ABSTRACT

A Focus on Gravity and Flotation Concentration and Intensive Leaching Rewrites Conventional Milling Circuit Design and Improves Environmental and Cost Outcomes

Authors: Gray, S., Hughes, T.

Upward pressure on all mining operations is coming from the triple bottom line. To some extent this is being offset by the rise in mineral prices but this may or may not continue. The other serious issue facing all companies is the replacement of economic reserves as exploration levels over the past decade continued to decline in line with falling mineral prices. In order to underpin the sustainability of the mining industry it is necessary to continue to reduce cost, reduce the mine environmental footprint whilst increasing community benefit. At the same time it is imperative that we increase the economic reserves. The highest risk is in adding new mineral discoveries as the strike rate for economic discovery decreases. Gekko Systems Pty Ltd recognises that the most simple and risk averse route to increasing economic reserves is to reduce cut-off grade in the mine thereby bringing formerly uneconomic reserves into the economic category. We have been developing a new process flowsheet which embodies the triple bottom line and the issue of economic replacement of reserves. This paper describes this flowsheet and presents three examples where this concept is/can be applied to bring about triple bottom line benefits. Sustainability can only be assured if we are the ones in control of our environment, costs and reserves.

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ABSTRACT

Upward pressure on all mining operations is coming from the triple bottom line. To some extent this is being offset by the rise in mineral prices but this may or may not continue. The other serious issue facing all companies is the replacement of economic reserves as exploration levels over the past decade continued to decline in line with falling mineral prices. In order to underpin the sustainability of the mining industry it is necessary to continue to reduce cost, reduce the mine environmental footprint whilst increasing community benefit. At the same time it is imperative that we increase the economic reserves. The highest risk is in adding new mineral discoveries as the strike rate for economic discovery decreases. Gekko Systems Pty Ltd recognises that the most simple and risk averse route to increasing economic reserves is to reduce cut-off grade in the mine thereby bringing formerly uneconomic reserves into the economic category. We have been developing a new process flowsheet which embodies the triple bottom line and the issue of economic replacement of reserves. This paper describes this flowsheet and presents three examples where this concept is/can be applied to bring about triple bottom line benefits. Sustainability can only be assured if we are the ones in control of our environment, costs and reserves.

INTRODUCTION

The Challenge " TO REDUCE CAPITAL & OPERATING COST WHILST REDUCING THE ENVIRONMENTAL FOOTPRINT" Often a more "Green" approach is seen as being less cost effective as a trade off is made in order to sponsor the best environmental outcome. At Gekko Systems Pty Ltd (Gekko) we believe we have combined Green and Cost Effective into one package.

If we are to change the way we process gold and silver ores by making a step change in technology whilst keeping control of the outcomes then we have to start with simple steps. It is possible to make a paradigm shift by re-arranging known technology to take advantage of the characteristics of the ore body. At this point it may appear that it has been done before however the key is the reliance on the coarse gravity recovery at a fine crush size to remove coarse liberated sulphides and heavies prior to any grinding. Also if possible these concentrates can be leached at their coarse size for high recovery of valuable metal.

Gekko has developed an integrated system which relies on the symbiotic relationships between comminution and recovery as well as a very important relationship between coarse and fine recovery. This coupled with the ability to achieve very high leach efficiencies on relatively coarse concentrates allows for the most flexible process circuit. We call it GFIL (Gravity, Float, Intensive Leach).

The importance of combining all systems is born out in the results. In order to reduce downstream operating cost it is important to work back from the final operating and closure costs. Issues with tailings containment facilities include cyanide and sulphides content and the size distribution. Typically cyanide as well as potential acid generating sulphides in the main tailings facility creates permitting and closure issues. If one could remove both cyanide and the majority of the sulphides from the tailings storage and backfill operation, it could be expected that permitting and closure costs and timing are significantly reduced. This flowsheet focuses on achieving all these targets.

A major outcome from the exploration of this system is the ability to produce a compact process plant which is capable of being deployed in an underground environment as a pre-concentrator prior to ore being transported to surface with the backfill being coarse in nature and kept close to the working face of the mine. This allows for a greatly reduced process plant on surface and a greater ability to transport concentrate to a more environmentally secure location than may be offered at the mine site. The de-coupling of the mine and the process plant by producing a higher grade ore stream allows for greater flexibilities in process options.

Dependence on the crush

In order to achieve optimised recovery of mineral it is important to ensure overgrinding does not occur. Therefore it is important to recover liberated mineral from the grinding circuit as soon as possible. This has been recognised for a long time and the "Flash Flotation Cell" (FFC) was developed. Although FFC does recover precious metals and sulphides from the grinding circuit it is still limited by its lack of ability to lift coarse mineral >150 um (Bourke). Using a high mass pull gravity recovery device such as the inline Pressure Jig (IPJ) in combination with a FFC provides a recovery system for the fine and coarse sulphides. This is shown in Figure 1 from actual data taken from a gold milling operation operating a FFC and IPJ in the same cyclone underflow circuit.

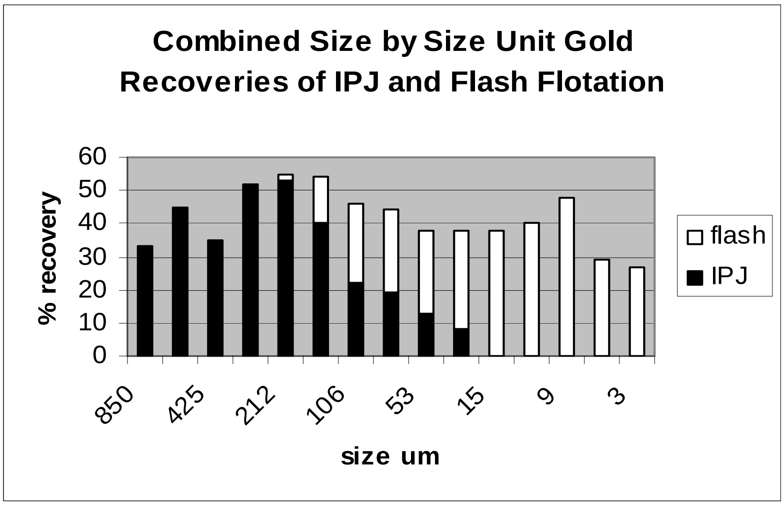

Figure 1: The strong symbiotic recovery relationship between IPJ and FFC

Gekko have recognised that the development of the FFC recognises the importance of coarse recovery prior to preferential grinding. It is important to firstly understand the ore and the mineral distribution in that ore before deciding which pre-recovery device should be used. We have found that many ores have a relatively coarse mineral distribution and in fact significant amounts of mineral can be liberated with a fine crush (p80um = 300 - 1000). These fine crushes can be achieved by both High Pressure Grinding Rolls (HPGR) and Vertical Shaft Impactors (VSI) with very high reduction ratios. The breakage in these units combined with Gekko's InLine Pressure Jig (IPJ) allows for high recoveries of mineral to a continuous concentrate stream at a coarse size. This can importantly reduce the heavy mineral loading on the downstream flotation or in some cases such as Lihir Gold Ltd's, Ballarat East Project (BGF) can give high enough recovery that flotation is not required.

The Circulating Load

The concentrator is run in closed circuit with the crushing device typically with circulating loads between 200 - 400%. Unlike a ball mill or rod mill which preferentially grinds heavies and in which the circulating load cannot effectively be controlled, both the HPGR and the VSI allow for the crush to be controlled. Material is introduced to the feed of these devices and 100% reports to the discharge in a plug flow with very little retention time. There is no preferential retention in the unit. This results in a controlled crush in which it is possible to make a small breakage and follow up with a recovery step. In both cases this breakage can be controlled by either pressure or velocity. It is essential to continue this process until the material is fine enough to pass the classification screen and report to the next process. The key to this stage is a series of smaller breakages each followed by a recovery step. Also the breakage function of the HPGR and the VSI is different to a ball mill with the mineral particles broken out of the gangue as complete crystals with very little physical damage (see Figures 2 and 3).

Figure 2: Free gold recovered from a milling circuit (Left) versus HPGR (Buerger, 2006).

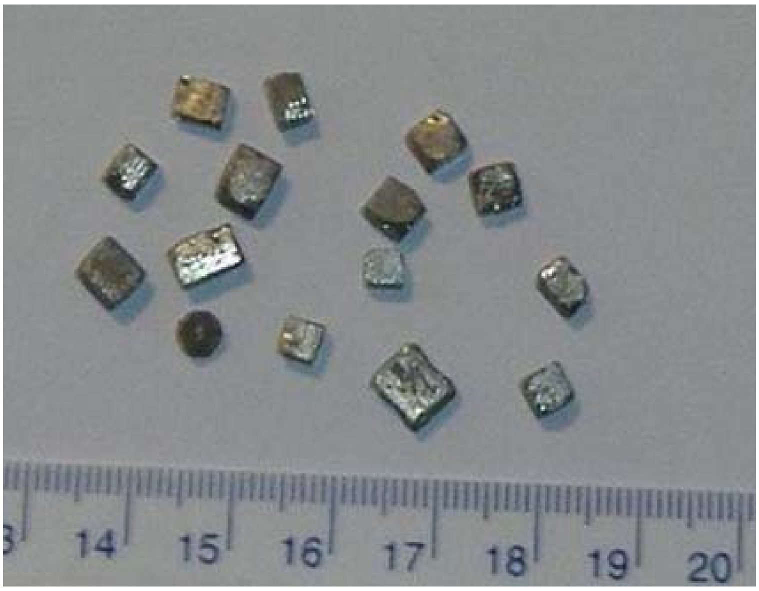

Figure 3: Pyrite crystals as liberated by a VSI. Scale is in centimetres.

Particle shape plays a very large part in gravity recovery. Keeping the particle aspect ratio as low as possible is critical in circuits in which gravity must be maximised (rather than optimised). Many gravity circuits are purely opportunistic in as much as they are set up to remove as much gold as is available in the existing circuit but the circuit is purely designed for the downstream leach or flotation circuit. In the case of GFIL the whole initial focus is on the comminution to ensure the feed is presented to gravity recovery in the best possible form for high recovery.

It is also important to recognise that the real target is the heavy minerals such as sulphides. If high recoveries can be achieved on the sulphides then the valuable minerals including gold and silver will follow.

The Scavenging Circuit

After the bulk of the mineral is removed by gravity it may be necessary to scavenge the tails. This will depend on the mineral size distribution and mass pull required in the circuit. If yield is high such as in the “Underground Processing Plant” (UPP) where the mass pull will be driven by the minimum amount of material that must be taken to surface due to the swell factor of the tailings then there is a far greater possibility that the total concentration could be carried out by gravity. Whereas in a circuit that requires a low yield to minimise operating cost it may be necessary to incorporate several stages of scavenging including possibly fine gravity recovery and flotation. Depending on the mineralisation it may also require finer grinding prior to scavenging. This will be ore specific. Obviously those ores that display the best coarse recovery characteristics will benefit most from this approach. All the concentrate streams are combined to give the overall yield and the scavenger tails are final tails. These tails should be very low in acid generating sulphides as well as containing minimal reagents other than a residual amount of flotation reagent.

Concentration Treatment Options

Depending on the type of mineral being recovered the concentrates will require various treatment routes. In the case of gold ores Gekko have developed a concentrate treatment system that has a very small footprint which contains the reagents inside a small bunded area. The complete system is self contained and includes leaching in an InLine Leach Reactor

(ILR), solution recovery in the G-Rex resin column and strip circuit followed by electrowinning onto stainless steel wool. Solids and solution residues are then sent to detox for cyanide destruct prior to despatch to the tailings storage facility. These tailings contain very low free cyanide and minimal WAD cyanide levels. This material can be stored separately in a lined storage facility or disposed of back to the mine. As it is typically a small amount of material containing the bulk of the “nasties” it is easily handled and disposed of.

Concentrates from ores other than gold or silver such as nickel and copper ores can be bought to final con grade ready for sale through re-grind and cleaner float or further gravity upgrade.

Laboratory Test Work

It is not possible to understand the recovery / grind relationship without proper metallurgical test work being carried out. Conventional centrifugal gravity recovery work does not give a reliable indication of the relationship between high yield gravity and grind size. Gekko have developed vibrating table and Dense Medium Separation (DMS) tests which have been found over the past ten years to accurately simulate the performance of an IPJ in a circulating load. With these tests it is possible to simulate crush/grind sizes up to 10mm and ensure processing can be simulated at the maximum possible liberation size.

It is critical to test the ore at as coarse a size as possible to determine the benefit from high mass pull gravity devices. An example of this is given in Figure 4. At a typical grind size of 106 µm the ore demonstrated reasonable good gravity recovery and most test work programs would stop at that point. However, presenting the ore to the vibrating table at progressively coarser sizes showed a dramatic increase in recovery to the point that gravity at a coarse size could be considered to be the solution to the processing of this ore.

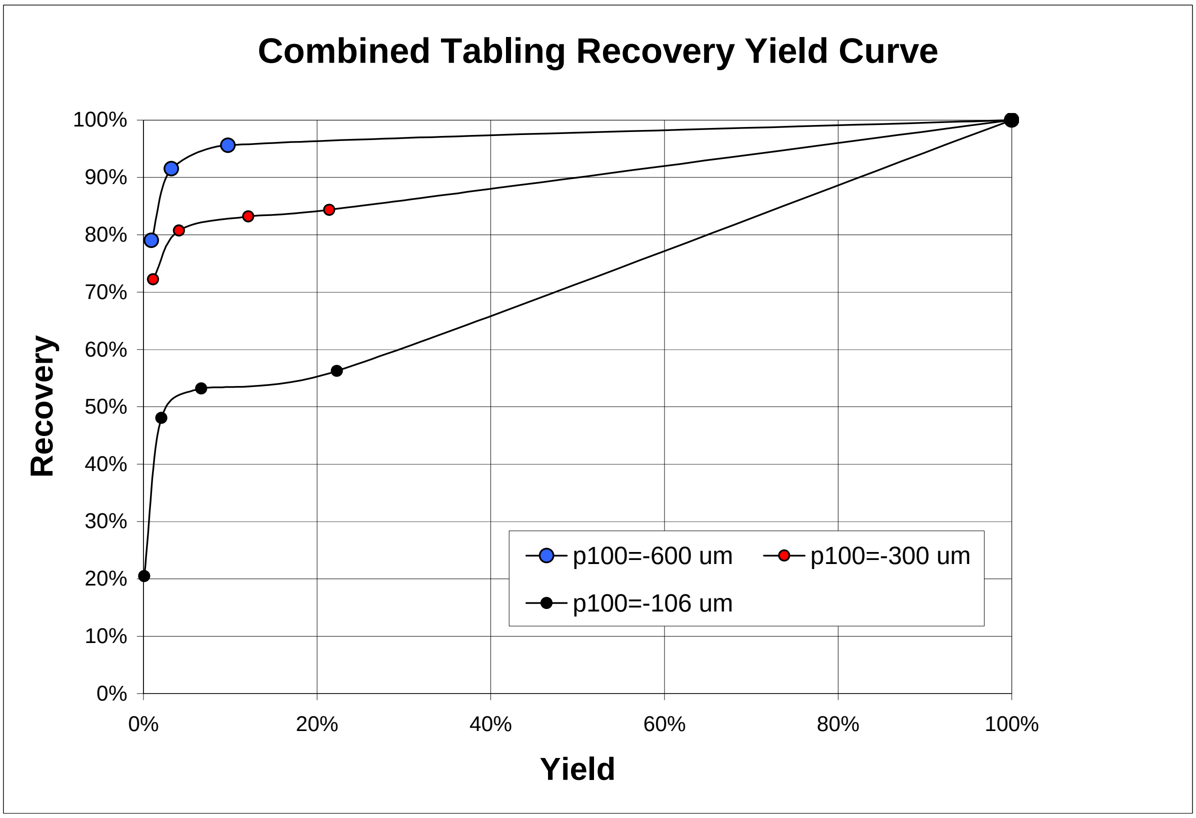

Figure 4: Affect of Over-grinding on Gravity Recovery

Examples of projects utilising, about to utilise or designing for this technology/concept are given below.

EXAMPLES

Ballarat Goldfields

Lihir Gold Ltd's Ballarat East Project (BGF) is located within the city of Ballarat, 100km NW of Melbourne, Australia. The Gekko designed, built and operated 600,000 tonnes per annum (tpa) processing plant was commissioned in December 2005 and whilst ore supply has been limited, the plant is operating at or above its designed levels given below.

Throughput	75 tph (annualised at 600,000 tpa)
Head grade	8.5 g/t (longterm)
Target grind	P100 = 1.0mm, P80 = 850 µm
Mass pull to concentrate	5%
Gold recovery to concentrate	90 - 95%
Arsenopyrite recovery to conc	50%

The circuit flowsheet is given in Figure 5 and the plant layout is given in Figure 6.

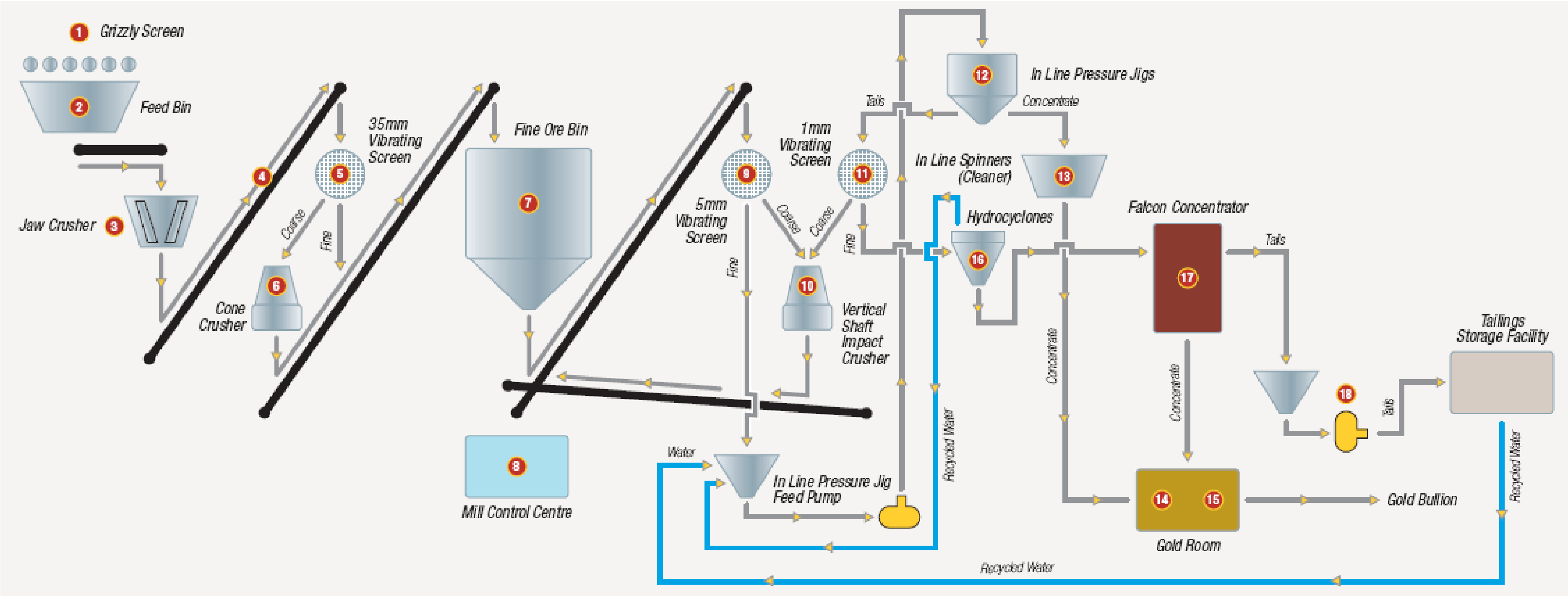

Figure 5: BGF's 600,000 tpa Gravity Only Processing Plant's Process Flow Diagram

Figure 6: The complete gold processing plant - designed and installed by Gekko.

The circuit consists of the following unit operations:

- Primary/Secondary crushing to a P80 of 20mm utilizing a Jacques 42*30 Single Toggle Jaw Crusher and a 60 inch Allis Hydrocone Cone Crusher. The circuit is designed to operate at +200 tph to allow stockpiling of crushed ore in a dedicated Coarse Ore Bin to remove the need to crush at night.
- Tertiary Crushing and Screening to < 5mm. An Auspactor VS200RR Vertical Shaft Impactor (VSI) is used to reduce the rock size from 20mm to nominally 600 um. Feed from the Coarse Ore Bin is screened at 5mm with the +5mm reporting to the VSI. The VSI product is returned to the 5mm screen. The screen undersize material is pumped to the gravity circuit. Circulating load around the VSI is between 200 and 250%.
- Gravity concentration is carried out in a Rougher/Scavenger/Cleaner InLine Pressure Jig (IPJ) circuit. The undersize from the 5mm screen is pumped to two IPJ2400 rougher jigs in parallel with the tailings from these jigs reporting to two IPJ2400 scavenger jigs. The concentrates from the roughers and scavengers are cleaned in an IPJ1500 cleaner jig. The cleaner tail reports back to the 5mm screen. Coarse gold in the cleaner concentrate is removed using InLine Spinner centrifugal concentrators. Both the InLine Spinner tailings and concentrate report to the goldroom for removal of free gold by tabling until the Stage 2 expansion of the circuit is completed (discussed later).
- The tailings from the scavenger IPJ's is screened over a 1.6mm aperture screen with oversize reporting to the VSI for further size reduction and mineral liberation. Screen undersize is pumped to a cluster of Warman CAVEX 250mm cyclones for water recovery. Cyclone overflow at <5% solids is re-used in the process for screen sprays and IPJ hutch water. Cyclone underflow passes through a Falcon SB1350 centrifugal concentrator before reporting to the tailings dam.

The performance of Stage 1 to date has exceeded expectations with high throughput and recovery. A gravity and grinding circuit survey was conducted in December 2006 to compare plant performance to the original circuit mass balance (see Table 1).

Table 1: BGF Plant Performance versus Design

Parameter	Units	Design	Actual
Plant Feed Rate	Dry tph	75	70.2
Vertical Shaft Impactor Feed Rate	Dry tph	175	167
Circulating Load	%	250	240
Rougher Jig Feed Rate	Dry tph	188	167
Rougher Concentrate	Dry tph	18.8	10.5
Scavenger Concentrate	Dry tph	7.0	5.4
Cleaner Concentrate	Dry tph	3.5	5.2
	Wt%	5	7.4
Final Tail P80	µm	850	570
Head Grade - Gold	g/t	8.5	3.87
Recovery – Gold (at actual head grade)	%	85	88.6
Recovery – Arsenic	%	50	83.0
Recovery – Sulphur	%	54	67.0

The survey showed very good agreement between the original design mass balance and the plant performance though feed tonnes and grade were lower than design during the survey. Significant differences include lower concentrate mass pull from the rougher and scavenger IPJ's than designed, finer product size than designed and significantly higher arsenic recovery than designed. The high arsenic recovery is directly attributable to the liberation characteristics of the VSI (see Figure 3) and the presentation of the arsenopyrite minerals to the IPJ's at as coarse a size as possible.

The performance of the circuit on a size by size basis is given in Figure 7.

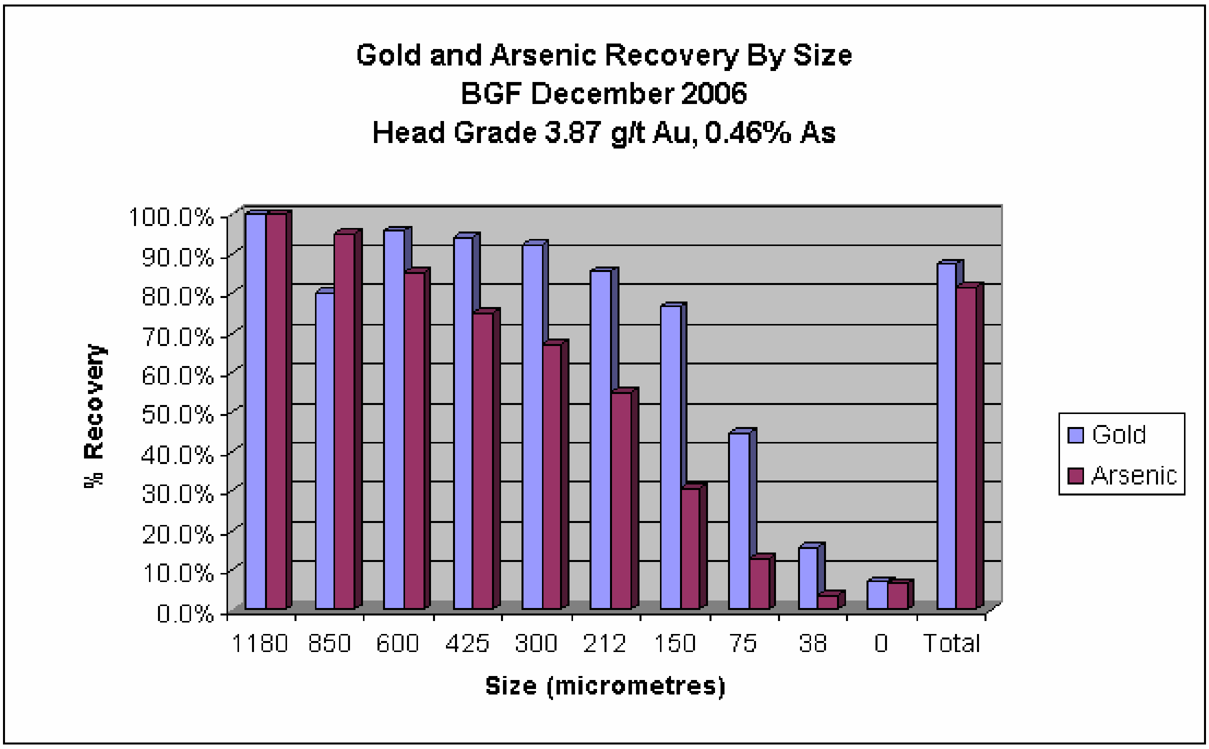

Figure 7: Gold and Arsenic Recovery by Size for BGF

The figure shows high gold and arsenic recovery at the coarse sizes with arsenic recovery dropping away below 300 µm and gold below 150 µm. This graph clearly demonstrates the benefit of not over-grinding the minerals before presentation to the InLine Pressure Jig.

Potential does exist to recover the finer gold and sulphides using flotation but the economics of this are yet to be determined as gold loss in these fractions are typically <0.30 g/t.

To maximise the recovery of gold to bullion from the Stage 1 processing plant, BGF have recently commissioned Gekko to construct a concentrate regrind, leaching and resin absorption circuit (see Figure 8 for the Stage 2 Concentrate Treatment PFD).

The tailings from the InLine Spinners will be ground to a P80 of 150 μm in a Gekko Traction Mill. The mill will be in closed circuit with a DSM screen to minimise over-grinding of the heavy gold and sulphide minerals. The ground ore will be leached in an InLine Leach Reactor (ILR) ILR10000CA continuous intensive leach reactor. The gold will be leached in 6 hours in a 0.5% NaCN solution.

The leach tailings are pumped to a CCD circuit to recover the gold in solution. The overflow from the first CCD reports to the resin absorption circuit which utilises the Gekko Resin Column and AuRIX®100 resin to recover the gold from solution. The barren solution from the column is mixed with the underflow from the first CCD in a second CCD to recover more gold from the leach tailings. Overflow from the second CCD reports back to the ILR whilst the underflow is pumped to the cyanide destruction circuit.

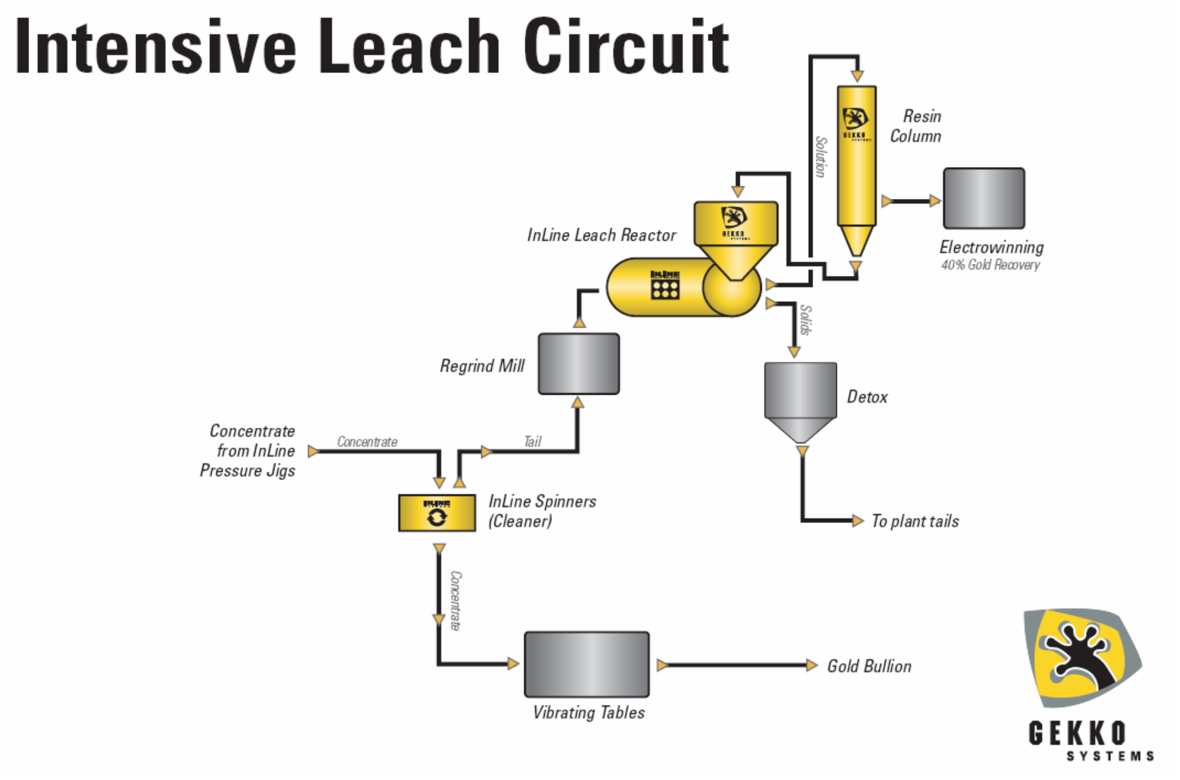

Figure 8: BGF Stage 2 Concentrate Regrind, Leaching and Resin Absorption Circuit

Loaded resin from the resin column, at up to 24,000 g Au/t resin, is stripped at 60°C in a 4% sodium hydroxide, 7% sodium benzoate solution for 8 hours before being returned to the resin column. Gold is recovered from the strip solution in a conventional electrowinning cell (approximately 40% of total gold production).

The leached solids are detoxified from 5000 mg NaCN/Litre to <50 mg WAD CN/Litre using the SO_2/Air process. The detoxified tailings will be mixed with the gravity tailings to produce a final tailings with less than 5mg WAD CN/Litre.

The circuit clearly demonstrates the benefit from separating the "liberation/concentration" step from the leaching step. Liberation of the gold and sulphides is very high at a P80 of 600 µm whereas leaching requires a grind of 150 µm to recover the gold from the sulphides. Doing this in two distinct stages removes the need to grind all of the ore to 150 µm resulting in significant power, and hence greenhouse gas, savings (approximately 5 kWh/t required versus 10 kWh/t for whole of ore grinding assuming a F80 of 5mm and BWi = 15 kWh/t).

The overall benefits of this type of circuit to BGF and the community are:

1) Low capital cost (<A$4,000,000/100,000 tpa processing capacity)
2) Fast construction time – approximately 6 months from order to first gold poured (Stage 1)
3) Minimal power consumption as only the valuable minerals are ground to the required leach size – approximately 5 kWh/t
4) Small percentage of ore directly exposed to cyanide
5) High sulphide and arsenic recovery to a small mass % concentrate

Phuoc Son Gold Project – Vietnam – Feasibility Study

The Phuoc Son Gold Project is located in Central Vietnam and owned by Olympus Pacific Minerals Inc. of Toronto. Ore for the processing plant will be sourced from the nearby Bai Dat underground workings. Gekko were commissioned by Olympus Pacific Minerals Inc. to design a crushing plant with a throughput of 350,000 tpa and a processing plant capable of handling 175,000 tpa of ROM ore.

The design parameters were:

Throughput	22 tph (annualised at 175,000 tpa)
Head grade	12 g/t Au, 21 g/t Ag, 1.7% Pb, 0.6% Zn
Target grind	P80 = 75 µm
Mass pull to concentrate	10%
Gold recovery to concentrate	94%

The coarse nature of the sulphides in this ore is demonstrated in Figure 9 and eventually led to the selection of a GFIL circuit for this project.

Figure 9: Sample of Phuoc Son Ore indicating coarse nature of Sulphides

The circuit flowsheet is given in Figure 10 and the plant layout is given in Figure 11.

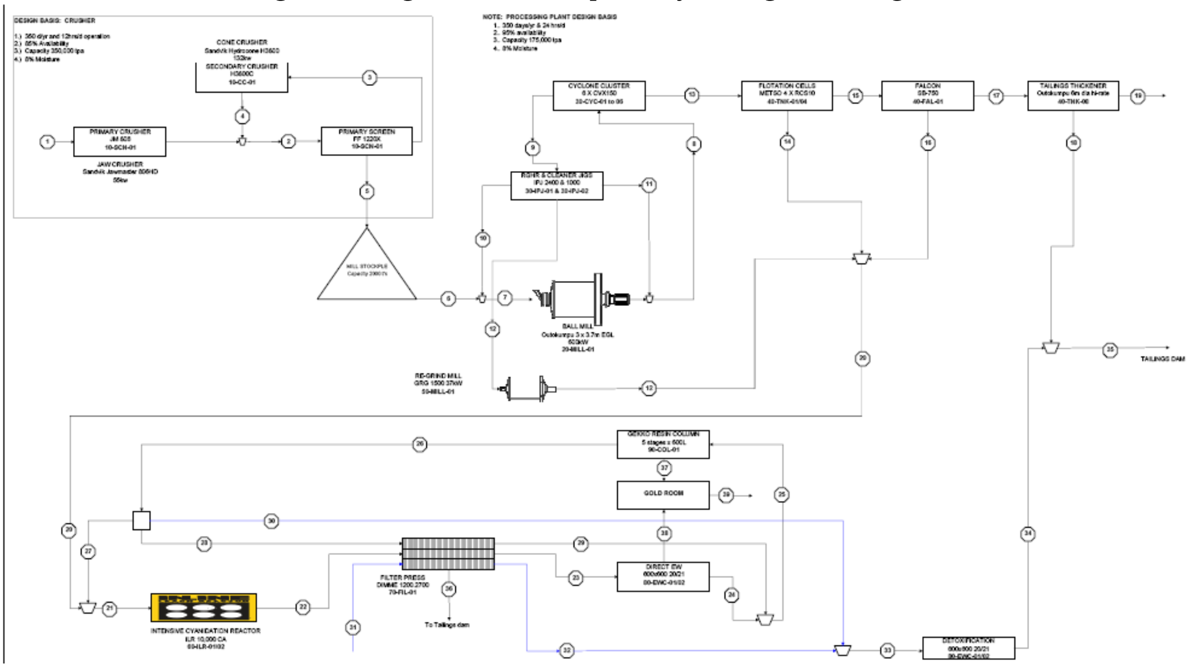

Figure 10: Phuoc Son Project proposed PFD

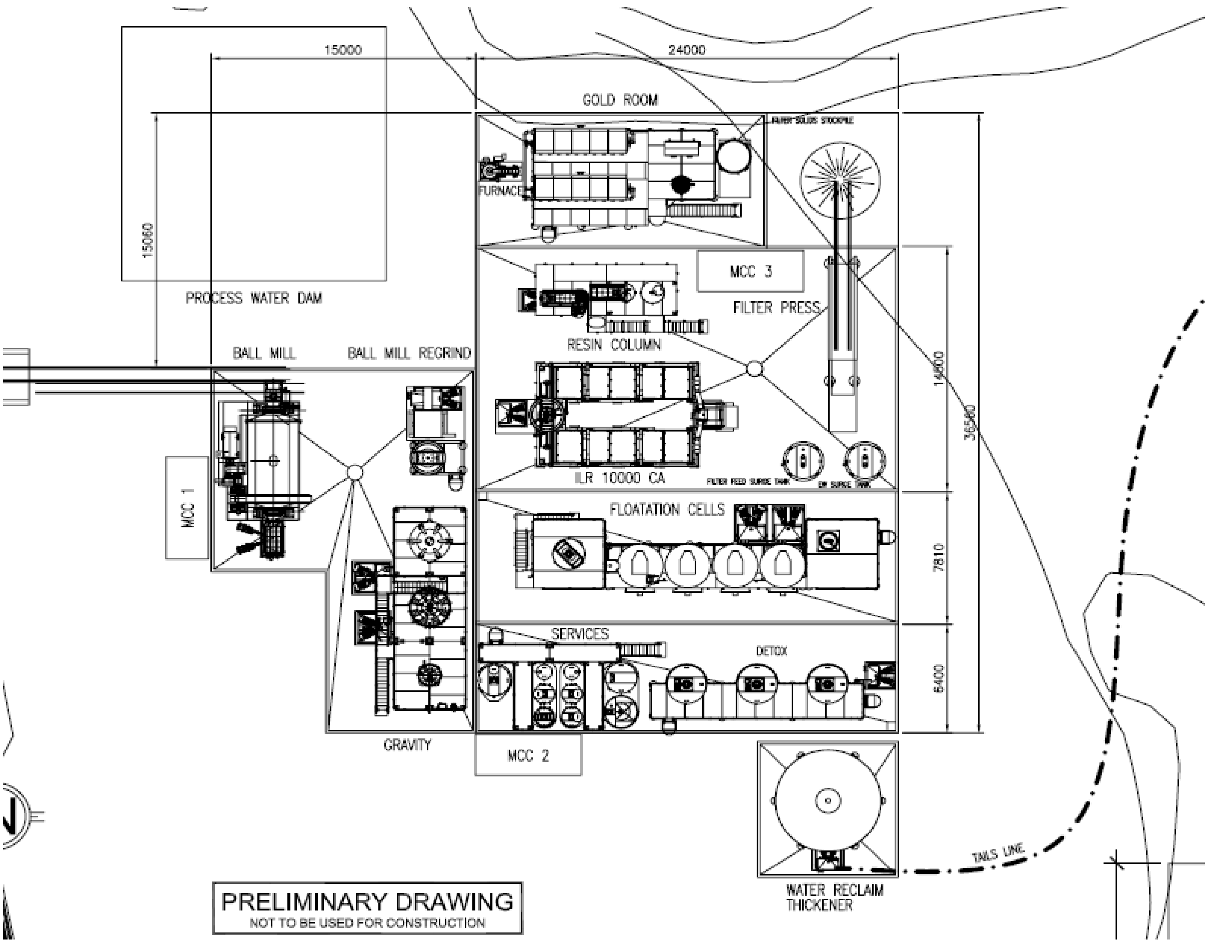

Figure 11: Proposed Phuoc Son Plant Layout

Ore will be delivered by truck from the underground mining operation to a run of mine (ROM) storage pad. Minus 600 mm ore is crushed in the jaw crusher before being further crushed in a cone crusher in closed circuit with a 15mm aperture vibrating screen. The screen undersize material is conveyed to the 2000 tonne capacity mill stockpile.

The crushing circuit capacity is rated at 110 tph and is designed for 12 hour per day operation at 85% availability. Sufficient capacity is available in the crusher for future processing plant throughput upgrades up to 350,000 tpa.

A single 600 kW ball mill (3 x 3.7m) is to be used in closed circuit with a CAVEX CVX150 cyclone cluster, to produce a grind size P80 of 75 microns in the cyclone overflow.

The entire cyclone underflow is passed though a rougher IPJ2400 with the concentrate reporting to a cleaner IPJ 1000. The rougher IPJ tails are pumped to the mill feed chute. At the IPJ1000 cleaner, the tails line discharge under pressure into the mill discharge sump and the concentrate reports to the regrind mill feed cone.

The two gravity units allow for a high continuous mass recovery which was shown to be required by testwork. The IPJ’s have been designed for a mass yield of 6% to concentrate, however due to the varying grades of sulphides in the ore (galena, sphalerite, and pyrite) the design has considered up to 12% gravity mass recoveries are possible. Surge capacity has been considered in downstream units for a larger mass recovery.

The designed gravity recovery is 60% Au into a concentrate grading 121 g/t Au.

The cyclone overflow is mixed with PAX, Copper Sulphate, MIBC and anti-foam and then directed to the flotation circuit consisting of 4, 10 m^3 Metso RCS 10 tank cells. The cells have been designed for extra capacity due to the potential for higher ore sulphide grades, and to minimise additional capital for any future plant upgrade. The tank cells were selected over conventional cells due to a lower capital costs, minimise short circuiting, more effective froth removal, ease of shipping and installation.

The designed flotation recovery is 36% Au into a concentrate grading 106 g/t Au.

The flotation concentrate is pumped directly to the intensive leach feed cone, while the flotation tails are pumped into the Falcon Concentrator (SB750) which scavenges any remaining fine heavy particles which have passed through the gravity and flotation units. The design indicates that the Falcon will boost overall recovery by between 1-2% for Au.

The concentrate stream from the Falcon, reports to the intensive leach reactor feed cone, via the flotation concentrate sump.

The tails from the Falcon flow by gravity to a water recovery thickener. The thickened tails are combined with CN detoxification unit solution tail, and are then pumped to the tailings dam.

The overall gravity/flotation/falcon recovery is 97.2% Au into a concentrate grading 115 g/t Au.

The cleaner IPJ gravity concentrate is thickened in a feed cone before entering a small 1.5 m x 1.5 m traction driven ball mill which is charged with 32 mm grinding media. The regrind mill reduces the particle size of the cleaner IPJ concentrate from approximately 3 mm to a P80 of 75 µm in order to increase leaching kinetics. The regrind mill will reduce the gravity product to 75µm at a rate of up to 1.5 tonne per hour.

All concentrates will be fed to the ILR10000CA continuous automatic leaching system. The system is arranged to collect all the feed to a single 15 m^3 feed cone that will thicken the feed to 70% solids and recycle water to the process water dam.

The ILR10000 contains two drum reactors that are fed from the feed cone. Continuous addition of peroxide and cyanide is delivered to the feed end of the drums via diaphragm pumps.

Barren solution from the resin scavenger column is returned to the leach circuit via the barren solution tank. The leached solids material exits the ILR drum to a sump from where it is pumped to the filter feed surge tank. The solution tenor is 49 ppm.

The expected ILR leach recovery for Au from the concentrate is 98%. The residence time within the drum reactors is 11.5 hours based on a concentrate mass pull of 10% of the primary feed. At a mass pull of 15% the residence time is 7.8 hours.

ILR leached tails are filtered in a Diemme plate and frame filter press (ME.1200.2700). The filtrate reports to the nearby pregnant liquor surge tank and the filter cake is periodically dumped into a chute. A conveyor at the bottom of the chute conveys the cake to a stockpile. A truck and front end loader is then periodically used to transfer the cake to a storage site.

The design incorporates a two stage wash to reduce gold losses and to minimise cyanide levels in the filter cake.

The pregnant solution (PLS) from the filter press passes into a PLS surge tank and then onto direct electrowinning (EW) in two high current density electrowinning cells in series. Each cell contains 20 cathodes (basketless) and 21 anodes. The electrowinning of the metals in this arrangement is conducted in such a way that the deposited metal forms in dendrites causing them to sludge off of the cathodes and fall to the base of the cells. The cells are then periodically stopped and cleaned with this material being drained onto a vacuum filter to collect the precipitate for further refining.

The cells are arranged in series to achieve a Au pass efficiency of 90%. Each cell will be able to be bypassed to allow continuous operation while cleaning operations are undertaken.

The EW exit solution along with the intermittent barren wash solution from the filter press, is directed into the resin absorption circuit.

Over 85% of the total Au production is recovered by direct EW.

The resin absorption circuit consists of a Gekko G-Rex Resin Column containing AuRIX®100 resin. The column is designed to scavenge the gold from the solution (Au @ 5.6 ppm) and consists of a down flow column with 5 stages of resin. Gold is extracted onto the surface of AuRIX®100 resin by ion exchange.

Resin in the circuit is transferred counter current to the solution flow in the column to produce the highest grade resin for stripping. Resin is transferred at regular intervals to the stripping circuit whereby the gold on resin is removed by a high pH, 60’C, and 200 ppm CN strip solution. The reagent Sodium Benzoate can be added to the solution to increase stripping kinetics. The loaded strip solution is then electrowon in a separate electrowinning circuit utilising a standard non-sludging electrowinning cell in a closed system. This strip solution is recirculated over many cycles until it is required to be refreshed due to excessive build up of contaminants.

The resin scavenger column pass efficiency for Au is 95%. Just less than 15% of the total Au production is recovered by resin ion exchange.

The method selected for detoxification is H_2O_2 destruction which uses Copper Sulphate as a catalyst. This method was selected due to the simplicity of the process, the lack of solids in the Detox feed and to minimise the reagents and associated equipment onsite.

Hydrogen peroxide and copper sulphate are added continuously at a rate that is required to produce the required cyanide discharge limit of less than 5ppm. The total residence time is 15 hours. The Detox discharge solution is pumped to the final tails sump at the dewatering thickener.

The precipitate from the direct EW and resin EW cells are collected in the base of the cathode wash tank. This material is periodically filtered using a vacuum filter press. The dewatered precipitate is then removed to the gold room and placed in a drying oven. When sufficient material is collected it is placed in a crucible with flux material and smelted inside a furnace, to produce gold/silver bullion.

The total processing plant Au recovery is 94.0%. The annual output of gold is expected to be 63,371 ounces.

Gekko selected a Gravity, Flotation, Intensive Leach plant design (GFIL) for the Phuoc Son Gold Project based on the results of testwork completed to date. Using GFIL, it was predicted that an overall recovery of 94% Au can be achieved. Advantages of the proposed flowsheet include:

- **Improved Environmental Outcomes** – Gekko have estimated a mass pull to concentrate of 10% for combined gravity and flotation. This means that only 10% of the ore will be exposed to cyanide. If a whole ore leach plant is utilized, 100% of the feed will be exposed to cyanide.

- **Capital and Operating Cost Reductions** – the Gekko GFIL design is simple and modularized requiring less infrastructure and engineering on site. Using gravity at the front end also means that there is potential to use a coarser grind which means lower power requirements and further operating cost reductions.

- **Greater Flexibility -** The GFIL plant design provides the opportunity to add on base metals and silver flotation simply and cost effectively. A cleaner sized float circuit can be utilized. The volume of material to be treated (leach reactor tails) will be much smaller than with whole ore cyanidation and the material itself will be much easier to float, as there will be minimal cyanide contamination.

Other features expected with our design are as follows:

- Smaller Footprint
- Faster delivery
- Mobility
- Ease of assembly and operation

Minera Santa Cruz S.A. - San Jose' Project

Minera Santa Cruz S.A. recently commissioned Gekko to design, construct and commission the gold and silver recovery circuit (from Ball Mill discharge to Goldroom and detox) for their San Jose' mine located in Patagonia, Argentina. The plant is undergoing commissioning at the time of writing this paper.

The design parameters were:

Throughput	32 tph (annualised at 266,000 tpa)
Head grade	7.7 g/t Au, 406 g/t Ag
Target grind	P80 = 110 µm
Mass pull to concentrate	13%
Gold recovery to concentrate	95%
Silver recovery to concentrate	94%

The circuit flowsheet is given in Figure 12 and the plant layout is given in Figure 13.

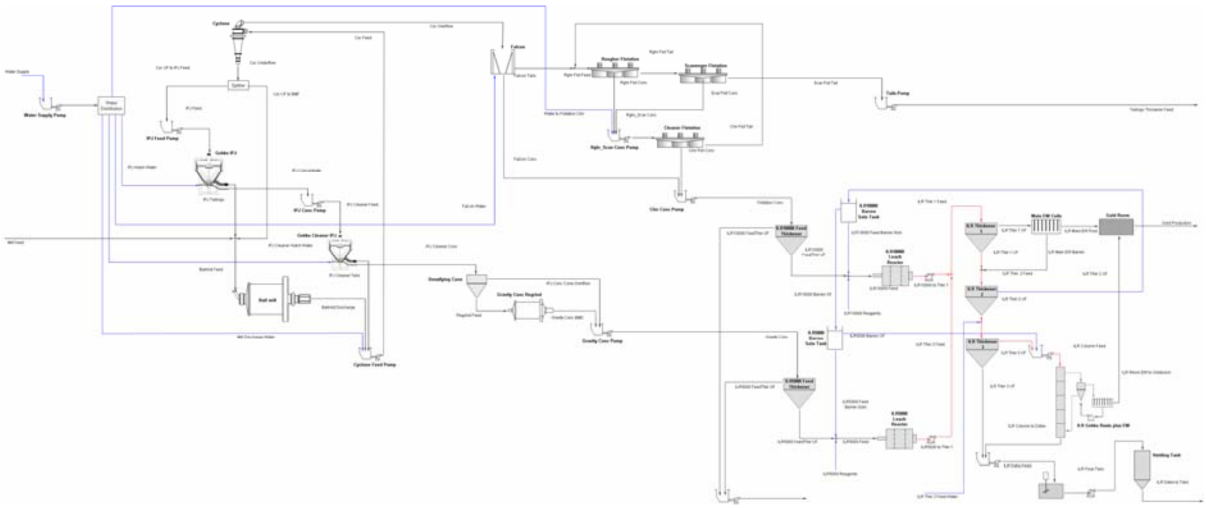

Figure 12: San Jose' GFIL Circuit Flowsheet

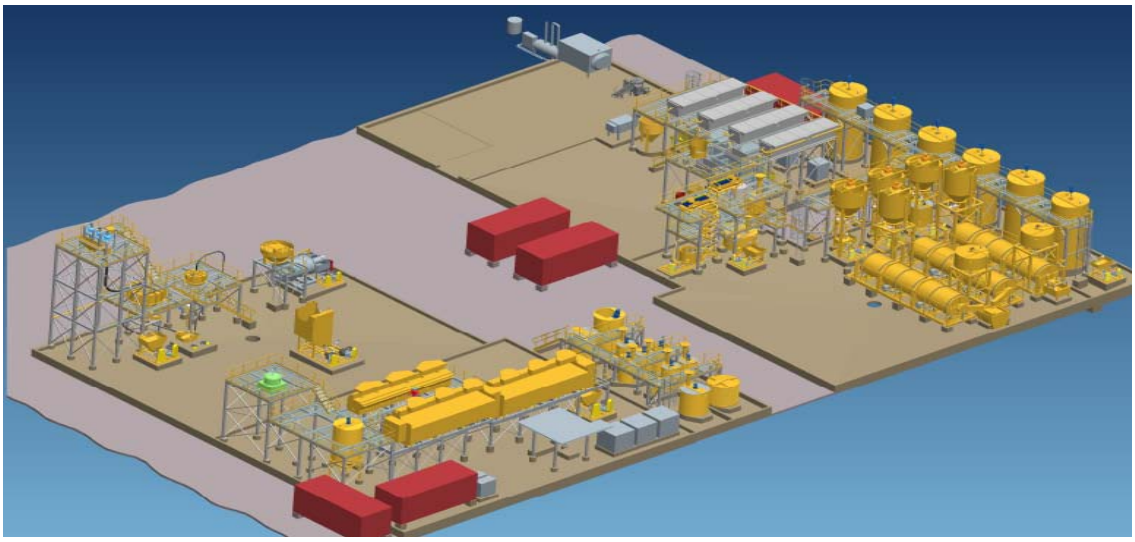

Figure 13: San Jose' GFIL Plant Layout (Post Ball Mill)

Ball mill discharge is pumped to two Warman CAVEX 250mm cyclones. The entire cyclone underflow stream is directed to a rougher IPJ2400 and the rougher tail is pumped back to the ball mill. The rougher concentrate (7 tonnes/hour) is fed to a cleaner IPJ1000 to increase the concentrate grade from 52 g Au/t and 2,325 g Ag/t to 152 g Au/t and 4,600 g Ag/t in one tonne per hour of concentrate. Gravity recovery is 59.8% gold and 34.5% silver into 3% of the mass. Cleaner tail is returned to cyclone feed.

Cleaner concentrate reports to a Gekko Traction Mill to reduce the minus 2mm gravity concentrate to 110 µm at the rate of 1 tonne per hour.

The entire cyclone overflow passes through a SB750 Falcon before reporting to the flotation circuit. Rougher/scavenger flotation is carried out in two banks of 3 x 300 ft^3 cells using copper sulphate as activator and potassium amyl xanthate as the collector. The Falcon and flotation circuits achieve a recovery of 35.4% gold and 59.7% silver into 9.6% of the mass.

Total gravity and flotation recovery is 95.2% gold and 94.2% silver into 12.7% of the mass. The flotation tailings are thickened before reporting to the Tailings Dam. Sulphur content in the ore has been reduced from 2.90% S in the feed to 0.15% S in the tailings.

The concentrates from the gravity and flotation circuits are leached in separate continuous InLine Leach Reactors being an ILR5000CA and ILR10000CA respectively to enable optimisation of leach times for the two different products. Leach recovery for both gold and silver is expected to average 96% after 9 hours residence time at 1.2% NaCN.

The solid and solution tailings from the leach reactors report to a three stage CCD circuit. In the first CCD unit the high grade gold and silver solution is separated from the solids and reports to the direct electrowinning module. The underflow from the first CCD unit is mixed with the barren solution from electrowinning in the second CCD unit. The overflow from this CCD unit is re-circulated back to the ILR's to maximise the re-use of reagents and to maintain an adequate feed grade to the electrowinning module. The underflow from this CCD unit is mixed with process water to maximise gold and silver recovery and to lower the pH level of the solution as the overflow from this CCD unit reports to the resin absorption circuit which uses a Gekko G-Rex Resin Column and AuRIX®100 resin to scavenge the remaining gold and silver from solution. Recovery of silver by AuRIX®100 resin reduces at high pH hence the need to lower the pH below 12 before the resin absorption circuit.

The direct electrowinning module provides the primary metal recovery system for the leached solution and incorporates solution heating to 70°C, four in series forty two cathode Summit Valley high current density cells and a plate and frame filter press. The electrowinning cells recover 92% of the gold and 96% of the silver per pass. The gold sludge collected from the cells is filtered in the plate and frame filter press before the sludge is retorted at 600°C to vapourise and recover mercury present in the sludge and to calcine other products contained in the sludge before smelting.

The resin circuit is designed to scavenge an additional 2% (total recovery) of the gold and silver from the leach tailings stream. The column uses 5 stages of resin beds to recover 95% of the gold and silver in the feed solution to it. Loaded resin is transferred to the separate stripping vessel to recover the contained gold and silver using the 60°C, 4% sodium hydroxide, 7% sodium benzoate strip solution. The gold and silver are electrowon using a small dedicated electrowinning cell separate to the main electrowinning module.

The underflow from the thrird CCD unit is pumped to the cyanide destruction circuit where it is mixed with copper sulphate, sodium meta-bi-sulphite, sodium hydroxide and air to reduce the cyanide concentration using the SO_2/Air process. Cyanide levels are reduced from 1.2% w/w NaCN to less than 50 ppm WAD CN.

The benefits of the GFIL circuit for this project include;

- Small footprint which was important due to low ambient temperatures and the need to fully enclose the plant
- Higher recoveries than previously allowed for
- No cyanide in main tailings stream so simple permitting on tailings dam.
- Simple handling of very high silver loadings without Merrill Crowe system which lowered the operating cost of the circuit.
- Reduced cyanide consumption

The "Ultimate" – Gekko Underground Processing Plant (UPP)

During 2004/2005 Gekko was awarded a AUD$1.2M research grant to both investigate and commercialise the idea of underground processing of primarily gold bearing ores.

The principle of the Gekko UPP Project involves size reduction, screening and gravity pre-concentration underground and as close to the working face as possible. In order to achieve this, low cost, low tonnage Gekko Modular units are being designed to be installed in drives nearby to each of the working stopes, such that as the ore is blasted it is removed by LHD or similar and delivered directly into the UPP grizzly feed hopper. This minimises the possibility of fines losses into footwall cracks etc.

The ore is then crushed and ground to the maximum economic liberation size for gravity pre-concentration. The liberation size is determined from the ore by testing.

The valuable component is then the only material removed from the mine to surface while the non-valuable tailings remain underground for backfilling.

It should be noted that only pre-concentration is being proposed underground. The classical understanding of gravity concentrates is extremely high grade, very low mass pull type units whilst Gekko are proposing a mass pull of 10-35% with recoveries greater than 90% giving concentrate grades of 3 to 10 times mined grade, and as such the security concerns which normally accompany 'gravity concentration' are no greater than those associated with conventional mining.

It would be proposed that a 35% mass pull from the UPP would be targeted, as a 65% bulk density factor is typically applied to backfilling (ie only 650kg for every 1000kg mined can be returned for backfill). Thus recovery can be easily optimised into this relatively high mass pull.

The schematic flowsheet for the UPP is presented as Figure 14.

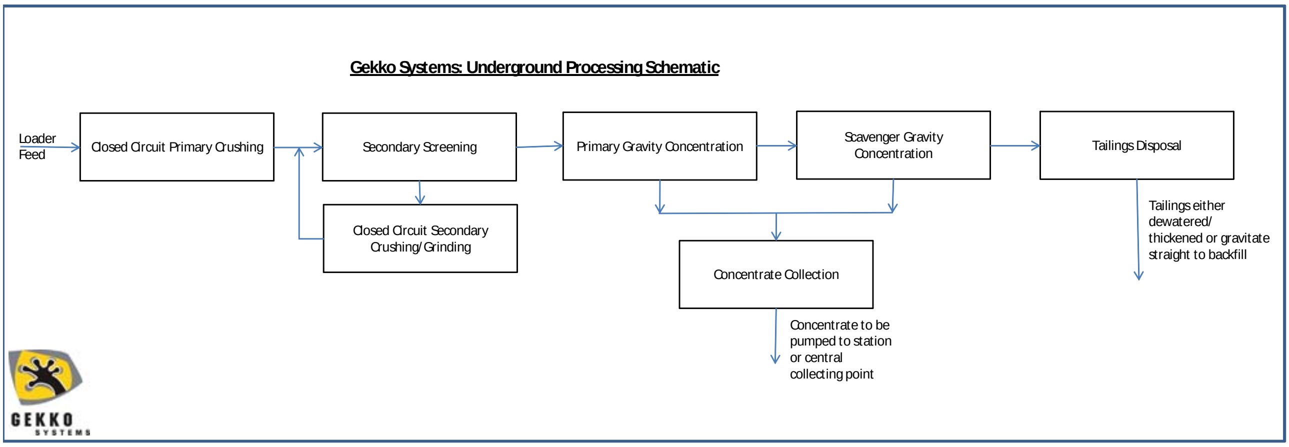

Figure 14: Underground Processing Flowsheet

There are a number of advantages to pre-concentrating the ore underground, which were the driving forces for Gekko to commence the Research Project, and some of these are summarised as follows:

- Improvement in Mine Call Factor due to less handling points for the ore en-route to the plant
- Reduction in tramming and hoisting costs due to lower tonnage required to be moved
- No necessity for backfill to be produced on surface and sent back underground
- Reduction in required surface plant capacity
- Reduced surface plant costs as lower tonnes will be treated at a higher grade
- Increased haulage rope life due to lower tonnes hoisted
- Much reduced power consumption over conventional processing (estimate of underground installed power 8kWh/t, vs 14-16kWh/t conventional milling power consumption)
- No detoxification requirements on backfill produced, it has not been exposed to cyanide.

This project is well advanced with a 20 tonnes per hour prototype being commissioned at Gekko's facilities at the time of writing this paper. The processing plant has been designed to fit within the typical underground drive design envelope thus minimizing the need for mine excavation (see Figures 15 and 16).

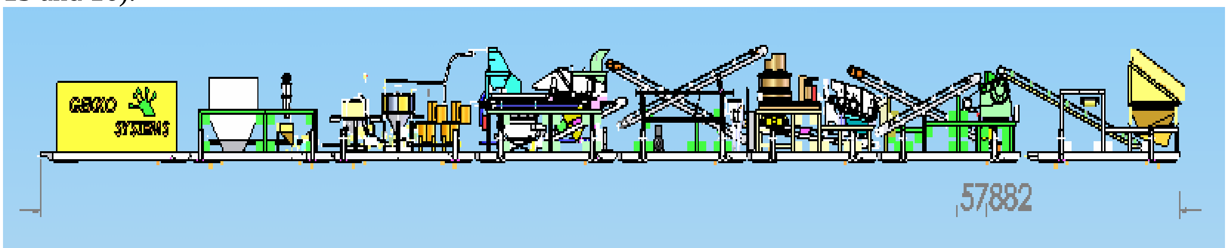

Figure 15: Underground Processing Plant from Feed Hopper to Tailings System

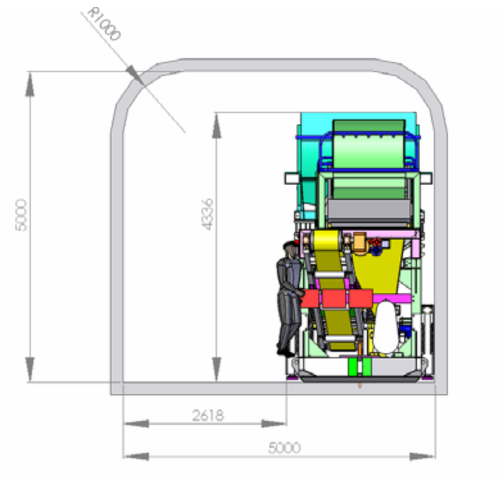

Figure 16: Underground Processing Plant in Typical Underground drive

Gekko is also undertaking ore amenability testing for a number of clients interested in this concept and expect to trial the plant at an underground mine late 2007/early 2008.

CONCLUSIONS

If we are to push for reduced environmental impact in the mining industry we must continue to reduce activities such as land clearing, power consumption and reagent usage. We must endeavour to remove minerals from the earth with the minimum of surface disturbance by reducing our footprint which includes plant sites, tailings facilities and access roads. It is not possible to expect that the industry will change this overnight however it is our duty to push forward as hard as we can in the direction of “greening” our industry. Gekko developed the GFIL and UPP concepts in response to a growing concern from the mining industry with regards the locking–up of more and more areas to traditional mining methods. We believe this is a positive step towards a vision of a completely new approach to mining in the future. The mining industry is an understandably conservative industry and as such it is necessary to make change slowly. These flowsheet options allow us to start to make the changes.

This paper provides an overview of Gekko’s latest exciting development of an integrated recovery system. The relationship between each stage of comminution and separation has been studied and a strategy has been developed to take advantage of the ore’s inherent advantages as well as a flexible process system that can handle wide variability’s in mineral type and size distribution. The interlocking and overlapping of device capability enables a sophisticated recovery system to be reduced into a simple package. It is the subtleties of this circuit and its control system that cannot be seen externally that make it the leading edge in recovery technology. Also, due to the compact nature of the system, it can be packaged into a high performance pre-concentrator for the processing of ore in an underground environment.

The advantages are many and start to lead us into the new century with one of the few significant changes in process technology in the past 100 years. To see a recovery circuit with no Ball or SAG mill anywhere in sight is a good start to power and cost reduction and a large advance towards more environmentally sustainable outcomes for our industry.

ACKNOWLEDGEMENTS

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