venkatakrishnan commenting recently on the pillars left after mining said "we've left 40% of the gold behind." One of the aims of the reef boring development is to exploit these pillar gold resources.

Venkatakrishnan said the system would not replace conventional mining, nor was it a form of mechanisation. But it would give South Africa's gold mines more time to recover what was previously inaccessible.

"We see this as a potential game-changer and potentially something which could arrest the rate of decline in gold production, but not enough to completely transform it," Venkatakrishnan said.

AngloGold Ashanti started testing the reef boring system in 2013, producing about 3,000 oz during the initial test phase at TauTona mine. Last year the system at TauTona produced about 13,000 oz and AngloGold aims to increase this to about 20,000 oz this year.

Venkatakrishnan said the company had invested more than $100-million in the project and the results were finally showing, especially because TauTona produces the highest grades. However, he warned that "it is a tough technology to roll out on scale."

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Orebody knowledge and exploration plays a critical part in the mine design of any orebody. Enhanced geological information will improve current planning practices and will be essential in the application of mechanical reef mining. In order to mine the different reef packages optimally, the location of the reef terraces, structural information and time to analyse geological information is essential for the success of mechanical mining methods

RC drilling is being developed to replace conventional geological drilling techniques.

The reef-boring technology is being developed to extract gold-bearing reef using mechanical boring techniques, with the aim of creating an explosive-free, and, therefore, continuous mining operation At the core of this initiative is the need to remove people from risk while creating a continuous-mining environment where only the reef is extracted - without diluting the orebody by up to 200% and more, as is the case with the current mining methods.

Three MK III prototype reef boring machines were deployed in 2015 at TauTona 97 Level in the Carbon Leader Reef prototype sites. One MK IV was deployed in the extended test site.

Reef boring cycle times have improved to 82 hours per hole, from roughly 160 hours per hole.

One MK III prototype reef boring machine was deployed in 2016 at TT 67 Level in the Ventersdorp contact reef prototype site.

The USHB: needs to be a support medium that is stronger than conventional backfill. The development has focused on a cost effective, UHSB 'recipe', which on curing will attain 170-200 MPa strength (as hard as the country rock).

Due to its density, this product needs a special delivery system to transport the USHB for in-hole placement as quickly as possible at a

*AngloGold Ashanti is well advanced on a reef boring project to cut mining costs and reduce waste extraction*

*Looking down an AngloGold Ashanti reef boring hole*

range of temperatures over a span of horizontal distances.

UHSB surface trials to pump the special backfill at a product temperature ranging between 30 and 35°C over a 1,000 m distance were successful.

In addition, an acoustic monitoring system has been installed to monitor the rock mass response during drilling. "Basically," explains Jacqueline Storbeck, Project Lead Engineering , Technology & Projects, "we measure the UHSB response in the rock while drilling to ensure that the rock conditions remain constant (the product is as hard as the rock thus filling the hole we try to keep the conditions constant)."

"As part of the ongoing process to install instrumentation to continuously measure the rock conditions, a software data logging system was installed in the prototype sites. We now log all information from the acoustic monitoring system."

The Rocmec thermal fragmentation system has seen a lot of development and the company has now become **Nippon Dragon Resources**. The team behind this innovation has been nominated to the *International Mining Technology Hall of Fame*. Jean-Yves Therien, one of the team, explained that "most often narrow-vein ore bodies are prohibitively expensive to mine [and] many producing mines will not extract veins that are under 1 m in width unless they are very high grade." Conventional long-hole drilling and blasting produces about 6 t of waste for every 1 t of valuable ore.

Essentially the technology uses heat to break up a narrow corridor of rock without damaging the waste walls. A diesel-fired burner is inserted into a 152 mm pilot hole. When lit, the burner raises the in-hole temperature creating thermal stresses that spall the rock (i.e. causing it to crack apart). The resulting ore dilution is minimal to none; only the vein is extracted. The broken material produced during the process ranges from fine grains to small fragments. Then low-powered explosives break up the space between drill holes, leaving the waste walls intact. The advantages are the rapid rates at which it can create large cuts, low operating costs, increased safety, small environmental footprint and mobility and minimal setup time.

This thermal fragmentation method can replace: room and pillar mining (flat or reef), the shrinkage method (manpower intensive) or small-diameter long hole methods with their inherent dilution problems. Nippon Dragon promotes seven key benefits:

- Major dilution reduction (4:1 ratio approximately)
- Little or no wall damage caused by blast vibration
- Significant cost savings related to ore handling and ore treatment (1 – 13 mm size fragments)
- Two person team per machine (efficiency)
- Green technology (500 t/d versus 2,500 t/d)
- Cash cost reduction (30%-60% approximately)
- Selective mining.

*In Nippon Dragon's thermal fragmentation, the first step is to drill a series of 15-cm pilot holes into the gold vein with a conventional drill. Then the thermal fragmentation equipment (thermal head, compressed air and water) is inserted and spalls the rock, quickly increasing the diameter of the hole to 30 to 110 cm. This is followed by extraction of the ore in 0-13 mm fragments. The final stage is to break leftover rock between fragmented holes to recover remaining ore*

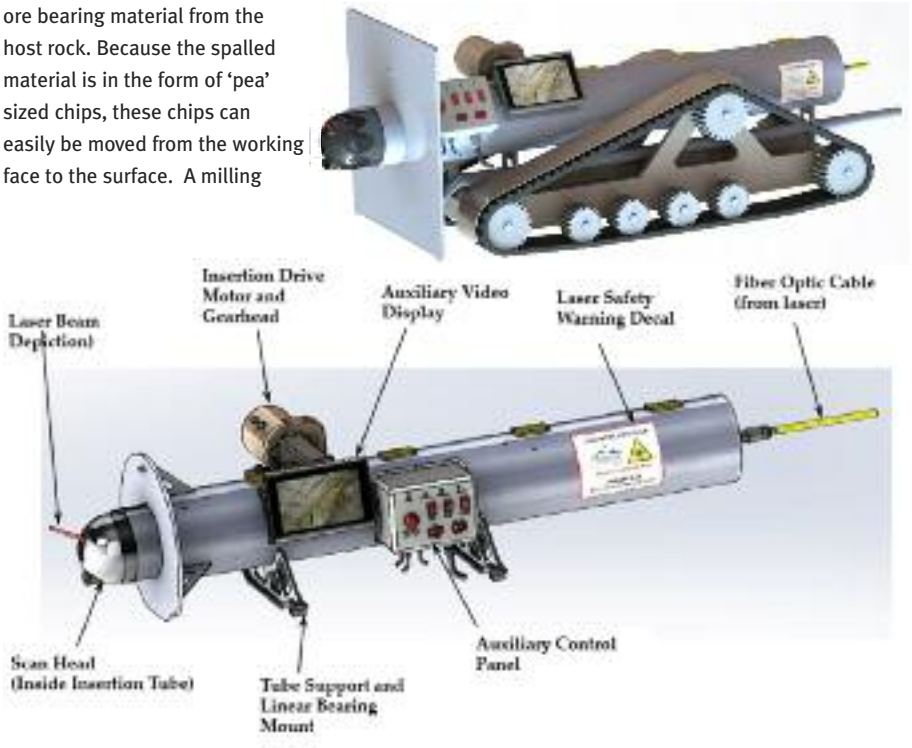
## Laser mining

Particularly interesting for narrow vein mining – gold being a prime prospect – **Merger Mines Corp** says using "lasers for spalling (breaking) rock underground or to drill blastholes in open pits, will eliminate conventional methods of drilling and blasting. Preliminary estimates indicate substantial savings can be realised in time, material costs, and operating costs.

"This new mining method involves the use of high optical power output lasers to cut or spall ore bearing material from the host rock. Because the spalled material is in the form of 'pea' sized chips, these chips can easily be moved from the working face to the surface. A milling advantage is that these small chips do not require crushing and can be discharged directly to the ball mill or leach pad."

Merger Mines is developing a single head laser mining device for use in underground mines. Initially, this single head laser mining unit will be used for narrow high grade veins. The mining width for this unit will be about 60 cm. Once the operating parameters of the single head mining unit are established, multi-head laser mining units can be developed for stopes wider than this. For example, a four unit laser mining array would work in a 2.4 m wide drift. Initially only the ore bearing material is removed, and then the waste is removed on a second pass with the unit.

With experience gained from the mining program, laser mining heads will be mounted on mobile equipment and used for driving drifts



and development headings. Plans are also in place for driving raises, either unlined or timbered. Not presently under consideration, but certainly not ruled out, Merger Mines says, is the sinking of shafts.

Underground, "lasers will reduce operating costs substantially as jacklegs, drill steel, bits, powder, blasting caps and a multitude of small tools will be eliminated from normal stoping costs. Labour costs for mining and material costs will be greatly reduced. Underground supervision will be simplified and overall mine safety should improve. Plans are in place to design a laser mining unit where a one or two person crew could operate multiple working faces from a central control module."

Merger Mines also believes that "in theory, mining without blasting could reduce or eliminate rock bursts."

In open pit mining, a laser mining head could be readily mounted on a standard track drill and be used for blasthole drilling.

The head has the capability to chamber, or enlarge the bottom of the drill hole for shaped charges for special blasting requirements.

## Cyanide-based recovery, or not?

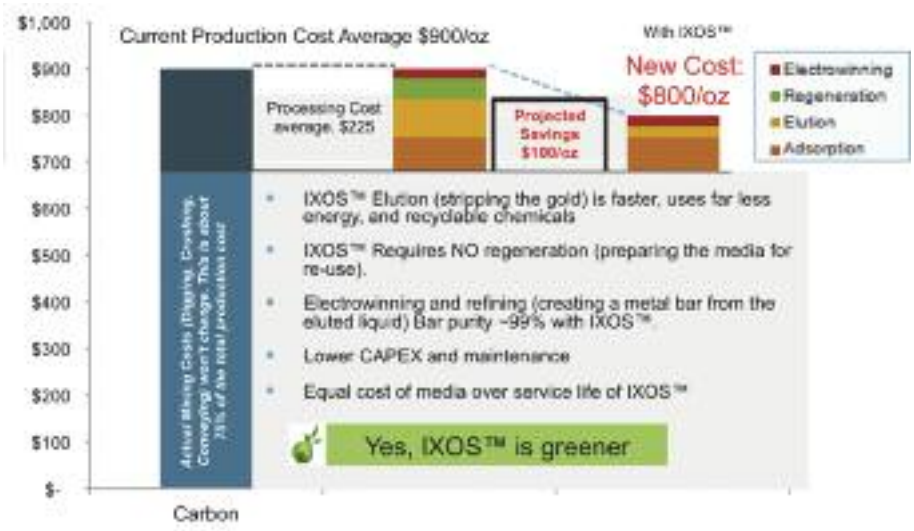
**Synergen Me**t has developed what it describes as "a world-first, transportable, modular process plant that manufactures sodium cyanide (NaCN) at the mine site – revolutionising the supply process for one of the most critical, but dangerous, reagents used in the global mining industry."

The Synergen NaCN plant is a modular, stand-alone production plant. Each plant is the size of a standard 40' shipping container and is readily transportable. Synergen's first pilot plant recently successfully completed test work at a mine in Australia, following six years of proof-of-concept, development and optimisation activities. The Synergen team is now talking to a number of mining companies about locating a 400 t/y production plant on a mine site to begin production by June 2017.

The plant eliminates a range of dangerous activities associated with the use of cyanide such as transportation, on-site handling, and maintaining large cyanide inventories. The technology has been through the PCT patent process and full patents have been granted in Australia, Mexico, South Africa and the two African patent regions of OAPI and ARIPO. Patents are under review or are near to review in the USA, Canada and Europe.

NaCN is made on-site to the exact specifications of the mine site, generally a 25 to 30% dilute solution. It is pumped directly from the production tank to the site's NaCN holding tank in a closed system.

The company notes that the process "can be up to 50% cheaper than the current market price of NaCN, depending on the cost of various reagents."




*IXOS makes it cheaper and easier, according to 6th Wave Innovations.*

In November 2014, Synergen Met and The University of Queensland were recognised at the Institution of Chemical Engineers' Global Awards for this process. The modular on-site cyanide production unit took the 2014 Award for Outstanding Achievement in Chemical and Process Engineering, as well as winning the Core Chemical Engineering category.

Synergen Met Managing Director, Chris Dunks, said at the time the company had already fielded interest from gold mining companies in Australia, Africa and North America, eager to consider the new system.

"For gold producers, on-site cyanide production is a game changer as it gives the producer control over an essential material in their production process, while cutting costs and risk. Our process will allow mining companies to reduce their transportation and manual handling of cyanide concentrate, and give more certainty over their supply chain while significantly cutting costs."

The first production unit is a 400 t/y plant and with strong interest being shown from around the world, the company expects rapid uptake as mining companies started to realise the benefits of the new technology.

"Our work means for the first time, mining companies can produce cyanide on demand and feed directly into existing mills. This removes the risk of supply delays and reduces the need to store large volumes of toxic chemicals in purpose built facilities," Dunks said.

The process differs from existing cyanide producers by using nitrogen instead of ammonia as a source material. Nitrogen is very abundant and can be extracted from the air for cyanide production using existing, off-the-shelf technology.

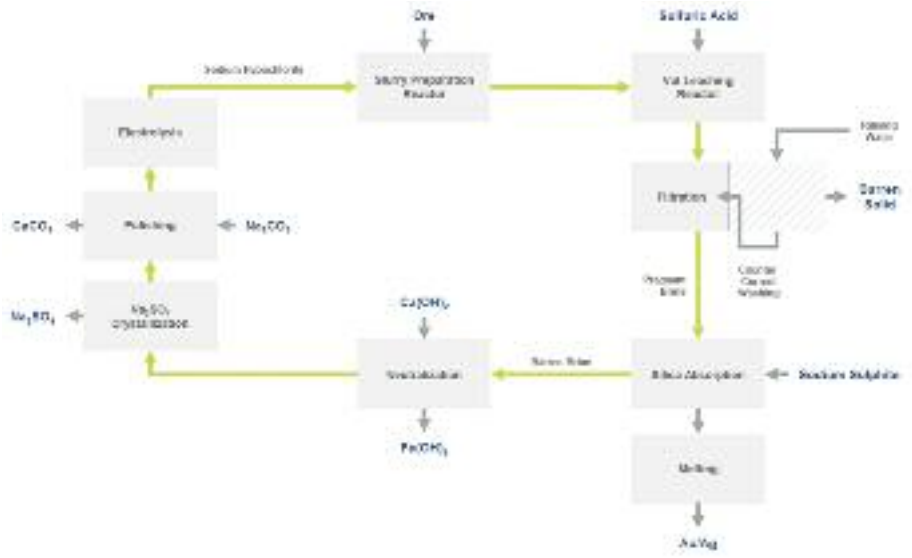
Coconut-based activated carbon (AC) is commonly used to recover gold from cyanide leach solutions in CIP, CIL and, to a lesser extent, carbon-in-column circuits. **6th Wave Innovations** says that "while these systems have been perfected over 100 years of use, AC has inherent limitations. Capacity for gold adsorption is highly dependent on the metallurgy of the ore, quality of the AC, pH of the pregnant solution, and other factors.

"IXOS™ nanotechnology shows stable and predictable performance across a wide variety of conditions. Gold capacity and selectivity remain significantly higher than AC regardless of the presence/levels of other base metals. Moreover, superior mechanical strength over AC allows for virtually 100% gold extraction with no loss to fines. The IXOS beads don't become poisoned with other base metals; they fully elute; and are re-usable for dozens of loading and unloading cycles."

The benefits, according to 6th Wave, include the potential for saving over $100 per ounce:

- Increased gold recovery (no loss to AC fines or solution loss); recent field tests showed as much as 10% more gold recovered, with essentially zero solution loss
- Higher capacity and selectivity translates to smaller plant and lower cost of operations
- No significant performance changes through many cycles
- Demonstrated to be highly effective with preg-robbing ores
- One step elution at low temperature and standard pressure
- NO regeneration/reactivation.

**Dundee Sustainable Technologies** (DST) has recently received independent certification of the performances of its cyanide-free gold extraction process (the DST Gold Process) from Environment Canada, through the Canadian Environmental Technology Verification (ETV) program. This confirms that the process successfully extracted an average of 81%, with a maximum of 90%, of



*DST Process chlorination circuit overview*

the gold content from a refractory gold bearing pyrite concentrate, while the cyanide extraction process achieved an average of 71% on the same material. This material is from a jurisdiction which has restricted the use of cyanide within its territory. This refractory concentrate was chosen due to the difficulty of extracting its gold using conventional processes, hence demonstrating the effectiveness of the DST Gold Process.

Throughout the ETV program, a total of 170 t of gold bearing refractory pyrite concentrate were processed. The performance test sampling was conducted at DST's demonstration plant according to the test protocol developed by STS Canada, and under its supervision. Samples were submitted for analysis to SGS Canada - Mineral Services.

All solid residues met environmental norms and DST's chlorination circuit delivered the anticipated gold recoveries which were higher on average than cyanide yields on same samples. In addition, the process successfully demonstrated its closed circuit operation with the recycling and regeneration of the reagents.

John W. Mercer, President and CEO of DST stated: "We consider this an important endorsement of the DST Gold Process; demonstrating its potential as an interesting alternative to cyanide".

DST is currently working on projects for the commercialisation of its technologies in Canada, Argentina, Bulgaria, Chile, Ireland, Namibia and Peru.

With several mining jurisdictions around the world banning or restricting the use of cyanide, some mining companies struggle with good projects due to increasing environmental and social concerns related to the use of cyanide.

This alternative process from DST uses chlorination in order to extract precious metals from refractory minerals. It operates in a closed loop circuit, which implies that no liquid effluents are generated, eliminating the need for costly tailings ponds. The chemistry and process design is also viable for treating precious metal deposits containing base metals. The tailings from the process are inert from toxic substances, sulphide depleted and not acid generating, and as a result, meet environmental norms. The efficiency of the process has demonstrated high gold recoveries within a fraction of the time needed for cyanidation to obtain similar results.

The efficiency of the process, coupled with its operating conditions, plant size and construction material allow for competitive operating and capital costs as confirmed by technical and economic validation by recognised engineering firms.

DST has a 15 t/d demonstration plan located in Thetford Mines, Quebec, that processes material on a commercial basis. The plant can extract gold and silver using DST's chlorination technology.

In May DST entered into an agreement with Empresa Nacional de Minería, Chile (ENAMI) for the purchase of 125 t of gold concentrate to be processed using DST's technology. This is part of a phased plan to establish a commercial processing facility, using DST's patented technology, in Chile.

The concentrate contains an estimated 115 g/t of gold, 9.0% Cu and mercury content in excess of 600 g/t. This complex material is difficult to process using conventional processing methods without the associated environmental liabilities and metallurgical challenges. An earlier piloting campaign successfully removed 99.7% of the sulphide and 99.6% of the mercury content. The calcine material was then submitted to acid and water leaching where 99% of the copper was recovered as copper sulphate. DST's chlorination process that followed achieved a gold recovery of 98.8% and a final gold deposition over silica recovery of 99.8%.

*Chlorination chemistry involved in the DST process. Chlorine, along with a catalytic amount of bromine, are used as oxidizing agents because of the particularly fast reaction of bromine with gold*

DST says the operating costs of its process are similar to cyanidation on a $/oz basis. However, there are lower capital costs due to:

- Reaction time, gold extraction in hours instead of days (shorter process time)
- Smaller plant and site
- No need of costly tailings pond facilities

There are reduced site rehabilitation costs due to smaller site footprint and fewer environmental liabilities.

## Enhanced CIL/CIP

Huntsman has been looking at addressing the operational challenge of processing ores containing problematic gangues to help customers achieve target mineral recoveries and concentrate grade. Drawing on its polymer technologies, and its recently commissioned metallurgical facility in Melbourne, Australia, Huntsman has been focused on developing dispersants and depressants that offer benefit for the treatment of ores bearing fibrous, micaceous and carbonaceous gangues. This includes ores from most of the world's major mining regions.

Huntsman's new POLYMAX®K50 & POLYMAX®K55 polymer dispersants have demonstrated beneficial effect on ores containing fibrous and mixed mica/carbonaceous gangues. Fibrous gangues i.e. asbestos, manifests in higher pulp viscosities, poor froth characteristics and drainage leading to lower grades, recoveries and process interruptions from fibre build up.

K50 dispersant, added at typically 50-70 g/t into the conditioning tank ahead of rougher flotation, has been shown to inhibit fibre build up, restore froth mobility and improve drainage. As well as improved recovery and grade, plant down time was reduced from the observed reduction in fibre build up rate.

Mica and carbonaceous gangues can inhibit flotation recovery and grade, leading to inconsistent and high reagent consumption and lower process efficiencies. K55 dispersant can enhance the performance of natural polymers, such as starch and dextrin, resulting in noticeable improvement in copper recovery, grade, and an overall reduced reagent demand.

Graphite and carbonaceous gangues can be

seen to cause a distinct increase in reagent demand and poor froth mobility leading to a loss in recovery and grade. POLYMAX®G30 and POLYMAX®G35 dispersants preferentially bind with active carbon sites and when added to the conditioning stage at a range of 25-50 g/t, can reduce reagent demand and enhance recovery and grade.

In addition to their use in flotation, POLYMAX K50, POLYMAX G30 and G35 dispersants can also improve the performance of CIP/CIL processes. K50 dispersant can assist with modifying the viscosity of ores containing high talc that causes issues of high viscosity slurry. At a dosage of 50-70 g/t, POLYMAX K50 dispersant can be added in the mill or leach conditioning tank to aid pumping and slurry rheology for improved activated carbon/leachant contact.

The presence of native carbon, graphitic and shale gangues in CIP/CIL circuits can lead to reduced circuit recovery from preg-robbing of gold cyanide complexes. POLYMAX G30 and G35 dispersants were developed to have preferential affinity for carbonaceous surfaces which actively blinds the carbon and reduces the preg-robbing opportunity. These dispersants, when added at 10-50 g/t have been seen to improve gold recovery, which is at a lower dose compared to the typical kerosene or diesel normally used for the same purpose.

## Bioleaching

Last year **Outotec** acquired Biomin South Africa, taking on the full intellectual property and marketing rights of BIOX® bioleaching technology; a proven method for the treatment of refractory gold ores. BIOX technology complements Outotec's portfolio of gold processing technologies. Gold orebodies are becoming more complex to treat and consist of more refractory ores as the less refractory gold ores become depleted. Roughly 20% of the world's current gold projects and a third of upcoming projects are based on refractory ore that needs to be pre-treated before the leaching process. There are three main pre-treatment methods for refractory gold ores; pressure oxidation, roasting, and bioleaching. BIOX is proven technology for bioleaching.

"A significant challenge for gold mining companies is to find an economically viable process to treat more complex orebodies. This acquisition will strengthen Outotec's position in the refractory gold ore processing market. Combining BIOX bioleaching expertise with our engineering capabilities and proprietary equipment, such as grinding mills, reactors and thickeners, we intend to provide gold producers complete sustainable plants with life-cycle services", says Outotec CEO Pertti Korhonen.

In Kazakhstan, Nordgold has launched an innovative Outotec HiTECC (Hot Leach) process at its Suzdal mine to recover gold from both historical and CIL future tailings.

*The Fosterville HiTeCC facility*

The company notes: "Suzdal is the second mine worldwide to launch a commercial Outotec HiTeCC circuit. The installation of the innovative HiTeCC highlights the strength of Suzdal's management team under Grigorii Iakovenko, General Director and deep technical expertise of Nordgold's international processing team under Philip Engelbrecht, Director of Metallurgy. The first commercial hot Leaching technology was constructed in 2009 at Crocodile Gold Corp's Fosterville BIOX® operation near Bendigo, Australia."

Biomin says the Fosterville installation has been "running very successfully with gold increases across the leach plant realising economically attractive recoveries."

Suzdal produced 75,300 oz of gold in 2015. The HiTeCC circuit will produce an additional 9 - 14,000 oz of gold doré per year for 10 years, a total of approximately 90-140,000 oz, generating additional profits. HiTeCC life-of-mine AISC is expected to be some $420/oz. Suzdal AISC decreased to $476/oz in Q1 2016 from $575/oz in Q4 2015 and $828/oz in Q1 2015.

Nordgold CEO Nikolai Zelenski: "The launch of HiTeCC is an important technical milestone for Nordgold, highlights our strategy of pursuing operational excellence. Suzdal is a long-time pioneer in the implementation of the best and most innovative operating solutions and we are proud the mine becomes only the second in the world to launch this technology which will have very real financial benefits for the company, both extending the life of mine as well as increasing production. The launch of the new gold recovery circuit using an innovative HiTeCC technology is yet another confirmation of Suzdal's leadership as a high-technology gold producer in CIS."

Construction of the new facility started in July 2015, and it will reach full operating capacity by the end of June 2016. HiTeCC will allow Suzdal to process more than 130,000 t of historical and future CIL tailings per year. Suzdal currently has 637,000 t of tailings at 7.17 g/t Au available for retreatment. Test results indicate the possible recovery rate of 40% to 70%.

Nordgold invested $5.8 million in construction of the state-of-the-art 1,800 m2 HiTeCC facility. The company expects to fully pay back this investment in less than 20 months (assuming gold price of $1,200/oz and 350 tenge/US$ exchange rate).

High Temperature Caustic Conditioning (HiTeCC) process is designed for treatment of double refractory ores. Through the BIOMIN HiTeCC process, gold is efficiently desorbed from the organic carbon by manipulating the ionic strength and temperature of conventionally treated CIL product slurries.

**Ekato** notes that "biological ore leaching is not only an interesting economic alternative to conventional pressure leaching but it is also ecologically safe – because it operates as a stirred process in closed conditions - in contrast to the usual but questionable heap leaching with respect to ecological balance. The ever increasing plant dimensions as a function of the economies of scale plant dimensions require a stirring technique which is able to suspend heavy ore particles in continuous operation and at the same time to disperse the air supply to the organisms and for the oxidation step."

*Ekato COMBIJET*

The company explains that its COMBIJET technology meets these requirements perfectly, since unlike conventional mixing or agitating, the suspension capacity is hardly affected at higher gassing rates. Thus, a stable operation of ten continuously stirred tanks with volumes of approximately 1,500 to 2,000m$^3$ is possible despite load variations or varying compositions of the ore.

The good suspending capabilities of the COMBIJET allow a reduction of the power input to that which is required for the mass transfer rate, exhibiting an annual energy savings of about 5–10 GWh for a complete system. This is particularly important in remote mining areas without regular electricity supply. In addition, the low power input protects the micro-organisms on the ore particles in an abrasive environment.

The investment costs are not only reduced because of the smaller agitator dimensions; a stable running of the impellers with gassing leads to lower hydraulic loads which also has a cost-reducing effect with respect to the vessel design and supporting structures.

## More refractory answers

The **Intec Process** operates in the chloride medium to recover base and precious metals from mineral ores and concentrates in a cost effective and environmentally safe manner. Monument Mining last year completed construction of an Intec pilot plant and commissioned it at the Selinsing gold mine in Malaysia. The plant was built as a part of the Intec Trial Testing Program to exploit Intec's sulphide dissolution and gold recovery technology using the existing Selinsing gold processing plant under the Interim Intec licence. An exclusive licence of Intec technology over southeast Asia will be granted upon success of the commercial Intec trial testing program.

The design of the pilot plant circuit is based on the first stage extensive metallurgical and chemical laboratory test work completed by the in-house Monument research and development team, which has successfully demonstrated the technical ability of the Intec technology to dissolve sulphides and recover gold from the sulphide material on a bench scale test work program in the Selinsing laboratories.

The purpose of the pilot plant trial testing work is to demonstrate two main aspects of the process; that the bench scale batch test work results can be duplicated in a continuous flow process and that the process can be successfully scaled-up. The Intec Process has been the focus of Monument's effort to provide a technology that has the ability to process sulphide gold material economically at Selinsing – and potentially elsewhere. If successful it will extend the life of the project using the existing Selinsing process facility and infrastructure well into the future. Based on the Intec success in sulphide dissolution and gold recovery results, the test work program will then be extended to exploit Intec technology to sulphide copper and other base metals.

Monument Mining says "the Intec Gold Process offers particular advantages for refractory or arsenical feedstocks. As example, where arsenic is present in a mineral concentrate (perhaps as arsenopyrite), the conventional roasting technologies become both potentially environmentally hazardous and expensive, due to the formation of volatile arsenic trioxide. By contrast, the Intec Process can leach the arsenopyrite to liberate the gold while leaving the arsenic behind as safe, environmentally stable ferric arsenate, an analogue to the naturally-occurring mineral scorodite.

"The process can be run without the use of cyanide for projects where this is a particular advantage, or can be combined with conventional technologies for efficient gold recovery with minimal technical risk."

In the second quarter fiscal 2016 the first trial pilot plant run was successful in achieving "steady state" for seven days where various parameters were tested using different sulphide feed stock materials drawn from selected ore samples in Buffalo Reef.

Monument Mining says "a second trial pilot plant run is planned for the fourth quarter to test the response of ores containing varying amounts of pyrite and arsenopyrite using sulphide ores from Buffalo Reef. This trial will allow the gold recovery of sulphide pre-concentration by flotation methods to be compared with the first trial on gravity concentrate. The second trial will be carried out with the assistance of Orway Mineral Consultants that has been engaged to oversee the pilot plant operation."

It was the *Conceptual Study: Use of the Intec Process as Pre–Treatment Step to Conventional Cyanidation of Buffalo Reef Concentrate* completed by DCS Technology in February 2014 that indicated that the Intec Technology, among other alternatives, may provide an economic solution to treat sulphide materials through Monument's Selinsing gold plant and for other gold projects.

In February 2015, the company acquired an interim license from Intec International Projects

*The Intec pilot plant at Monument Mining's Selinsing gold mine in Malaysia*

Pty Ltd, under which Monument has the right to exploit and test the Intec Technology in respect of both copper and gold processes, and to use the Selinsing plant as an alpha site.

The Intec test work is a four–stage program including laboratory trial test work, the pilot plant trial test work, building a demonstration plant, and building a commercial plant.

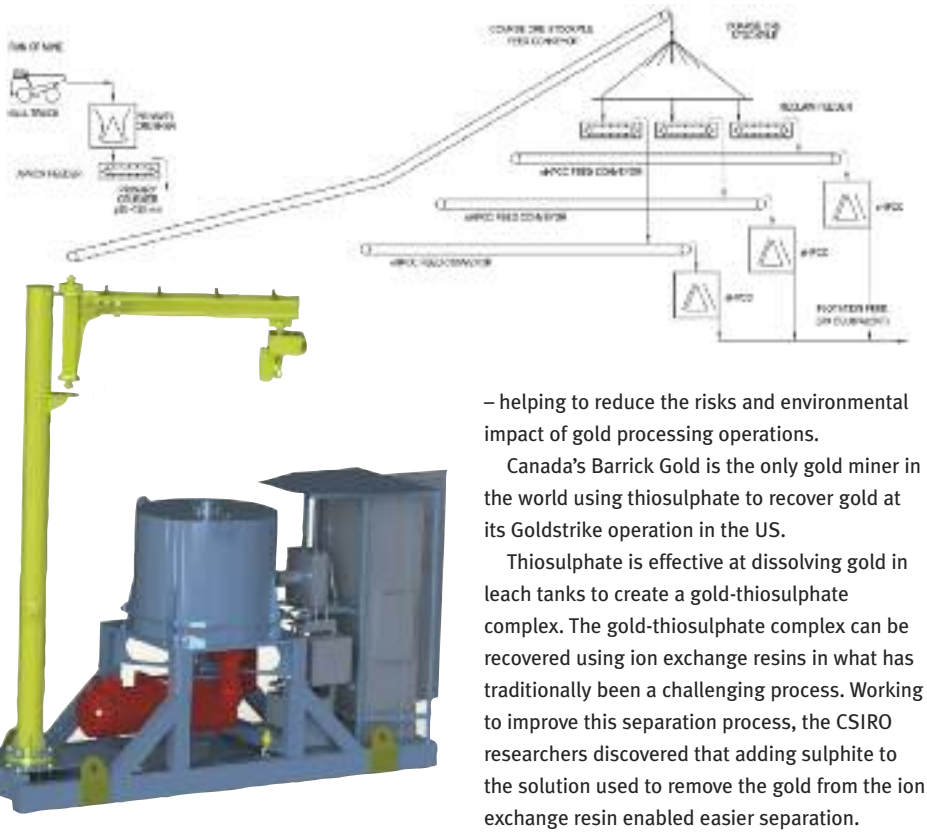
The second trial of the pilot plant is planned for the fourth quarter to test the response of ores containing varying amounts of pyrite and arsenopyrite using sulphide ores from Buffalo Reef. It will allow the effects on overall gold recovery of sulphide pre–concentration by flotation methods to be compared with the first trial on gravity concentrate. The second trial will be carried out following recommendations by, and in agreement with Orway Mineral Consultants, engaged by Monument to oversee and report on the pilot plant operation.

During the third quarter, metallurgical drilling for the Intec Project comprised of 14 RC pre–collar drill holes for 1,107 m and 19 DD drill holes for 1,901 m across Buffalo Reef South, Buffalo Reef Central and Felda Land to collect representative ore samples for the second pilot plant run. Those samples have been concentrated by flotation and will be fed into the pilot plant for testing in the fourth quarter. The results of this second pilot plant run were anticipated to be available in July 2016 for Orway to complete economic analysis of the Intec technology based sulphide gold recovery process. The economic analysis will be incorporated into an updated NI43–101 technical report.

Ian MacCulloch, Managing Director at **Coomooroo Explorations** reports that "for some time, Leslie Thompson of **Pintail**, Denver, Colorado and I have been researching and conducting trials on the use of bacteria to beneficiate both ferrous and non ferrous metals. This work has had two approaches with one being the direct reduction of ferrous and non ferrous metals and the second approach has been the removal of gangue minerals from ores. This capacity has been created as a byproduct in researching the removal silicates from refractory gold ores to then enable the follow on dissolution of gold from these complex ores.

"Pintail has already been able to form goethite along with copper supergene minerals such as native copper, chalcocite from mine water waste. This trial was witnessed by the Denver, Colorado office of the USGS and formed the basis of a feasibility study on the remediation of the severely contaminated groundwater at the Summitville mine, Colorado."

Pintail has also been able to create elemental chromium from chromium contaminated soils sampled from the banks of the Clyde River, Glasgow. Here the aquifer results for soils and water can reach 30,000 ppm Cr. The bacteria are capable of functioning normally in a very toxic environment and producing lumps of chrome metal.



*eHPCC: an image representing the machine constructed and scheduled to be commissioned early July 2016 and how eHPCC might be used in a large throughput application. For a small throughput only one feeder and eHPCC might be needed*

Direct reduction of arsenic has also been achieved from other sites. In other mine waste studies such as at McCoy Cove, Nevada, Pintail has been able to lower the soluble metal load to almost zero for transition elements (USAEPA/McCoy Cove sponsored trials).

Pintail has treated up to 8 Mt at a time on gold spent ore heaps. Treating large amounts of iron ore for either upgrading or for on site direct reduction is therefore not an issue as the methods of creating large volumes of bacteria at the right concentrations under non sterile conditions have already been undertaken.

## Future innovations

The CSIRO has begun early discussions with industry for the development of new gold-processing technology. The concept hopes to build on the patented technique developed by the agency for recovering gold without the use of cyanide.

The novel gold recovery process replaces cyanide with thiosulphate – a non-toxic chemical – helping to reduce the risks and environmental impact of gold processing operations.

Canada's Barrick Gold is the only gold miner in the world using thiosulphate to recover gold at its Goldstrike operation in the US.

Thiosulphate is effective at dissolving gold in leach tanks to create a gold-thiosulphate complex. The gold-thiosulphate complex can be recovered using ion exchange resins in what has traditionally been a challenging process. Working to improve this separation process, the CSIRO researchers discovered that adding sulphite to the solution used to remove the gold from the ion exchange resin enabled easier separation.

The CSIRO process can be tailored for treating high-grade gold concentrates, and is also be valuable for use in other applications. For example, in-situ leaching in deep mines and for use in treating ores that contain carbonaceous material or those with high cyanide-soluble copper.

CSIRO Gold Processing Team Leader Paul Breuer and Senior Project Engineer Rueben Rajasingam met with executives from privately owned **Prima Resources**. Prima was founded by two former Alcoa mechanical engineers in 2013. Prima Resources is in early discussions with Linden Roper, **JTG Consultants**, also an ex Alcoa Engineer, who conceived the eHPCC, a concept of combining a crushing, milling and classification circuit into a single unit.

A prototype of the company's high-pressure crushing mill has been successfully tested in laboratory trials over the last three years.

A 2.5 t/h eHPCC prototype is to start trials at Bapy Mining LLC, according to Prima Resources Managing Director Gaye Money.

The mill is anticipated to significantly reduce energy consumption, capex, and opex, with elimination of grinding media, dependant on the material and the number of milling machines in the circuit it replaces,according to Prima, who have shown an interest in the CSIRO technology to explore new processing opportunities.

Breuer said discussions were still in their conceptual stages, but the technology had the potential to transform the gold sector in the same way as CIL processing in the 1980s.

Prima Resources has also formed an alliance

with West Drill to investigate using the new CSIRO process to commercially develop uneconomic gold deposits. Breuer notes that by "uneconomic we are referring to the use of current technologies, such as gravity (where cyanidation can't be used) or cyanidation. There are not only low grade deposits but also high grade small deposits that this technology can unlock with the reduced regulatory approvals and requirements as compared to cyanide."

Dr Yeonuk Choi, Senior Manager, Strategic Technology Solutions, Barrick Gold (Canada) gave the Gold-PM keynote address at this May's ALTA 2016 conference: *Selecting the Best Process for the Treatment of a Refractory Gold Ore - Barrick's Experience* (available from ALTA Free Library).

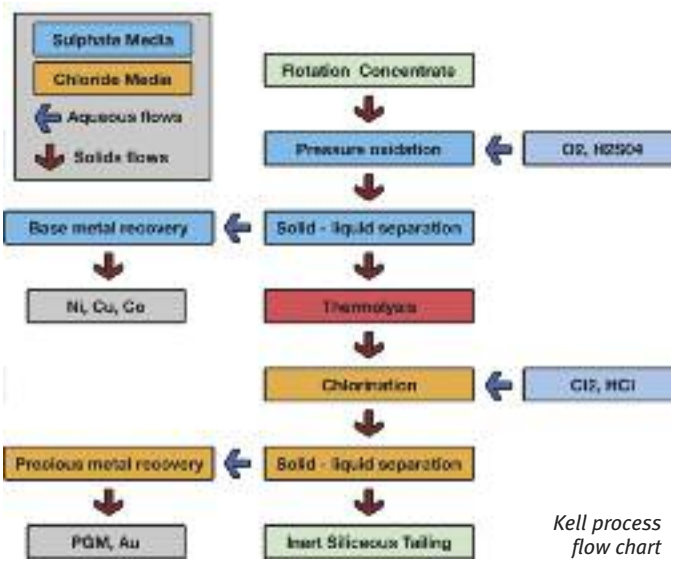
He emphasised that the choice of process, in most cases, will be site specific, influenced by the metallurgical and mineralogical characteristics of the ore and as well as capital and operating costs. He illustrated this using Barrick's Goldstrike operations where a number of processes have been applied including the newly developed thiosulphate leaching technology (see above).

Featured projects in the Gold-PM sessions included Goldstrike thiosulphate leaching project (USA), Syama Expansion (Mali), and CGT Gekko G-REX IX operation (Australia).

The Refractory Gold Ores Forum and Panel discussion included presentations on comparison of pretreatment methods, ore characterisation, additives to inhibit preg-robbing, autogenous thiosulphate generation and leaching, glycine-cyanide leaching synergies, behaviour of arsenic, and role of polythionates on stability of gold in thosulphate leaching. Other topics included project development, small scale mining, processing of high clay ores, agitators for abrasive ores, gold IX, glycine leaching of e-waste, process control, modelling and optimisation, and alternatives to cyanide leaching.

## KellGold

The cyanide-free, low-emissions KellGold process is capable of high recoveries of gold, silver, base and rare metals from a range of refractory concentrates and other materials considered to be problematic, intractable or otherwise poorly responding to many conventional treatment routes. The process was developed for the extraction of platinum group metals (PGMs) and base metals from sulphidic flotation concentrates. It has been successfully tested at batch and continuous pilot scale on various flotation concentrates, including those from the UG2 chromitite horizon, Merensky reef, the Platreef mafic/ultramafic layer and various polymetallic ores. It has been shown to consistently provide high (typically ⋯›95%) and selective extraction efficiencies for key valuable metals, e.g. Pt, Pd, Rh, Au, Ni, Co, and Cu and has been subjected to several engineering studies all showing favourable project economics. Pallinghurst Resources is assessing potential construction of a full-scale Kell plant to extract base metals and PGMs at its Sedibelo Platinum Mines subsidiary.




*Kell process flow chart*

The KellGold process consists of several commercially proven unit operations and utilises know-how gained from the processing of PGM concentrates. The process has been applied successfully to refractory gold and copper-gold concentrates and other gold-bearing materials such as calcine-leach tailings where cyanidation recoveries are low. Reagent consumers and valuable byproducts such as S, Cu, Ni and Co are first selectively removed by use of a pressure oxidation step during which the dissolution of precious metals is minimised. High recoveries of gold and silver are achieved by subsequent chlorination, with typically low reagent consumptions due to prior removal of reagent consumers and the use of efficient lixiviant recycling. The core steps within KellGold are similar to well-proven conventional unit operations in common use elsewhere, as are the subsequent metal recovery steps to provide marketable high-purity primary and secondary end products such as refined metal sponges, bars or coins. In this way, third-party smelting, treatment, transportation and refining costs are removed from the value chain, with saleable metals being produced on the mine site. Residues have similar characteristics to flotation tailings and may be co-disposed. A Kell plant can be constructed close to the mine site, removing the often costly transportation and wharfage costs for shipping concentrate.

The process generally consumes significantly less energy, less electricity, and requires lower capital and operating costs than the equivalent conventional smelting and refining facilities for the same duty. Unlike conventional smelters or bioleaching plants, for example, which lock up considerable gold and other precious metals in circuit, the Kell process locks up substantially less metal inventory and hence, releases significant working capital early in the project, sometimes enough to pay for most of the plant capital costs.

The costs of cyanide detoxification and management are avoided, as are the risks associated with cyanide transportation and potential spill events. No toxic gases or acids are emitted.

Laboratory test work and engineering investigations have shown that some 10 samples of refractory gold-bearing materials all responded well to KellGold and poorly to cyanidation, suggesting that the cyanide-free KellGold process could potentially unlock the value from conventional refractory concentrates, double refractory carbonaceous concentrates, calcine tailings dumps and copper-gold concentrates, inclusive of highly arsenical and antimonial cases. The process could potentially provide an alternative to concentrate treatment at a copper smelter, avoiding transport, treatment and refining charges as well as comparatively low Net Smelter Return (NSR) payments (70-80% of metal value).

Mike Adams, Process Consultant (Kell Process) and author of the new Elsevier book *Gold Ore Processing: Project Development and Operations, 2nd Edition* says "the high metal recoveries, along with the elimination of both cyanide usage and toxic gaseous emissions, warrants the serious consideration of the KellGold process in any refractory gold, copper-gold or polymetallic project or operation. The process may represent the next step change towards clean processing of refractory and polymetallic gold concentrates."

## Gold and water

Water plays a key role in many of the processes to recover gold. It is also a valuable resource that must be used and re-used efficiently. **Kemira's** line of mining products combined with its application expertise can help. Kemira offers a broad range of chemistries that are widely used in the processing of all types of gold ores. Kemira says its "expertise in water quality and quantity management enables us to add value to these

water-intensive processes."

One example of this is an extensive line of scale-control products. Scale build-up, for instance in the heap leach distribution system, is often an unseen problem that can block pipework and nozzles, causing significant decreases in productivity if they are not managed properly. Kemira's wide range of KemGuard® chemistries can help prevent this scaling problem. The KemGuard 5000m series offers a unique polycarboxylate chemistry that is highly effective at controlling calcium sulphate and calcium carbonate under a wide range of pH conditions. These inhibitors include very effective dispersants and crystal nucleation retarders, proven effective in gold operations in high pH/cyanide conditions.

Proper solid-liquid separation is a key to increased production rates, and here Kemira suggests Superfloc® flocculants. It reports: "Superfloc products have been effective in water-intensive gold mining applications for many years. Flocculants are commonly used in both flotation and leaching operations for pre- and post-leach thickening, counter current decantation (CCD), paste and tails thickening duties. Kemira offers a full range of anionic, nonionic, and cationic products to ensure the correct product charge both with and without lime addition. Additionally the Superfloc portfolio, featuring a wide range of molecular weights, is ideal for high-rate, ultra-high rate and paste thickeners. The high molecular weight cationic flocculants are ideally suited for Biox CCD circuits."

Along with the Superfloc products, Kemira is a major manufacturer of both organic and inorganic coagulants. These are particularly relevant in gold-processing for waste water clarification as well as arsenic-, selenium- and heavy metals-removal processes.

Kemira offers an even broader array of solutions to improve customers' processes including defoamers to control foam in concentrate thickeners and BIOX leach tanks. In Europe and Africa, Kemira supplies hydrogen peroxide used to manage the oxidation potential within CIL/CIP circuits and for cyanide destruction circuits. Kemira is a major producer of $H_2O_2$ in Europe with plants in Finland, Sweden, and the Netherlands. The product can be supplied as 60% or 70% solution. ***IM***