Mining3 (Australia) is leading a transformational initiative called ‘In Place’ mining, that involves both innovative mining and processing techniques. Mining3 reports that “traditional In Situ Leaching (ISL) or In Situ Recovery (ISR) is well known as an established low-cost method for commodity extraction that does not depend on rock movement. The ore is processed in situ. It is used extensively in the uranium sector and for extraction of water soluble salts (for example potash) where favourable, generally sedimentary hosted deposits allow it. The economics in such instances are attractive. The circumstances do not depend on energy but rather metal recovery where the right geology, geometallurgy and permeability, in particular, are key parameters.

“However, for ISR, there are of course noted social/environmental barriers and concerns relating to conventional acid and cyanide lixiviants and their potential toxicity issues in ISL. Likewise, fracking is a concern often referenced in debates about ISL. Many of these concerns will be overcome but remain a challenge in the short to medium term in applying this more broadly to ore deposits.

“A key enabler for ISR is the development of new lixiviants. In particular, the glycine technology developed by the gold technology group at Curtin University (now being marketed by MPS) is a game changer. It is a non-toxic, non-volatile reagent. When placed in an alkaline environment, it is selective in its ability to leach base and precious metals without taking gangue minerals of iron and manganese into the solution. It is also reusable provided it is kept in a closed system. As it operates in an alkaline environment, there are no corrosion issues such as can be seen with acid systems. The opportunities to use this technology in saturated (ISR) or unsaturated conditions (IMR) represent a very exciting opportunity.”

Very recently, Gindalbie Metals executed two separate non-exclusive licence agreements with Mining & Process Solutions Pty Ltd (MPS) for the use of the innovative GlyLeach™ mineral processing technology. This is an alkaline based process that will leach copper from copper oxide, mixed oxide and supergene sulphide ores, and primary copper sulphide ores. It will also leach gold when the temperature of the Glycine is raised to 60°C.

The first licence, executed together with Terrace Mining, is a territory specific licence for the use of the technology at the Mount Gunson copper-cobalt project in South Australia. GlyLeach is one of a number of potential process solutions currently being evaluated for the processing of ores from Mt Gunson. Gindalbie and Terrace are currently working together with MPS to evaluate the potential application of glycine technology to the project during an ongoing scoping study and feasibility work.

Gindalbie has also executed a global licence (excluding China and Zimbabwe) for the use of the technology on primary gold, copper and zinc projects. This licence provides Gindalbie with the right to use the technology on new projects that may be identified during ongoing business development and strategy work. Gindalbie will work with MPS to identify deposits on a global scale that are amenable to the application of the glycine technology, especially where this application is likely to result in near-term revenue flows.

Under the agreement, MPS will receive a
royalty for the use of the technology based on an NSR from future revenue flows of projects where the technology is applied. As an early adopter of the technology, Gindalbie has secured a significant discount to standard market royalty rates. Any other fees paid to MPS will be based on a standard schedule of rates for test work.

Gindalbie Chief Executive Officer Chris Stevens said that the agreement provides “a fantastic option to use this innovative Australian developed processing technology at Mt Gunson as well as globally in other potential Gindalbie projects. We are delighted to be working with MPS who not only bring their GlyLeach technology but also a wealth of knowledge and expertise in the field of mining and mineral processing.”

MPS Managing Director, Ivor Bryan commented: “MPS has had a long association with the Mt Gunson project and is delighted that Gindalbie is coming on board to help fund and progress the feasibility of the project.”

The GlyLeach process was invented by Professor Jacques Eksteen and Dr Elsayed Oraby, from Curtin University’s Western Australian School of Mines. Curtin has awarded MPS an exclusive global licence to the process. According to Eksteen, the process has a number of immediate applications including leaching of low grade ores, differentially leaching copper and gold ores, upgrading concentrates, and tailings retreatment.

The major reagent in the process is glycine which is the simplest and cheapest of the amino acids, and is available in bulk ranging from food to technical grade. It has a number of attractive chemical and physical properties that gives it significant advantages over any other copper or gold lixiviant:

- Environmentally safe and stable reagent
- Biodegradable and easily metabolised in most living organisms
- Active as a selective leach agent only when used in an alkaline based circuit between pH 8 and 12
- Step change in copper leaching with enhanced solubility of copper ions in aqueous solutions and forms stable complexes with copper
- Effective leaching agent for almost all copper minerals except chrysocolla - a copper silicate mineral
- Easily recovered and recycled (apart from normal process losses expected at less than 5%); keeping operating costs low.

MPS Technical Director, Frank Trask stated that GlyLeach is a simple process requiring no new equipment to be designed, has low operating costs due to regeneration of the principal reagents, and is expected to provide high recoveries with almost all copper minerals even chalcopyrite (long considered the ‘Holy Grail’ of copper leaching). It will also offer the gold industry a non-toxic method of leaching gold, something that is becoming more important in many jurisdictions around the world.

MPS has also entered into an agreement with Curtin and a major ASX listed mining company to support a collaborative project to research specific aspects of glycine leaching of gold dominated polymetallic ores. This will be a three-year, A$800,000 program. Curtin University (Gold Technology Group, WASM) will be the Chief Investigating Partner with MPS being a sponsor and collaborative partner.

**Rapid Oxidative Leach (ROL)**

As gold deposits become increasingly complex to treat and grades continue to deteriorate in known reserves, treatment solutions for refractory ores gain in importance. Some 15-20% of current world gold production involves refractory ores that must be pre-treated prior to downstream recovery by cyanidation.

Ores are refractory for many reasons but commonly because gold occurs as tiny inclusions or submicroscopic gold within a sulphide mineral matrix. This mineral matrix must be physically and chemically altered to liberate the gold for subsequent leaching.

Mike Woloschuk, FLSmidth’s global Industry Director for gold says there are many undeveloped gold deposits where the resource head grade is simply too low to be economically viable using current refractory processing technologies. “The industry needs a step change in technology that will significantly reduce processing cost, thereby lowering cut off grades for refractory resources. We believe ROL for gold has this potential.”

FLSmidth is pioneering Rapid Oxidative Leach (ROL), which is a mechano-chemical pre-treatment process for refractory gold ores. Sally Rocks, senior R&D chemist believes her team has made an extraordinary breakthrough which will have a profound effect on the industry. "We have discovered an economically viable method to process low-grade stockpiles and low-grade refractory gold deposits."

"Initially, we are targeting refractory gold-bearing iron sulphides where the gold is locked inside the sulphide mineral matrix and cannot be recovered without pre-treatment."

Unlike other refractory processing techniques that require ultrafine grinding or high temperatures and pressures, the FLSmidth ROL gold process uses the application of mechanical energy coupled with oxidation under atmospheric conditions.

The process relies on Stirred Media Reactors (SMRT) to accelerate the oxidation of sulphide minerals. “Other technologies have relied on ultrafine grinding to increase the surface area of the particles. While ultrafine grinding is sometimes effective, it also requires a lot of energy and thus incurs a very high cost. We have successfully engineered a new low-energy process without having to ultrafine grind,” she explains.

In the ROL process, the abrasion of the particle surfaces which occurs when the SMRT is activated is balanced to match the leach rate of the particles. Rocks notes: “Judicious use of mechanical energy allows us to accomplish chemical reaction rates that are otherwise impossible without the use of high temperatures or pressures. The end result is a process that uses simple equipment and low-cost operating conditions for refractory gold pre-treatment.”

At present, the main refractory gold processing methods include ultrafine grinding, pressure oxidation (POX), roasting, or bioleaching.

Pressure oxidation, roasting and bioleaching have been successful in oxidising refractory sulphide minerals to expose gold in solid solution that cannot be recovered by ultra-fine grinding alone.
However, POX and roasting have high capital intensity due to the extreme operating temperatures and pressures, exotic materials of construction and the ancillary equipment required to provide reagents and environmental controls.

Bioleaching operates at low slurry density and has comparatively longer residence time, often several days, which inflates the size of the leaching circuit. Bio-oxidation is also very sensitive to cyanide and thiocyanate as they are toxic to bacteria, so it is necessary to keep the pretreatment and cyanidation systems separate.

Pressure oxidation and roasting have high processing costs. Although processing costs can vary widely depending on power and reagent consumptions associated with sulphide oxidation, recent industry information indicates POX ranges between $50 and $65/t and roasting about $25-35/t. Woloschuk states that processing costs are typically the highest component of plant operating costs for refractory deposits. This means that at a gold price of $1,250/oz, these current methods need 0.6-1.6 g/t Au just to cover processing costs. Many miners are faced with the dilemma that their refractory gold deposits are either too small to justify the capital outlay for current refractory processing technologies, or too low grade to cover the operational costs, or both.

FLSmidth is working closely together with miners to unlock value, develop more productive operations, improve energy efficiency, reduce consumables consumptions, and lower operating costs, Woloschuk says. “The industry continues to focus on increasing margins through optimisation initiatives, and the ROL pretreatment is a technology we believe has the potential to unlock significant value in the gold space. When you couple low operating cost with low capital intensity, it has significant impact on the asset Net Present Value (NPV),” he explains.

“Due to the high capital intensity and high processing costs of current refractory processing methods, only assets with long mine life and high grades are achieving investment hurdles. There are a lot of undeveloped refractory gold deposits that have less than 3 g/t gold head grade, and some are coupled with small resources which translates into short mine lives. Currently those assets have little to no value as greenfield deposits and they need a step change in technology to unlock value,” he concludes.

Industry data on known refractory gold deposits show that the amount of gold contained in refractory Measured and Indicated (M&I) resources is approximately double the contained gold in refractory gold reserves. Woloschuk says, some portion of those M&I resources did not meet cut-off grade using current processing methods. These are deposits that are sufficiently drilled and some portion of the M&I resources would convert to economically mineable reserves at a lower cut-off grade.

Large deposits are becoming increasingly scarce. Since 2012, there have been less than 10 major gold deposits discovered globally. Looking at the five years prior to 2012, there were nearly four times as many major discoveries. While not all of these discoveries where refractory this is an indication that there isn't the abundance of large gold deposits left, so the industry needs to find ways to treat smaller deposits going forward.

The ROL process is not merely applicable to new deposits. According to Woloschuk, there could be significant benefits to existing operations as well: “Many existing refractory operations have low grade stockpiles that are waiting to be processed at the end of the mine life. If you add ROL pretreatment to an existing operation, it could become viable to process low grade stockpiles earlier, rather than processing them at the end of the mine life. By reducing the cut-off grade, you can move those ounces forward to generate cash flow earlier and this will increase the asset NPV.”

FLSmith’s ROL technology could be a game-changer for the gold industry displacing current refractory processing methods, Woloschuk says. “When we have proven this technology successful, miners will be looking at a completely different life of mine plan; by lowering the cut-off grade, more ore will be converted into reserves, extending mine life.”

Refining Albion

The Albion Process™ is a combination of ultrafine grinding and oxidative leaching at atmospheric pressure. The feed is base or precious metal concentrates. The sulphides in the feed are oxidised and liberated, allowing the wanted metals to be recovered by conventional means.

GT’s HyperSparge is a proven and cost effective system for delivering air, oxygen or other process gases into tanks or vessels for leaching or oxidation processes. It is a gas sparging technology that uses an alloy steel injection lance fitted with a hard wearing ceramic nozzle to inject a concentrated supersonic jet of gas into the process solution or slurry. The supersonic gas jet enters the process stream at velocities in excess of 400 m/s, creating a region of very high local shear, resulting in very efficient mass transfer.
Increased bubble/particle collision rates and decreased buoyancy restrictions.

Decreased bubble/particle sliding time.

Oxygen mass transfer and oxygen utilisation.

A novel fluidised-bed flotation system has been developed from the laboratory to the industrial scale at the GPM Albion Process plant which achieves greater than design performance in terms of oxygen mass transfer system. It then examines plant survey data from the GPM project to demonstrate the very high oxygen utilisation that can be achieved with a correctly designed oxygen mass transfer system.

The authors conclude that: “Oxygen injection using convergent-divergent nozzles generate superior thrust and oxygen mass transfer compared to other gas injection techniques. Power delivered to the system is more efficient through gas injection rather than mechanical agitation. The HyperSparge is a development of the convergent-divergent nozzle and offers additional advantages over other sparging techniques contributing to a safer work environment, maximising process run-time and optimising energy input through the agitator. GT successfully scaled up the oxygen mass transfer system from the laboratory to the industrial scale at the GPM Albion Process plant which achieves greater than design performance in terms of oxygen mass transfer and oxygen utilisation.”

And optimising flotation

Conventional flotation machines are typically limited to a particle size of 150-200 µm due to inherent constraints created by the pulp and froth phases. To overcome these limitations, a novel fluidised-bed flotation system has been developed by Eriez – the HydroFloat™ Separator.

Its specific purpose is to float coarse particles containing only small amounts of exposed hydrophobic minerals. Over the last decade, this technology has been successfully applied to industrial minerals with several full-scale units installed to recover particles up to and exceeding 3,000 µm in diameter.

More recently, sulphide-based test work has shown that this novel device is also capable of recovering metalliferous values at a grind size that is much coarser than currently used in industrial concentrators, according to J D Miller et al in the IMPC paper Significance of Exposed Grain Surface Area in Coarse Particle Flotation of Low-Grade Gold Ore with the HydroFloat™ Technology, Quebec City, September 2016. Mike Mankosa, Eriez Executive Vice President of Global Technology, was a co-author.

“"In the current study, high resolution X-ray microtomography (HRXMT) was used to experimentally compare the degree of exposed grain surface area necessary to recover coarse particles using the HydroFloat technology to that attainable using a traditional mechanical flotation cell. The data indicate that exposed grain surface area is a critical factor for coarse particle flotation. For the gold-bearing sulphide ore examined in this study, the HRXMT data suggest that near complete recoveries of coarse (850×500 nanometre) multiphase particles containing as little as 1% exposed grain surface area were realistically attainable using HydroFloat. As such, this new technology may offer a unique opportunity for increasing concentrator capacity by increasing the primary grind size needed for rougher/scavenger separations.”

The HydroFloat Separator is an aerated fluidised-bed (or teeter-bed) separator. The synergistic effect of combining flotation with gravity concentration results in an outcome that cannot be achieved by either approach alone, says Eriez.

“Air bubbles are dispersed by the fluidisation system, percolate through the hindered-setting zone and attach to the hydrophobic component altering its density and rendering it sufficiently buoyant to float and be recovered. The use of the dense phase, fluidised bed eliminates axial mixing, increases coarse particle residence time and improves the flotation rate through enhanced bubble-particle interactions. As a result, the rate of recovery is high for both fully-liberated and semi-liberated particles.

"HydroFloat separators improve coarse particle recovery through:

- Increased bubble/particle collision rates
- Increased bubble/particle sliding time
- Increased residence time
- Decreased mixing
- Decreased turbulence and detachment
- Decreased buoyancy restrictions.

As we know, froth flotation selectively separates hydrophobic materials from hydrophilic materials. Air bubbles can only stick to the desired mineral particles if they can displace water from the mineral surface, and can only continue to support the mineral particles at the surface if they can form a stable froth achieved by using flotation reagents.

“As the characteristics of froth can vary from day to day, a thorough understanding of froth transfer applications is critical when designing and selecting froth pumps. Insufficient froth volume factor (FVF) knowledge can often contribute to incorrect froth pump selections and hopper designs,” states Warren Taylor, Product Specialist at Weir Minerals.

Pumping mineral froths using standard slurry pumps often leads to problems for operators, especially when treating mixed ores. Furthermore, froths can easily vary from brittle froth - generally large bubbles that are easily broken down, to very tenacious froth - generally fine, tightly bound air bubbles that remain in a froth state for many hours.

In high FVF conditions such as medium to tenacious froths, air separation from the liquid contributes to air-binding within the eye of the impeller. This may create the expectation of cavititation, but rather than the collapse of vapour pockets, the entrained air bubbles rapidly expand in areas of low pressure within the pump impeller.
Weir Minerals' Warman® advanced centrifugal froth pump with Continuous Air Removal System (CARS)

to decrease both head and efficiency, causing air-binding.

As a result, poor froth pumping performance normally leads to overflowing hoppers and the loss of valuable concentrate.

As flotation performance is greatly influenced through the on-going development of new and improved reagents, companies producing mining chemicals are continually striving to develop “super performing chemicals”. Collectors are being developed to further increase the separability of the hydrophobic and hydrophilic particles, while froth advancements aim to create more stable froths to increase flotation kinetics and allow for improved drainage of entrapped gangue material.

To meet the demands of flotation plants that exhibit complex and tenacious froth conditions, Weir Minerals has developed the heavy duty Warman® AHFC froth pump with Continuous Air Removal System (CARS) technology.

“Our Warman AHFC froth pump technology is purposely designed for flotation processes that produce medium froths, and very tough froth concentrate transfer applications that produce long lasting, tenacious froth conditions,” states Taylor.

The pump has open inducer vanes that protrude into the large intake throat area, designed to create a strong swirling air core, while drawing the froth air bubbles into the impeller-eye. This process separates the valuable concentrate from the tenacious froth bubbles. Weir Minerals’ CARS technology is then able to expel a vast amount of air into the atmosphere, enabling more efficient froth concentrate pumping.

“Our enhanced froth pump technology, CARS, is expertly designed for heavy duty slurry froth pumps and is successfully operating in a number of Gold plants around the world,” says Taylor.

To support optimum froth pump performance, froth hopper design and geometry is absolutely critical.

“Every one of our froth hoppers is uniquely designed to suit both the application and the chosen Warman AHFC froth pump. Froth hoppers must be designed to enhance the efficiency of the froth transfer system by reducing ‘froth generation’ turbulence inside the hopper, while ensuring that the froth slurry concentrate is effortlessly induced into the AHFC inlet,” explains Taylor.

As some degree of flotation plant instability is always to be expected, especially during plant start-up, it is likely that under extreme, adverse conditions the froth hopper may overflow. Anticipating this instability, Weir Minerals has innovatively designed large overflow launders with a large down-pipe feeding directly into the spillage handling system to minimise the loss of valuable froth concentrate.

“Successful froth concentrate transfer projects are only achievable through detailed process plant reviews, involving a team of process engineers and froth pump application engineering consultants. We always partner with our customers to deliver an autonomous flotation process,” Taylor concludes.

Solvay continues to develop collectors designed for the flotation recovery of precious and base metals from primary and secondary ores. This family of collectors is based on the novel chemistry, MAXGOLD™. This chemistry is offered under the name AERO® MAXGOLD 900 promoter and mineral-specific formulations. The AERO MX-900 promoter series, developed using FLotation MATRIX 100™ is for flotation recovery of gold values from primary gold ores (free gold, auriferous pyrite, auriferous arsenopyrite and other gold-bearing sulfides) and copper-gold ores.

MAXGOLD chemistry is a sustainable alternative to the traditionally used sulphide collectors such as xanthates. One of the major benefits of MAXGOLD chemistry is that they are highly concentrated liquids, which afford greater flexibility and lower dosages.

**Aachen reactor versatility**

One of the problems many gold operations face is how to manage the transition from oxide material to more refractory sulphide material. As the orebody changes from free milling oxide through transitional material to full sulphide, recovery levels begin to drop. The drop off in recovery is often associated with reduced oxygen levels. Whilst a lance system may be adequate for a low oxygen demand free milling orebody it cannot address the higher oxygen demand and other process issues such as passivation which are associated with more aggressive orebodies.

This problem can be solved through the flexibility of the Aachen reactors whereby initially when oxide material is treated only a light pre-oxidation and downstream oxygen boost would be applied but then as the material becomes more refractory the oxygen levels can be increased through a combination of an increased throughput through the reactors combined with additional reactors. Assuming the ore is amenable to flotation then Imhoflot flotation could be introduced due to its improved cost/performance benefits over conventional tank flotation to produce a flotation concentrate which would then be subjected to ultra-fine grinding as the circuit migrates into the Leachox process. As the ore becomes increasingly refractory then a fully oxidative process such as pressure oxidation can be pursued.

The above approach allows for a phased capital approach and minimises upfront capital expenditure allowing the operation to generate revenue and reduce risk as process problems can be rectified without major capital investment.

The ‘secret’ to the Aachen shear reactor’s success is the high amount of shear generated within the reactor which in addition to the high oxygen levels generated removes passivating films which can otherwise stall the leach reaction. The shear at the mineral surface thins the boundary layer of the bulk solution enhancing kinetics. Importantly unlike a lance system or partially mixed reactor the Aachen reactor is designed so that all of the slurry passes through the Aachen reactor at least once so that every slurry particle is exposed to a combination of high shear and very high dissolved oxygen level.

Maelgwyn Mineral Services (MMS) has significantly increased the number of installations of its Aachen shear reactors and...
also extended the range of applications beyond its well-known Leachox process for refractory gold processing.

The Aachen shear reactor is essentially a highly efficient mass transfer device developed and refined over many years out of experience with Maelgwyn’s Imhoflot flotation technology. The versatility of the reactor is evident by the ever-growing list of different process applications. These include:

- Mild pre-oxygenation to reduce cyanide consumption through oxidation of cyanide consuming species combined with efficient oxygen utilisation
- Aachen assisted leaching (AAL). As a highly efficient mass transfer device and also a shear reactor Aachen reactors are finding increasing applications within gold and silver leach circuits to accelerate leach kinetics, reduce cyanide consumption and reduce surface passivation
- Partial sulphide oxidation (typically up to 60-70%). This role is normally as part of the Leachox process and when combined with ultra-fine grinding can significantly increase gold recovery for refractory flotation concentrates through partial oxidation of the sulphide matrix
- For cyanide destruction by supplementing the INCO process when oxygen is rate determining
- Tailing treatment operations where kinetics are constrained due to high throughputs.

Currently there are over 40 Aachen reactors installed across various operations and processes but mainly installed in pre-oxidation and Aachen assisted leaching roles.

As every orebody is different the benefits vary from operation to operation depending upon how optimised the cyanidation circuit is but gold recovery benefits of up to 5% have been realised. The typical benefits include:

- Increase in gold recovery
- Enhanced kinetics
- Reduced cyanide consumption and reduced lime consumption
- Downstream benefits for carbon plants due to steeper leach profiles
- Improved oxygen utilisation
- Lower residual cyanide concentrations.

One Australian gold mine that already had an Aachen reactor on site for the cyanidation circuit was experiencing difficulties in floating copper and gold minerals after regrinding a pyrite rougher concentrate. The high oxygen consumption of fresh pyrite surfaces created during the regrind resulted in a low Eh and dissolved oxygen level. Following consultation with MMS it successfully trialled the leach Aachen to boost the DO level for this application with this installation now being made permanent.

The Aachen units can be manufactured in a range of sizes to suit the site-specific flow rate.
requirements up to a maximum flow of 1,200 m³/h for a single reactor and, enable efficient oxygen dispersion under high shear (velocities of up to 10 m/s within the unit) and pressure (3 bar) generated by the feed pump. Furthermore, the shear exposure reduces boundary layer resistances that influence most solid/liquid reaction rates. This can enhance the reaction kinetics tremendously and enable process options not feasible otherwise. Essentially all of the requirements of Elsner's equation governing gold leaching are met ensuring that rapid dissolution of gold can take place.

A more recent application of the Aachen reactors is within the well-known INCO cyanide destruction process. Often cyanide destruction is restricted due to oxygen being rate limiting. However, Aachen reactors are able to solve this through their very high oxygen transfer rates. A successful trial was conducted on a West African gold mine and this process is now being implemented on a plant in South Africa.

In conclusion, then in can be seen that whilst Aachens are now established technology they are continually finding new applications with further development work now being directed towards base metal leaching applications.

Cyanide-free gold

Approvals have been granted for implementation of a full-scale Kell hydrometallurgical processing plant at Sedibelo Platinum's Pilanesberg platinum mine in South Africa's North West province, and up to five Kell plants in Zimbabwe. By partnering with Sedibelo Platinum Mines, the South African Industrial Development Corp (IDC), and the Zimbabwe Mining Development Corp (ZMDC), industry and government buy-in to the Kell initiative is demonstrated. The lack of power capacity in these regions and high cost of establishing platinum smelters and refineries is taken care of by Kell, which uses less than a fifth of the electricity required for smelting at a fraction of the capital and operating costs, and refines the PGMs and gold on site to high-purity gold concentrate. The cyanide-free, low-emissions Kell Process is capable of high recoveries of gold, silver, base and rare metals from a range of feed materials, which are currently lost in smelting, are maximised. Other value elements such as cobalt, concentrate grade, chrome, MgO and other reagent consumptions due to prior removal 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.

Capital costs for a gold concentrate processing plant may be substantially reduced by co-location of a KellGold plant at the same site as a KellPGM plant, exploiting economies of scale, with shared common processing areas, reagents handling, administration, marketing and operational management.

A range of refractory gold, copper-gold and polymetallic concentrates have now undergone proof-of-concept laboratory amenability test work and preliminary engineering investigations. For example, in ~2 kg tests, refractory gold-copper-cobalt concentrate returned extractions of 96% Au, 98% Cu and 97% Co, while a refractory polymetallic concentrate returned extractions of 98% Au, 97% Ag, 99% Zn, 97% Pb, 99% Cu, and 95% Sb. Several specific applications are currently being assessed for pathways to implementation.

The Kell process has been described as a "game changer" and by removing concentrate transportation and wharfage costs for shipping concentrate.

The Kell 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, due to very fast reaction rates 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 well as applications in other sectors.
constraints could unlock more value from ores at lower costs in a process that is inherently environmentally responsible, being free from the use of cyanide and with no emission of sulphur dioxide to the atmosphere. Greenhouse gas emissions are also significantly lower than for conventional smelting and refining processes. Also, the process does not require expensive fine grinding or attrition reactor pretreatment to achieve high metal recoveries. The Kell process is an alternative to concentrate treatment at a smelter and warrants serious consideration in any primary PGM, refractory gold, copper-gold or polymetallic project or operation. The process has been termed the “next step change” towards the highly efficient and clean recovery of precious and base metals concentrates.

Dundee Sustainable Technologies (DST) has developed a chlorination process as an alternative to the conventional cyanidation process for the extraction of precious metals from ores or concentrates. DST says “the technology offers viable and efficient gold recoveries and the ability to handle refractory ores and contaminated material (As, Hg, etc.).” The process has been successfully demonstrated on hundreds of samples provided by various mines, exploration and development projects and has evolved from laboratory experiment to demonstration at an industrial scale.

A gold bearing pyrite concentrate was treated at the demonstration scale (15 t/d) for the extraction of gold using the process. The pyrite was depressed in the flotation circuit in order to promote the flotation of copper and to achieve a sufficient copper grade to meet the copper smelter criteria. However, the recoveries of copper were 80% and only about 50% for the gold was found in the copper concentrate. The balance of the gold (50%) and copper (20%) contained in the pyrite concentrate as a reject from an overall flotation circuit. The grade in the pyrite concentrate is 5.40 g/t Au and about 0.77% Cu. About 170 t of pyrite concentrate were processed in the DST demonstration plant. The concentrate was first oxidised using a fluid bed to produce a calcine. Copper was then extracted as copper sulphate using diluted sulphuric acid. The residual solid was submitted to the DST chlorination process for gold extraction. Thereafter, the gold was recovered from the pregnant brine by precipitation over silica using DST proprietary process. The maximum gold recovery by chlorination was 90%. The average gold recovery by cyanidation of these calcines was 71%.

Green Gold
Green Gold designs, develops and integrates technological innovations that maximise gold, silver, and cyanide recovery. Its products are commercially proven, economical, efficient and environmentally friendly.

The company offers three areas of expertise: The Recyn process for cyanide recovery and detox; the Gold Room for innovative gold and silver recovery solutions for carbon circuits; and a Non-Chemical System (NCS) process incorporating the new InCon centrifugal concentrator. Recyn is a specialist technology offered for the recovery of cyanide and dissolved metals from precious metal plant process streams. The process is based on the use of a functionalised resin bead, pre-treated to allow the dual duty of recovering free and complexed cyanide ions from solution with a high degree of efficiency. The GGT Treatment Plant is custom designed for each operation to match the various solution chemistries and throughputs. The two areas of cyanide recovery and metal detoxification are balanced to achieve the desired compliance levels. Equally applicable to slurries and solutions, Green Gold says “the process is technically and economically superior to all others currently available for the detoxification of gold plant tailings.”

Carbon-based flow sheets (Gold Room) include innovative processes that increase metal recovery and reduce operating costs.

NCS retrieves gold and silver that is otherwise lost in the tailings dam. It offers enhanced, back-end metal recovery using specialised sizing and gravity equipment designed and built by Green...
Gold. It is a natural extension to Recyn that can also be applied to mineral sands and alluvial projects.

There are three parts to the evaluation process for Recyn: free cyanide recovery, detoxification, and metal recovery:

**Cyanide recovery** is simply an economical consideration, although often it will overlap with detox requirements. The two commercial applications in Indonesia are based on free cyanide recovery; but they find this also satisfies detox requirements, resulting in substantial cost savings and recovery benefits. The capital cost is easily justified and usually results in payback in less than one year. Economics are more favourable for larger projects and higher cyanide levels.

**Detox** is a more complex evaluation because it involves detailed solution chemistry and compliance requirements. The same adsorption plant can be used for detox, but a metal recovery plant must be added. The evaluation generally splits into two areas, compliance for tailings dams and compliance for river discharge. Either level can be accommodated with the Recyn process. The cyanide code level of 50ppm CN WAD for discharge to tailings dams is easily achieved, usually just by free cyanide recovery. For river discharge, the levels are more country specific, but can easily be accommodated with the Recyn process, usually by including a metal recovery stage.

**Metal recovery** is required for the detox of tailings, but can be assessed on a stand-alone economic basis if there is no detox requirement. Recyn is used directly following the CIL circuit. Slurry flows through several stages of adsorption contactors. The resin stream is pumped counter-current to the slurry flow to maximise resin loadings and minimise tails values.

Loaded resin is transferred either as a batch or continuously to the elution section of the plant. Metal elution and cyanide elution occur in separate columns at ambient temperature. Stripped resin is returned to the final adsorption stage. The relative flows of loaded resin to the tailings solution cyanide and metal levels.

Metal recovery typically involves either EW to remove gold or precipitation to remove copper and other metals.

Cyanide recovery involves volatilisation and scrubbing to form a concentrated cyanide solution that can be returned directly to the leach circuit. The detoxified slurry is discharged to the tailings dam.

**MIPs**

6th Wave Innovation is a nanotechnology company focused on extraction and detection of target substances at the molecular level that says its products “provide significant advantages in cost and performance.”

“These advantages are derived from application of our patented technologies in the highly specialised field of molecularly imprinted polymers (MIPs).”

6th Wave now offers IXOS®, a line of extraction polymers for the gold industry. IXOS beads, it says, “are more selective, more efficient, have higher capacity, are less expensive to use, and more environmentally friendly than competitive solutions. 6th Wave has completed extensive testing in the laboratory and field trials with some of the world’s largest gold mining companies. ADR plant design using IXOS technology is similar to conventional ion-exchange resins, reducing switching costs.”

In the Alta 2017 paper *Molecularly Imprinted Polymers – Initial Field Trials at Kinross Bald Mountain Mine*, Glen Southard, Chief Scientific Officer, and co-authors explain “MIP beads that were imprinted for sequestration of dicyanoaurate were prepared by suspension polymerisation techniques. An imprint molecule, one capable of being chemically incorporated into a polymer, was prepared by chemical condensation of the desired molecule with a hard base ligand featuring a vinyl group. The imprint molecule was polymerised under suspension polymerisation conditions with styrene monomer and divinylbenzene as the cross-linking agent; to yield high quality beads about 600 to 850 µm in diameter. The purpose of the MIP is to provide highly selective and uniform adsorption sites on the polymer because they are keyed to both the charge complex and shape of the target molecule (in this case dicyanoaurate).

“The MIP beads were found to be mechanically strong and capable of undergoing numerous load, elution, and regeneration cycles without loss of performance or notable breakdown of the resin despite wide swings in pH or ionic strength. Gold loadings of up to 40 g/kg of beads or higher were realised with some formulations, without loss of mechanical strength.”

The bead formulations with the greatest degree of mechanical stability and capacity were chosen for the first IXOS field trial at Bald Mountain mine, located near Elko, Nevada. “Two formulations of IXOS resin were tested in two campaigns. In each campaign IXOS resin was loaded into a three column carousel pilot system and subjected to roughly the same temperature, humidity, and chemistry variables as found at the site.”

“The IXOS Au resin was to be fed with the
same pregnant leach solution (PLS) that was being provided to the activated carbon adsorption circuit, only at much smaller volumes. The gold content of the PLS and barren solutions were monitored daily to determine the beads gold uptake from the PLS. The resin columns were then returned to the 6th Wave Innovations laboratory in Salt Lake City for further analyses, which included elution conditions, capacity determination, and all metals uptake as measured by Inductively Coupled Plasma-Mass Spectroscopy (ICP-MS) and verified by Fire Assay Analysis (FAA).

“Results of the testing mimicked those of laboratory testing. IXOS resin outperformed carbon for selectivity of gold over other metals in the PLS, greater capacity for gold than the operating carbon system, and higher efficiency; virtually all of the gold in the PLS was adsorbed onto the resin, while the operating carbon system consistently failed to adsorb a significant percentage of gold.”

Ore sorting

Sensor-based automatic ore sorting technologies can efficiently remove waste and sub-marginal grade material from crushed and screened run of mine (ROM) ore, producing a coarse (typically 30mm) upgraded pre-concentrate at an early stage in the mineral processing circuit. This avoids additional energy intensive downstream processing of this rejected component of the ROM feed, leading to lower unit operating costs and reduced tailings disposal volumes.

Steinert’s published work on ore sorting has demonstrated quick payback periods and high potential for simple, economic concentration of low-grade stockpiles. For example, at Central Norseman Gold’s low-grade stockpile, the technique enabled low cost retreatment of gold grades at 0.66% g/t Au to produce an output stream at 1.5% g/t Au grade, with a mass reduction of 85%, providing a cost-effective means of extending resource life and adding value to existing operations.

Test work on bulk low grade gold ore stockpile samples from Norseman indicated high gold recoveries as well as high material rejection rates. A financial model, based on these results, evaluates grade sensitivity and identifies a minimum stockpile grade for adequate financial returns. The base case modelling estimates that the ex-stockpile grade (including the fines bypassed fraction) can be more than doubled through ore sorting and that treatment will be highly viable with strong cash flow generation at stockpile grades as low as 0.73 g/t Au. The modelling enables the company to benchmark ore sorting options against stockpile reclaim and screening operations currently employed.

The historic Norseman gold mining operation, some 200 km south of Kalgoorlie in Western Australia, has a production history dating back to 1894. It is located at the southern extent of the Norseman-Wiluna Greenstone Belt in the Eastern Goldfields Province of the Yilgarn Block. The underground mining operations have been primarily based on high grade narrow vein quartz reef mining, supplemented by some open cut mining of lower grade ores. It was recognised in 2014 as Australia’s longest continuously running gold mining operation with 120 years of operation and the extraction of an estimated 5.5 Moz of gold.

Norseman Gold has re-started limited operations including low grade reclaim mining and screening of dumps and stockpile following 10 months of trials at various locations. Ore is treated through the Phoenix mill, which is a conventional gold processing plant (primary crushing, SAG mill, ball mill, gravity separation and carbon in leach (CIL) gold recovery) with a nameplate capacity of 720,000 t/y.

With such a long history of narrow vein high grade underground mining, it is not surprising that in the vicinity of the various mining operations there are extensive surface stockpiles of what was considered, at the time of mining, sub-marginal low grade ore. These stockpiles would have been generated through underground development on-reef in sub marginal ground or from parcels of low grade ‘halo’ ore mined from the highly variable grade nuggety reef systems.

One of the major stockpiles comprises low grade run of mine (ROM) ore extracted from the Bullen, Ajax and St Pats underground mines. The Bullen mine was commenced in 1991 and is accessed via a decline. The Bullen low grade stockpile is situated approximately 2 Km from the Phoenix mill. It is estimated that the stockpile contains approximately 1.2-1.5 Mt of low grade ore. No systematic program of mining data review or sampling and assaying has been undertaken in order to determine an accurate estimate of the grade profile or an average grade of the Bullen low grade stockpile.

In the case of Bullen low grade stockpile samples obtained from Norseman Gold, initial evaluation confirmed that it was probable that either colour sorting (using the colour difference between the light coloured quartz reef and the darker gangue minerals) or XRT sorting (using the consistent atomic density differential between quartz reef and gangue minerals) would be most likely to achieve effective pre-concentration.

XRT was chosen as the preferred option for evaluation test work, due to the fact that in most applications it is a dry process. The sorter feed does not require washing or scrubbing to remove surface dust or other adherents due to the fact that the absorption signal used to sort individual rock particles is derived from the x-rays passing through the full thickness of the sample. In contrast to this, colour sorting will be affected by surface layers of dust or other materials and typically requires a wet scrubbing process prior to sorting to remove any interfering surface layer.

The above is taken from the paper Upgrading low-grade gold ore stockpiles by preconcentration using ore sorting – an assessment of the economic impact and viability by A. N. Parry and G. van Wyk, Mill Operators Conference 2016

In what it describes as “a huge quantum leap forward,” TOMRA Sorting Mining is now introducing a new multi-channel laser sorting machine which it says “is destined to set entirely new standards within the industry. Minerals

ROCKMORE
which could not be differentiated with existing technologies, such as colour-sorting, X-ray transmission or near-infrared sensors, can now be identified and separated. The new ore sorting technology (Lightsabers mineral processing) enables the user to define and apply a greater number of sorting criteria, and thus sort with much greater precision."

The laser identification technology consists of a multi-channel laser scanning system with high-resolution imaging, and cutting-edge colour and textural selectivity. Multiple material characteristics such as brightness, colour, size, shape and surface texture are processed simultaneously.

TOMRA’s patented multi-channel sorting technology measures reflection, absorption and fluorescence and uses the scattering effect of multiple lasers inside a detector unit. Typically, the focused laser beam, which is a monochromatic light source, hits a rock or mineral and is absorbed or reflected. When this laser beam hits a larger, translucent crystal – for example quartz – the laser beam enters the crystal and is reflected, refracted and scattered inside the crystal. The beam then returns as a blurry glow which is of relatively low intensity. Large translucent crystals will scatter more efficiently than smaller ones. This differentiated physical behaviour is captured in high-resolution by high-sensitivity tools inside the new sorting system.

“Analysing results from tests and practical trials at several installations, we have demonstrated that we can achieve higher recovery, better quality and more consistent sorting of quartz material with laser sorting than with other sensor technologies,” comments Ines Hartwig, Product Manager at TOMRA Sorting Mining. “But other segments could also benefit from this technology: Any application in which a crystalline structure helps to separate the valued material from the waste can also be targeted. So, possible applications could, for instance, include minerals such as gold, calcite, fluorite, rock salt, or talc to name just a few.”

Looking generally at gold, TOMRA explains that the available sensor technologies for particle sorting are not able to directly detect gold occurring at the typical fine grain size of most deposits, be they refractory or free milling. Therefore, the sensors are used to detect minerals associated with gold or alternatively characteristics of gangue or waste material. For example, gold is often associated with sulphides such as pyrite or arsenopyrite, which can be detected by XRT sensor technology. This sensor type is most often used on belt type particle sorters as shown below in Figure 1. Higher atomic weight atoms have higher X-Ray absorption and therefore can be identified by the system.

Gold is often also associated with quartz and in particular, concentrated in the contact zone of quartz veins. Quartz can be detected by the recently introduced laser sensors, which are most commonly used in the chute-type particle sorter. This is a multi-channel technology capable of measuring reflection, absorption, refraction, scattering and fluorescence in order to characterise the measured material. Multiple lasers are used on both sides of the particle stream as shown in Figure 2. In the case of quartz and other crystalline materials, the laser light enters the crystal and is reflected, refracted and scattered by the internal structure of the crystal. The crystal will then exhibit a low intensity glow over a wider area than the laser, which can be used to differentiate the crystalline minerals from opaque minerals that only reflect or absorb the laser light. Depending on the geometallurgy, gold can concentrate preferentially in certain size fractions. The minimum particle size for sensor-based particle sorting is in the range of 8-18 mm. Field experience indicates that preferential gold concentration in fines and small size fractions is more common, allowing some preconcentration by screening alone and contributing positively to the upgrade and recovery in a sorting plant, where the fines are combined with the sorter product before being fed to the concentrator.

Gold ores are typically amenable to particle sorting to some degree, often either with XRT or laser sensors or a combination of both. Experience with gold ores from across the globe shows that a two-step sorting flow sheet consisting of an XRT rougher and laser scavenger or laser rougher and XRT scavenger has optimised recovery for a number of deposits tested. The interpretation of these results is that even for quartz-type gold deposits, the gold can be associated with pyrites both within the quartz vein and outside (halo effect) as well as purely with the quartz, albeit often in lower concentration. Recovery of over 90% and mass removal of 30 - 60% has been regularly experienced with these two-step particle sorting flow sheets.

General Kinematics (GK) reports interest in its Two-Mass system from gold miners, and one Canadian company in particular. That gold mine was looking to partner with a vendor that could meet its standards for optimising its process and for a machine capable of handling increased production volume, with lower overall operating cost. It needed a unit that could sorting extracted material to a size of 22 mm and that could handle the high capacity abrasive material moving over the screen 24/7.

This customer was not familiar with GK but was intrigued by the Two-Mass system and its potential. The ability of the STM-SCREEN™ to...
respond to load surges and increase current capacity limits fit the processing requirements the mine was looking to achieve.

The vibrating STM-SCREEN proposed was designed with two polyurethane decks and a light misting function on the bottom deck for dust suppression. The polyurethane decks allowed rocks that traditionally were easily trapped to wriggle free and not clog the screen. The polyurethane is produced in tiles to allow for easy replacement of damaged segments without replacement of the entire screen section. “The Two-Mass system allows for the entire screen to handle seven times as much force and capacity as competitive brute force machines,” GK reports.

“The increased capacity for the Two-Mass system and the durability of the polyurethane screen will be able to run the high capacity and abrasive material with ease and offered a better screening process that yielded increased product quality and consistency.”

Gravity enhancements

Gold miners around the world have had to deal with gold recovery and loss issues for hundreds of years. Unfortunately technology has not kept up with the times for gold miners, according to GoldHog®. “It’s a small industry with little room for technology development and research. This ‘gold loss issue’ often leads to thousands of dollars of placer gold being lost in the waste (tailings) of the miners, especially when it comes to ultra-fine gold.”

GoldHog believes it has finally developed a cure for many gold losses. For over six years the team has been developing and selling new innovative gold recovery mattings for both gold prospectors and miners alike. It now sells in 25 countries and along with the mattings has also developed high efficiency gold recovery equipment. Now the company has introduced a new patent pending gold sluice matting, which it believes will save commercial gold operations from many of these losses.

‘Doc’, the founder and CEO, addressed the issues. “The biggest gold loss factor we see in commercial gold mining ops is from slurry viscosity issues. Once a plant is running their slurry becomes quiet thick. A thick slurry has a great deal of energy. If you have any turbulence, whatsoever, in a sluice, that creates a strong scrubbing action which will scour out the fine gold. Our new Motherlode Mat™ offers aggressive capture and exchange, but with very little turbulence. Hence it helps to eliminate this common loss issue.”

GoldHog says that by reducing the turbulence in the sluice most operations can increase their capture rates greatly, especially on fine gold. The company works with commercial gold miners around the world and this issue is present everywhere, but is extensive in places like Africa and South America where silts and clays create a heavy mud. In these areas traditional sluices can lose up to 70% of the fine gold, which has been measured. “We have seen massive losses of fine gold in commercial ops running thick slurries and they usually don’t have a choice. Either it’s the material or limited water supplies that have to be recirculated. Either way this new mat is a dream come true for them. Smooth running, little turbulence, and great capture rates.”