IXOS®

Molecularly imprinted polymer for the gold mining industry

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What's inside this brief

- 6th Wave Innovations estimates that its **IXOS®-AuC** nanotech bead can increase gold mining profits by as much as **$100 per ounce—** in ADR cost savings
- IXOS® virtually eliminates solution losses yielding lower AISC and addional shareholder value.
- Our smart beads have undergone rigorous independent laboratory testing and field trials with major mining companies which confirm their unique and valuable qualities.
- The fast extraction kinetics and known resistance to organic fouling confers a clear advantage over activated carbon or ion-exchange resins.
- Whether you're planning a new mine or retrofitting an existing mine – we can make you money.

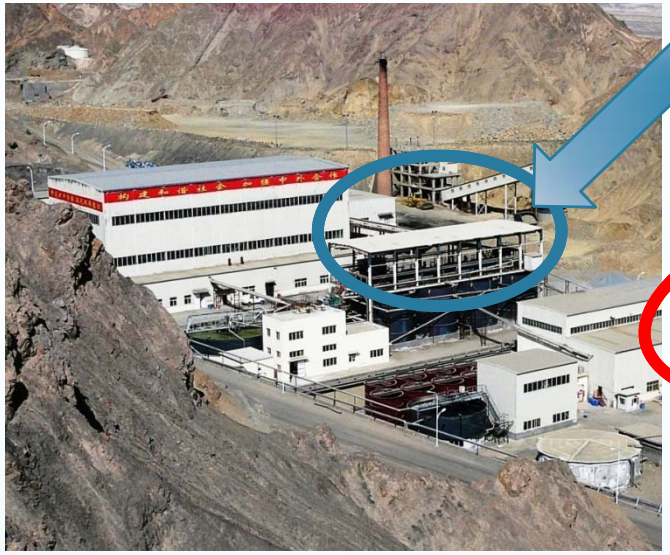
Praise for IXOS®

*"6th Wave's resin technology has great potential. **IXOS®** works well under very challenging conditions and appears to be more highly selective for gold than carbon. I can see it replacing carbon as the adsorbent of choice".*

Susan Ritz, Principal Process Engineer and President
Jack Rabbit Consulting

Based on experience at customer pilot plant tests.

We've developed "smart" nanotech filters, *and we're bringing them to gold mines*



These filtration stacks are used to extract gold from leached solution. 6WIC intends to replace this with its IXOS® beads wherever possible.

Fun Fact: Mines like this one process about 80 million oz of gold last year worth about $100 Billion

We aim to save over $100/oz on gold extraction, without changing any of the upstream processes (digging, crushing, etc)

X = $8 Billion/yr

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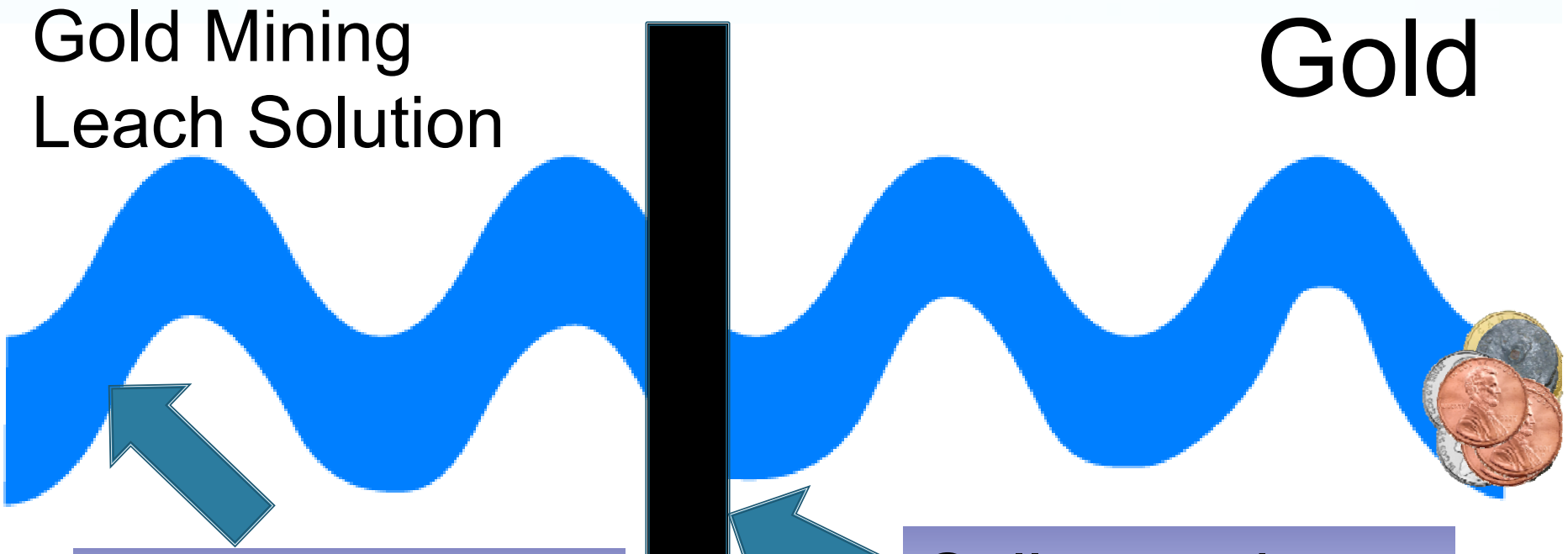
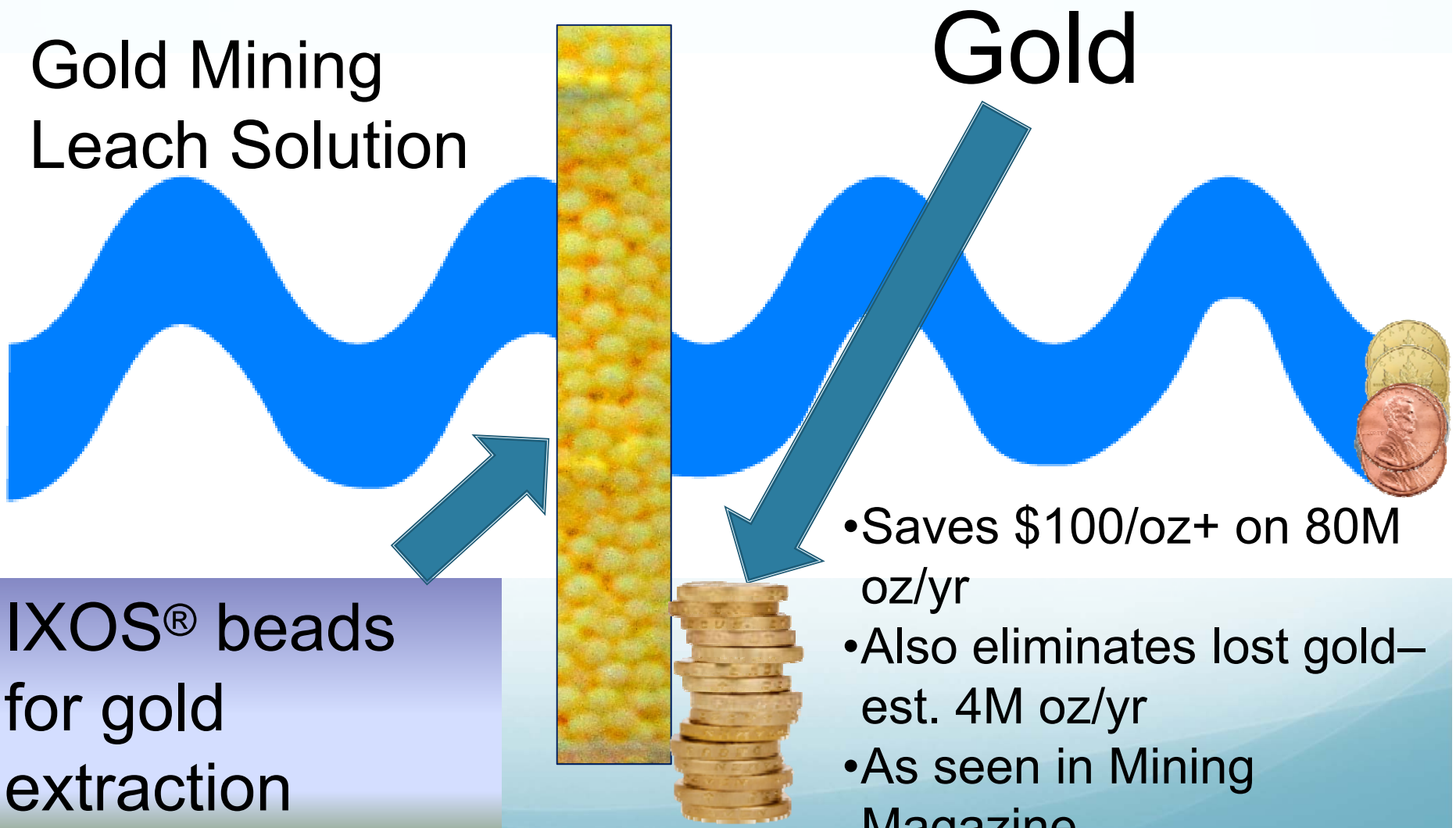
Carbon does OK, not great



IXOS® Extracts Gold Better, Faster, Cheaper



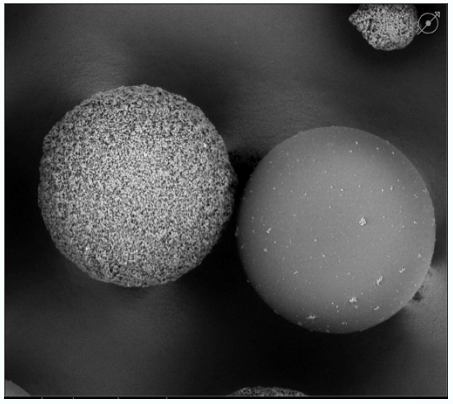
IXOS® beads for gold extraction

- Saves $100/oz+ on 80M oz/yr
- Also eliminates lost gold– est. 4M oz/yr
- As seen in Mining Magazine

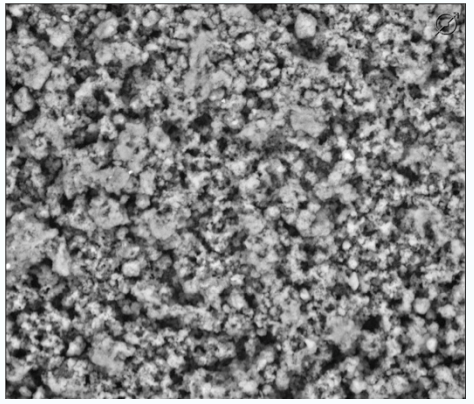
IXOS®: The Product

Naked Eye

Magnified 500x



Magnified 5,000x



A macroporous polymer bead with tremendous surface area with which to capture gold

- High Gold capacity (~25g/kg)
- High selectivity (>97%)
- Virtually no solution loss!!!
- Single step, low temperature elution with direct electrowinning
- No regeneration
- Virtually no attrition and extended re-use

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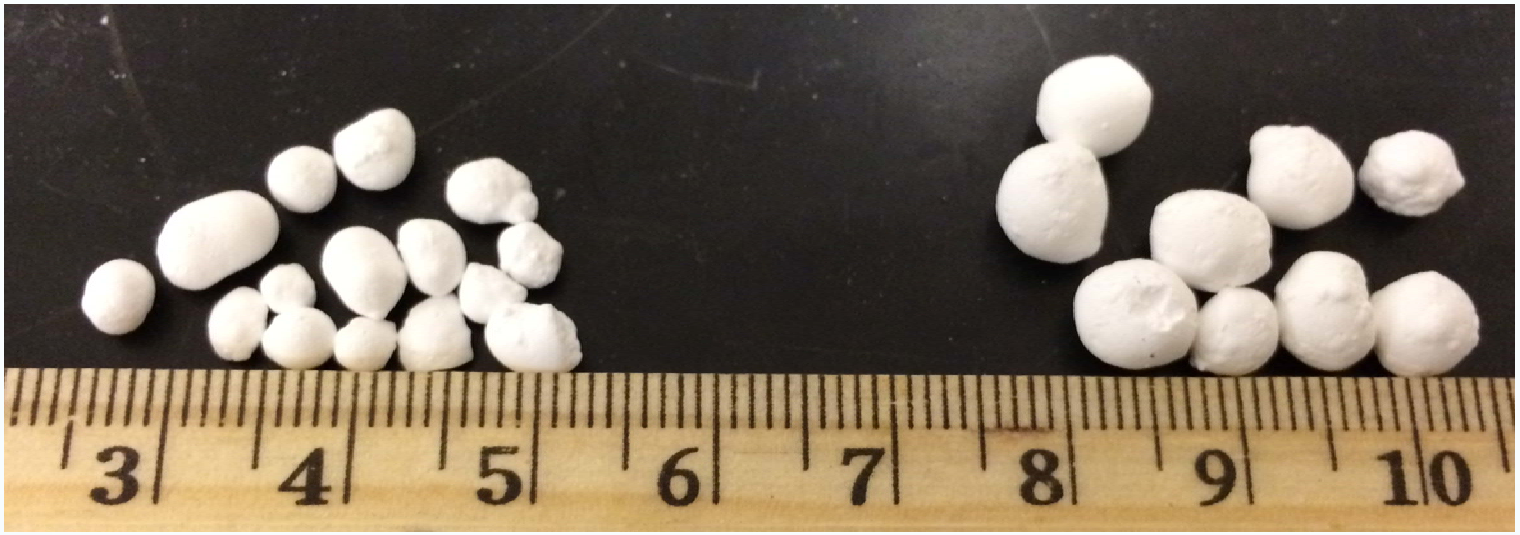
Large Format Beads



- Beads in the 2-5mm range available for specialized applications (.65-1.4mm std.)
- Working capacity for large format beads ~20g/kg
- Hardness equivalent to ~30newtons
- Density of ~.45 g/kg

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Activated CARBON HAS A BIG FOOTPRINT FOR THE GOLD MINING INDUSTRY

- ~$225/oz to extract gold and recharge carbon
- High heat, pressure = high energy use, capital equipment
- $15B+/yr across industry

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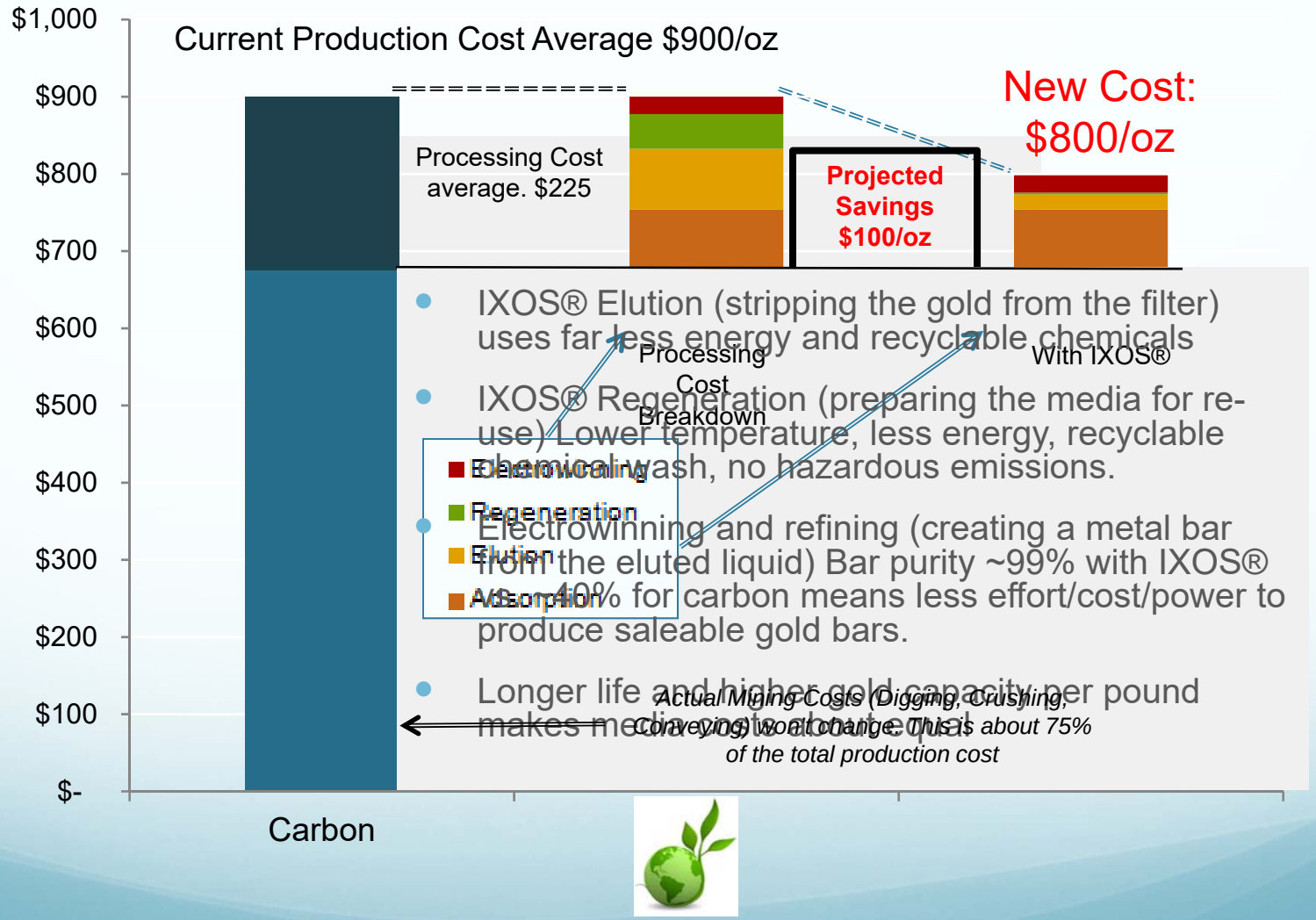
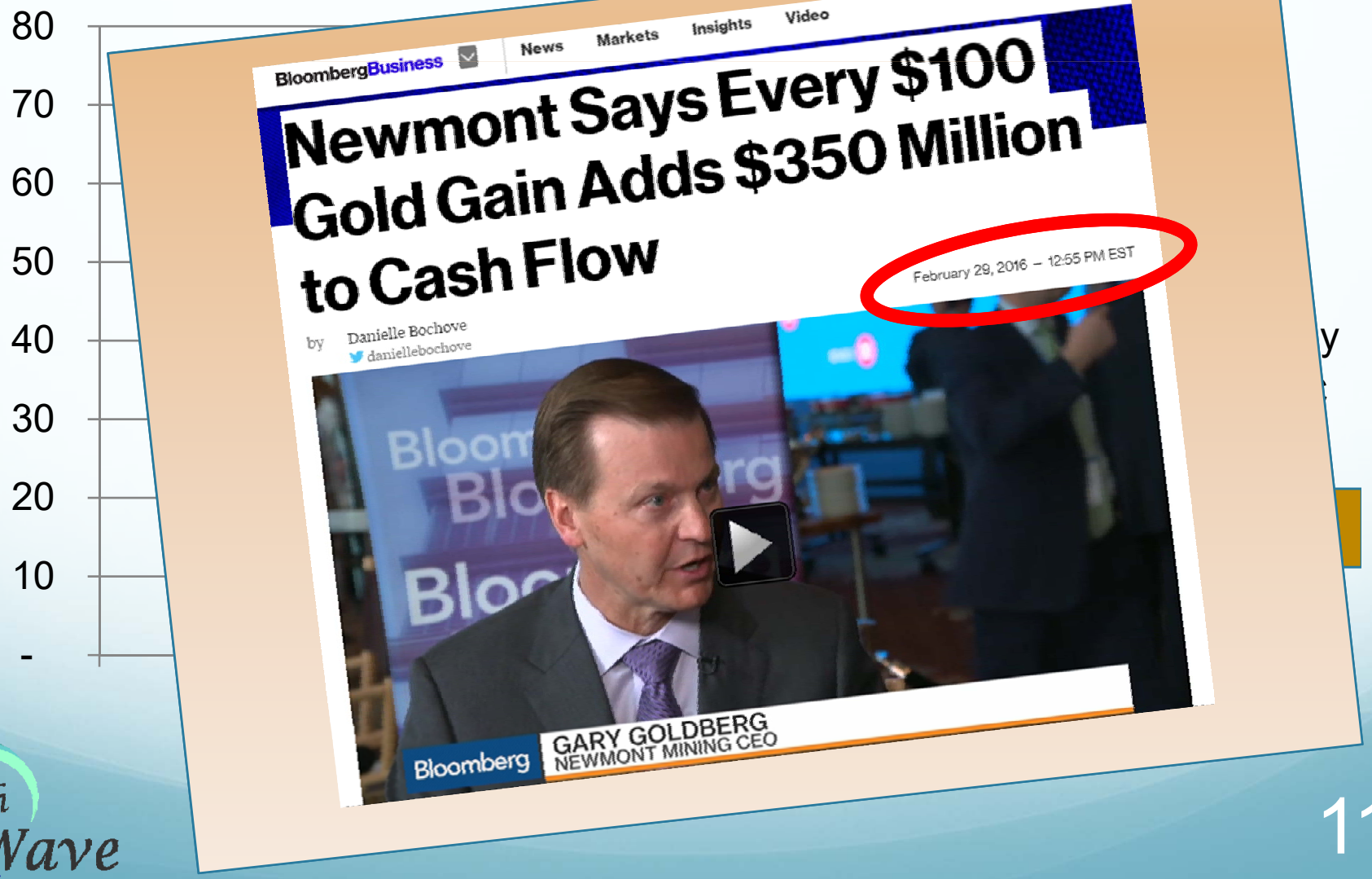
IXOS® makes it all easier



- IXOS® Elution (stripping the gold from the filter) uses far less energy and recyclable chemicals
- IXOS® Regeneration (preparing the media for re-use) Lower temperature, less energy, recyclable chemical wash, no hazardous emissions.
- Electrowinning and refining (creating a metal bar from the eluted liquid) Bar purity ~99% with IXOS® vs ~40% for carbon means less effort/cost/power to produce saleable gold bars.
- Longer life and higher gold capacity per pound makes media costs about equal

Projected Impact on Industry: lower costs, much higher profitability



BloombergBusiness News Markets Insights Video

Newmont Says Every $100 Gold Gain Adds $350 Million to Cash Flow

February 29, 2016 – 12:55 PM EST

by Danielle Bochove
daniellebochove

Bloomberg GARY GOLDBERG NEWMONT MINING CEO

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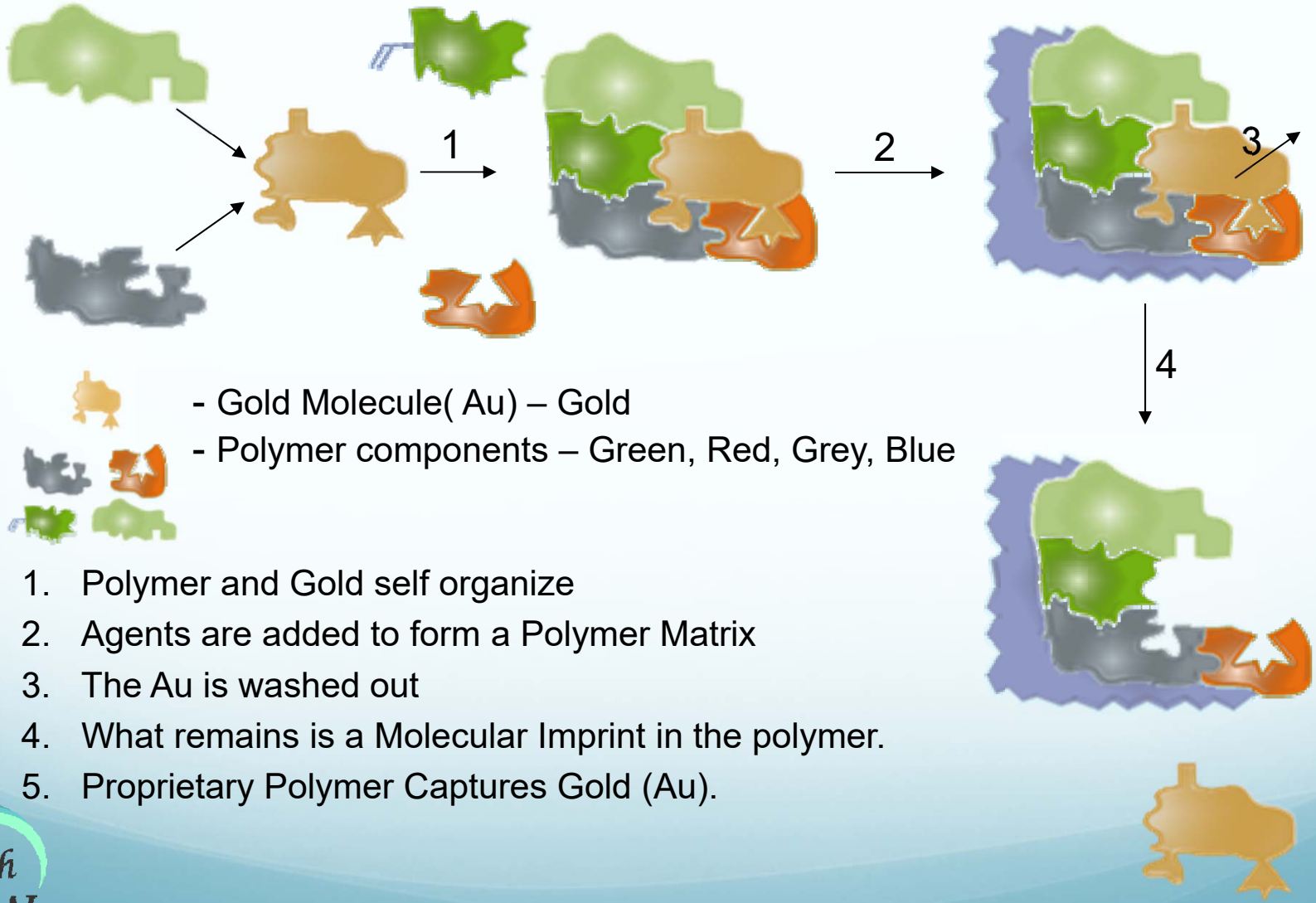
Behind the Curtain: Molecular Imprint Polymers



- Gold Molecule(Au) – Gold
- Polymer components – Green, Red, Grey, Blue

1. Polymer and Gold self organize
2. Agents are added to form a Polymer Matrix
3. The Au is washed out
4. What remains is a Molecular Imprint in the polymer.
5. Proprietary Polymer Captures Gold (Au).

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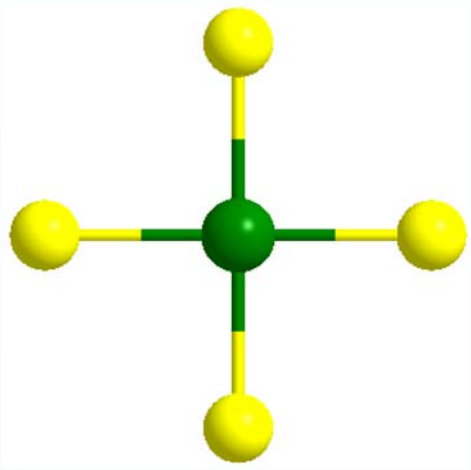
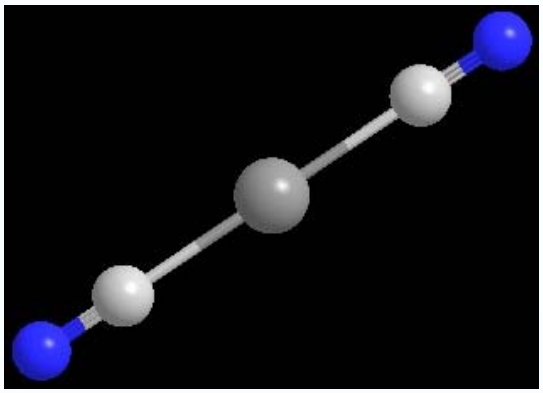
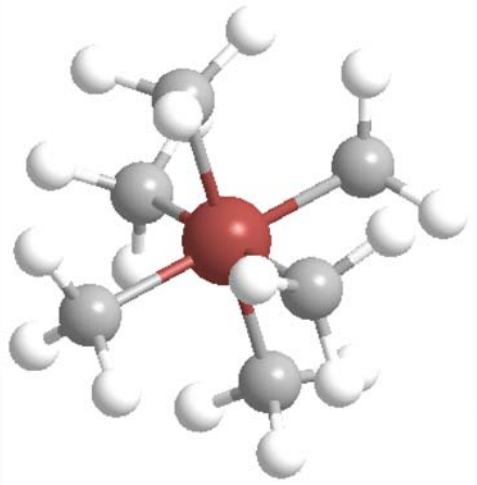
Metals Have Diverse Chemistry which Make Them Unique







Metals in solution have different “shapes” which are dependent upon:

- pH of the solution
- The oxidation state of the metal
- Ionic strength of the solution
- Other dissolved non-metals, such as chloride or sulfate

6th Wave **designs** polymerizable ligands specifically to take advantage of the shape and charge of the desired metal to increase selectivity

Heap Leach Pilot Plant Testing

Heap Leach Pilot Plant

- Multiple continuous flow extraction and adsorption circuits

- Split flow of PLS between a carbon bed and IXOS® columns
- Equal flow rates for both carbon and IXOS® beads but different bed volumes resulted in higher real flow rates for the IXOS® adsorbent

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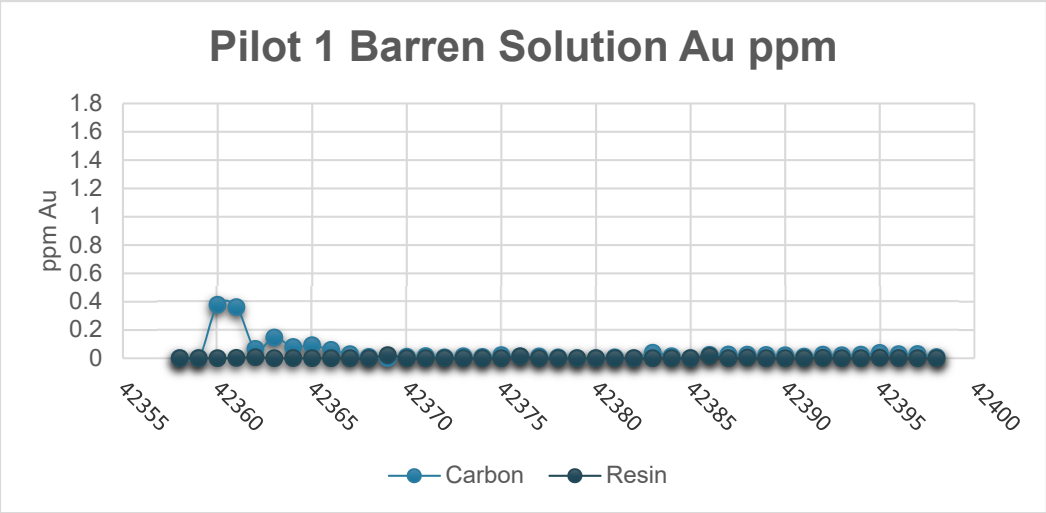
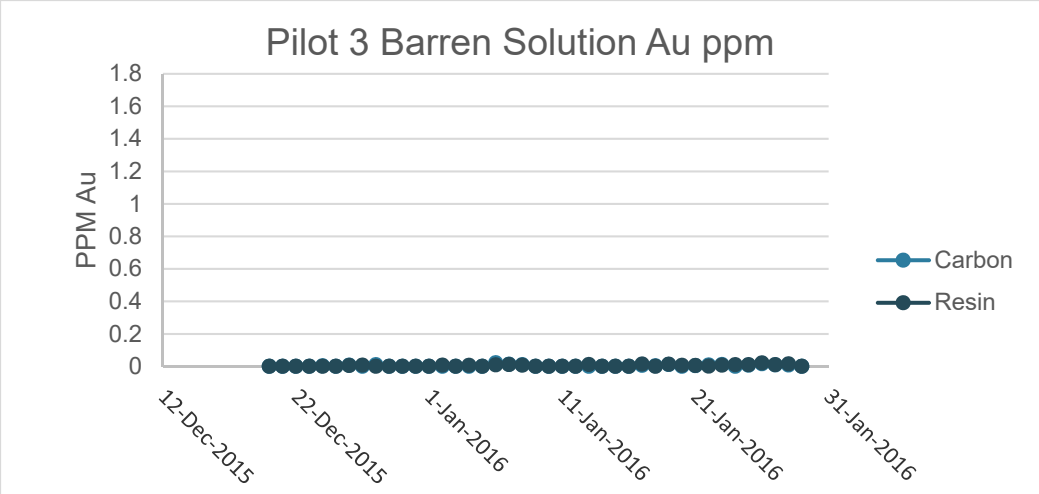
Loading Conditions
Flow Rate

Loading Conditions								
	Total Adsorbant Used (dry g)		Column Bed Volume (ml)			BV/min		
Ore Body	IXOS®	Carbon	IXOS® Col 1	Carbon	Flow Rate (ml/min)	IXOS®	Carbon	IXOS® Flow Rate Compared to Carbon
Pilot 1	164.63	1,882.85	158.96	4,184.11	155	0.975	0.04	26.32
Pilot 2	707.40	1,831.30	963.49	4,069.56	155	0.16	0.04	4.22
Pilot 3	57.38	1,597.15	17.048	3,549.22	155	9.091	0.04	208.18
Pilot 4	413.67	1,707.58	573.99	3,794.62	155	0.27	0.04	6.61
Pilot 5	223.42	1,760.96	127.70	3,913.24	155	1.21	0.04	30.64

IXOS® columns sized based on estimated Au content of the ore in the leach beads

Pilot Plant Loading Results

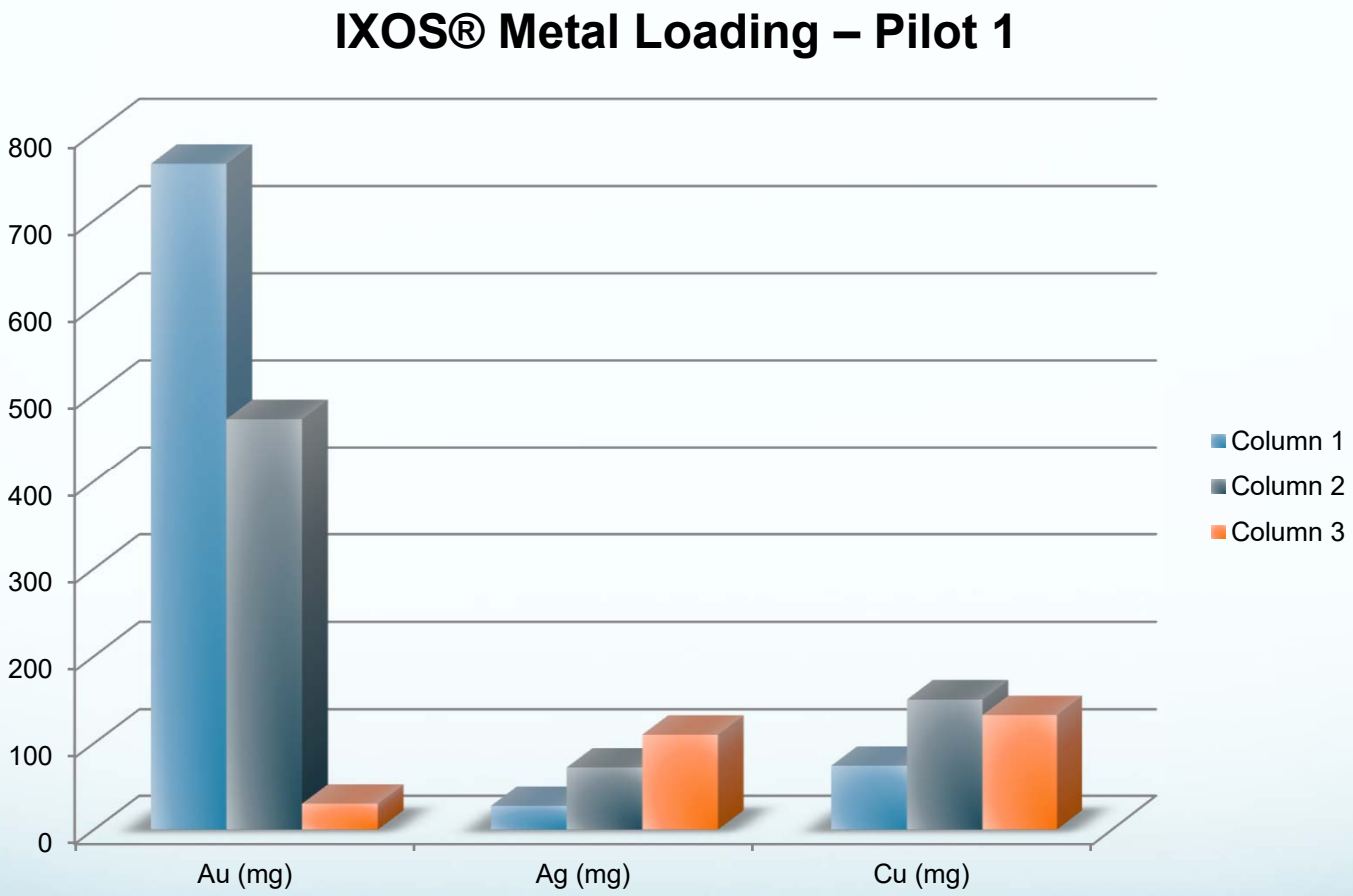




Overall Au Adsorption Efficiency = Au adsorbed ÷ Total Au Recirculated through columns		
	IXOS®	Carbon
Pilot 1	99.3%	83.4%
Pilot 2	98.2%	98.5%
Pilot 3	96.9%	98.0%
Pilot 4	84.4%	97.0%
Pilot 5	62.2%	73.0%

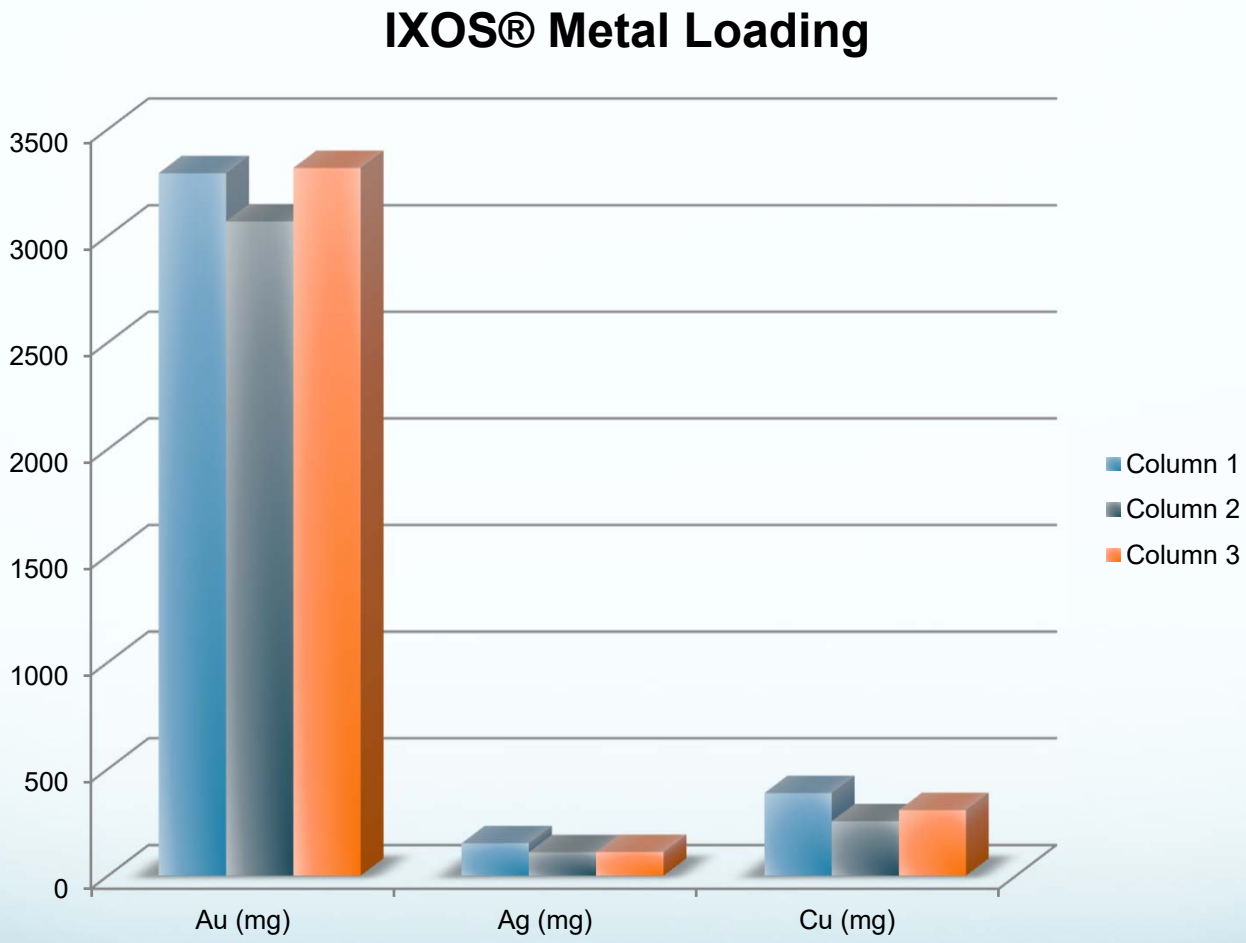
- IXOS® had equal or higher efficiency for Au capture even at significantly higher flow rates
- Pilot 4 & 5 had non-IXOS® related issues that effected performance

Pilot Plant Results



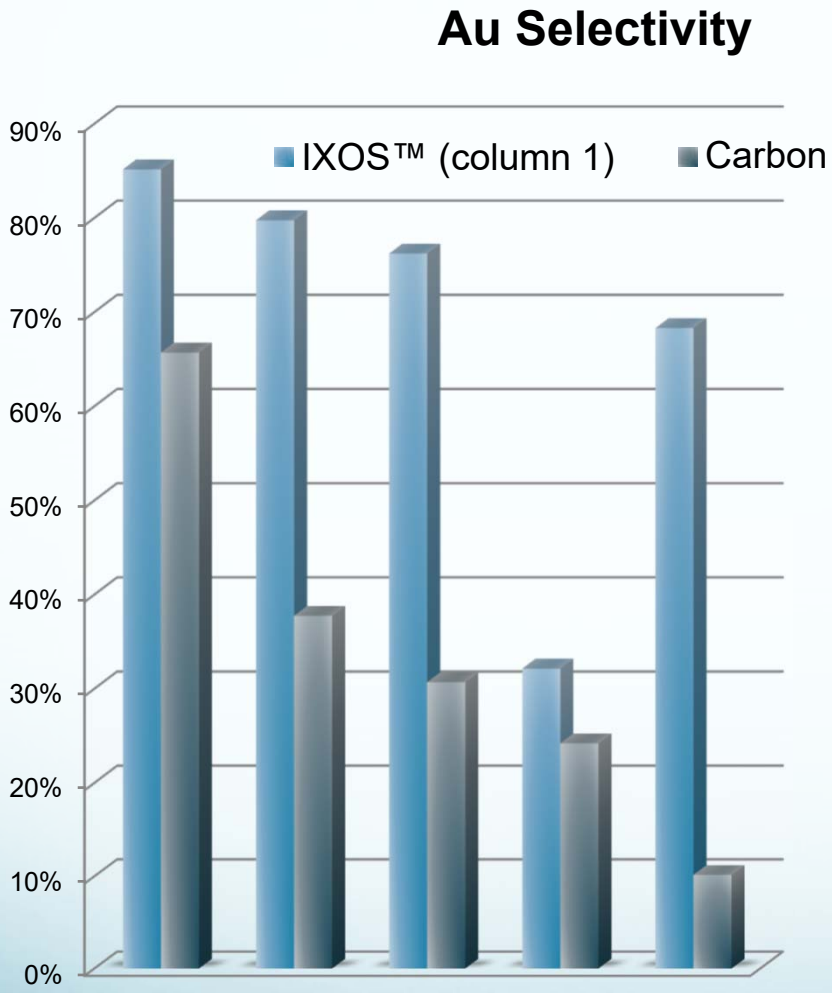
Column 1 Au loading >17g/kg (550oz/t), 85% purity

Plant 2 Results



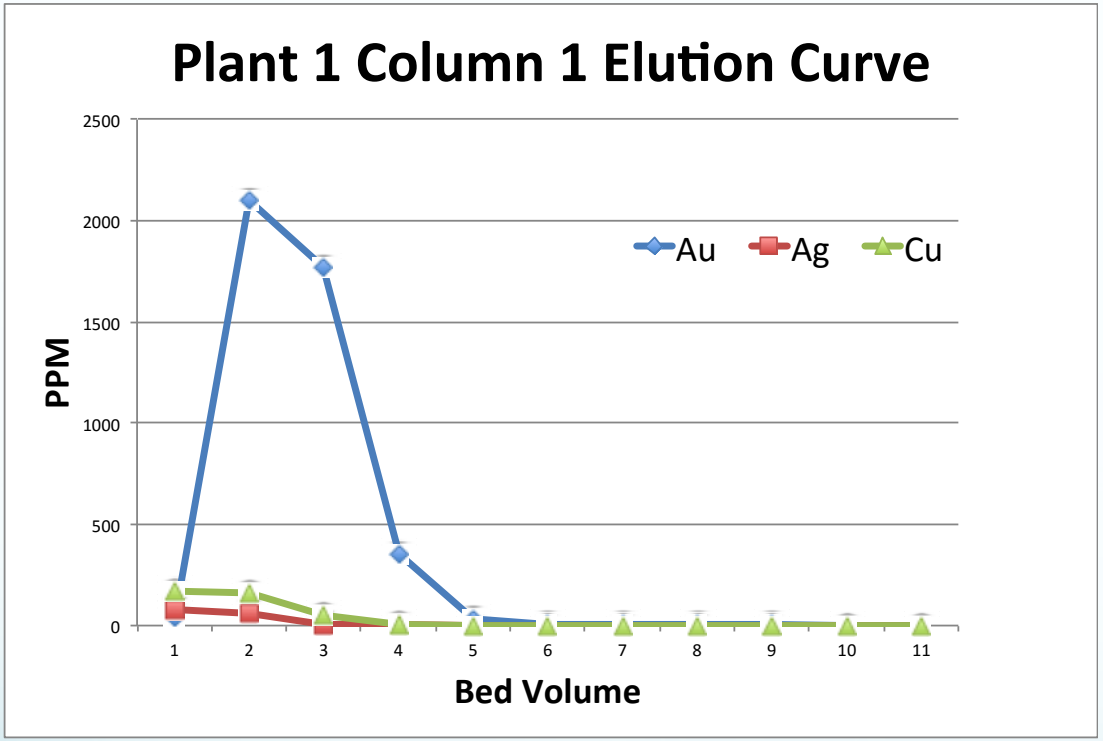
Au loading in all three columns >13mg/g

Gold Selectivity Plants 1-5



- Au selectiveity was uniformly high and better than carbon in all cases.
- None of the IXOS® columns achieved full loading (not enough Au actually extracted).
  - Purity increases as the columns continue to load due to non-specific binding of Cu (predominantly) that is eventually displaced by Au
- Plant 4 overall operations were impacted by several factors including high levels of thiocyanate which impacted both extraction and adsorption
- Plant 5 was artificially spiked with additional Cu which had a slight effect on overall Au selectivity for IXOS® but a dramatic effect on carbon

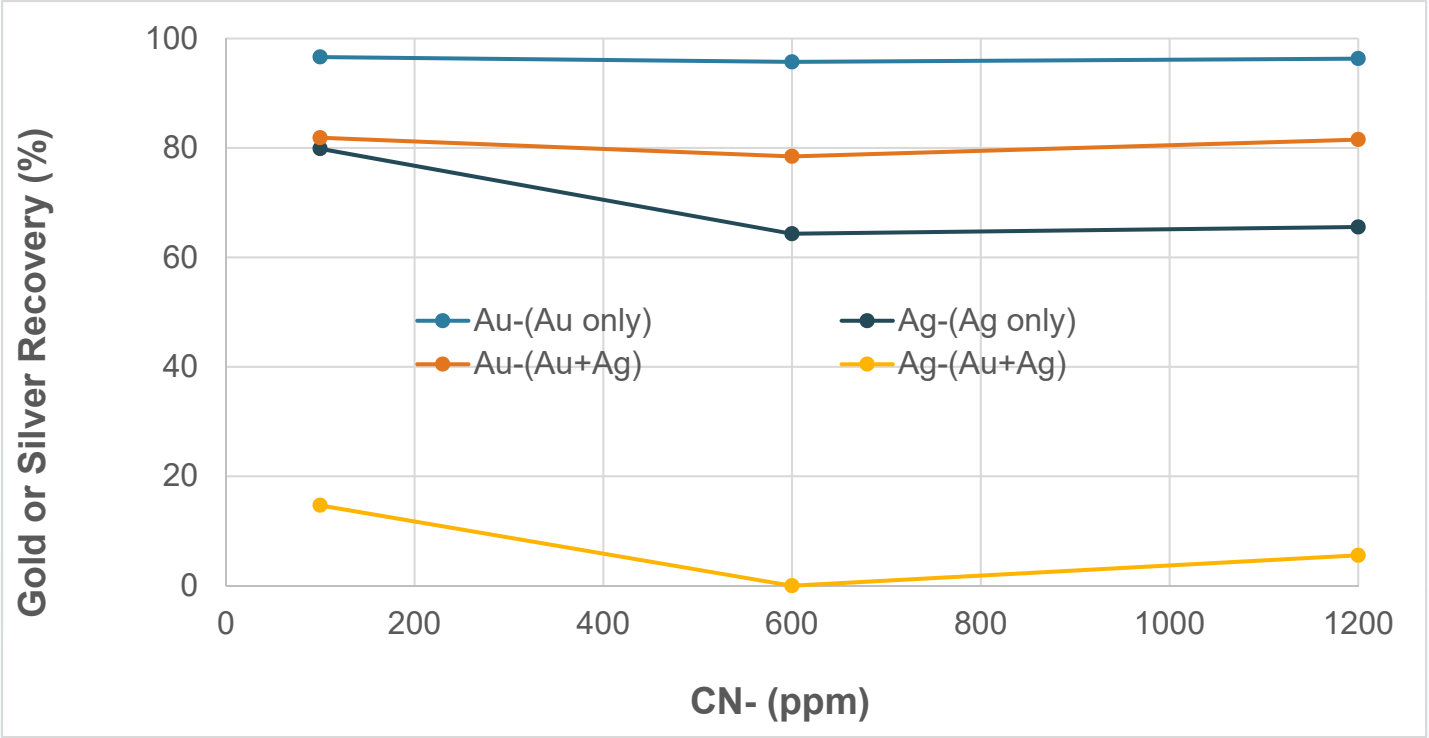
Thiourea/Sulfuric Acid Elution Curve



- Elution performed at 0.25bv/min @ 60°C.
- None of the elution curves differed for the five pilot plants
  - Elution can be efficiently done below 50°C with extended elution time
- Mass balance analysis indicate that full elution was obtained with little to no retention of any metals on the IXOS® beads.
- Use of this eluent allows the IXOS® beads to be put back into the adsorption circuit with NO regeneration or other processing
- Eluent is re-usable
- Eluent supports direct electrowinning

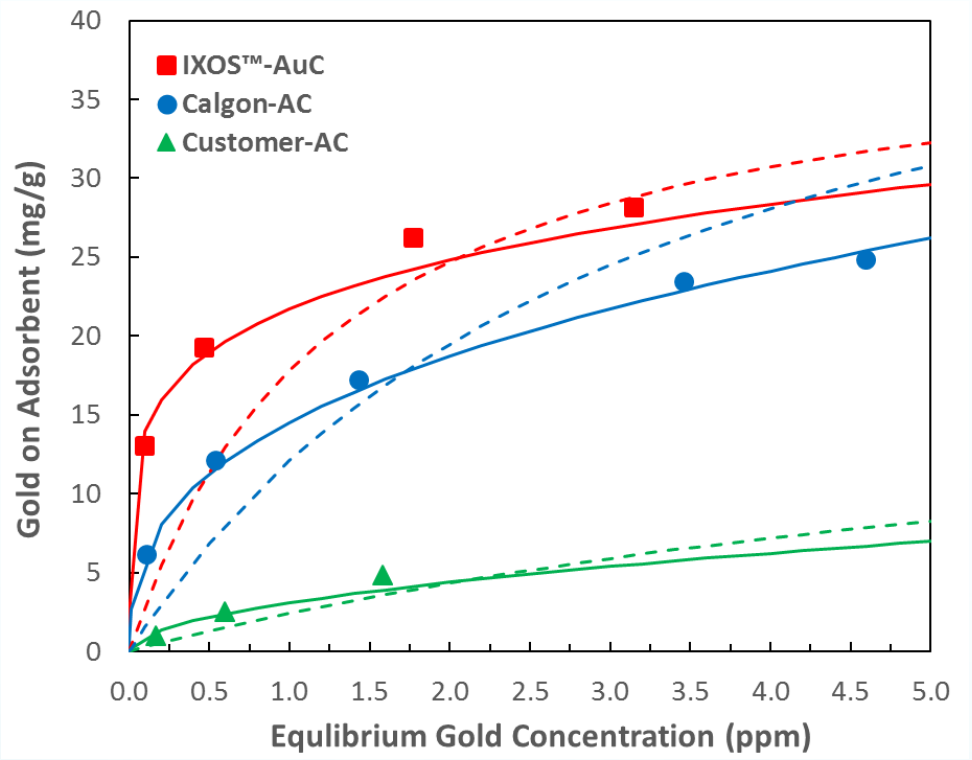
Laboratory Testing

Au vs Ag Adsorption as a function of free Cyanide



- Static loading tests show that IXOS® Au-C beads will load Ag but is highly preferential to Au.
- At lower levels of free cyanide as typical of heap leach operations Ag recovery is possible if desired
- At high levels of free cyanide as typical of RIL/RIP Ag recovery is not likely.
- Cyanide can be effectively used as an eluent for Ag

Gold Adsorption Capacity of IXOS®-AuC Bead vs. ACs



Solid line: Freundlich model

$$Q_e = K\, C_e^{1/n}$$

Dash line: Langmuir model

$$Q_e = (Q_m\, b\, C_e) / (1+b\, C_e)$$

1. IXOS®-AuC bead has higher adsorption performance than activated carbon.
2. IXOS®-AuC exceeds at low Au concentrations making it PERFECT for addressing solution losses and ensuring complete extraction

- Adsorbent loading (W) = 0.1 g, Adsorption temperature (T) = 25 °C, Shaking speed = 210 rpm, Volume of Au ion solution (V) = 100 ml, pH = 10.5;
- MIP = IXOS®-AuC, ACs = Calgon Gold Plus 6X12, Customer

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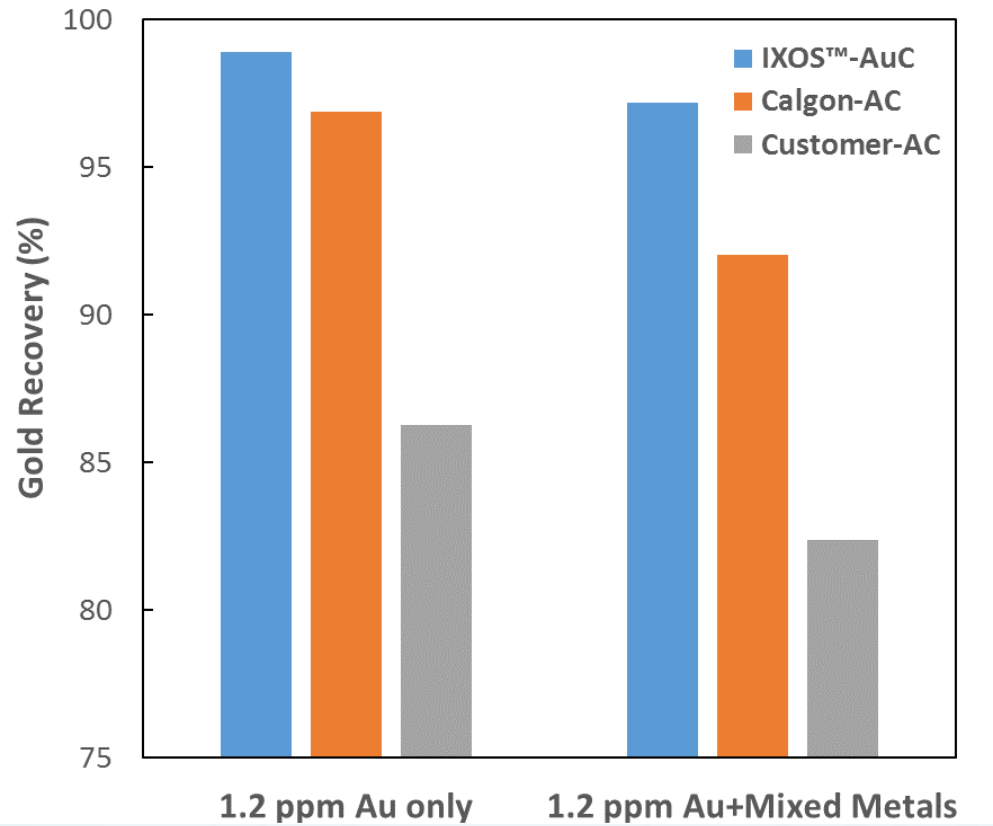
Effect of the Other Metals on Gold Adsorption



Other Metals:
Hg = 2ppm, Ag = 3 ppm,
Cu = 2 ppm, Ni = 2 ppm,
Zn = 0.2 ppm, Fe = 22 ppm

(Simulated to PLS solution)

The gold recovery of the IXOS bead is less influenced by the additional metal complexes than those of the two activated carbons.

- Adsorbent loading (W) = 0.1 g, Adsorption temperature (T) = 25 °C, Shaking speed = 210 rpm,
- Volume of Au ion solution (V) = 100 ml, pH = 10.5; MIP = IXOS®-AuC, ACs = Calgon Gold Plus 6X12, Customer

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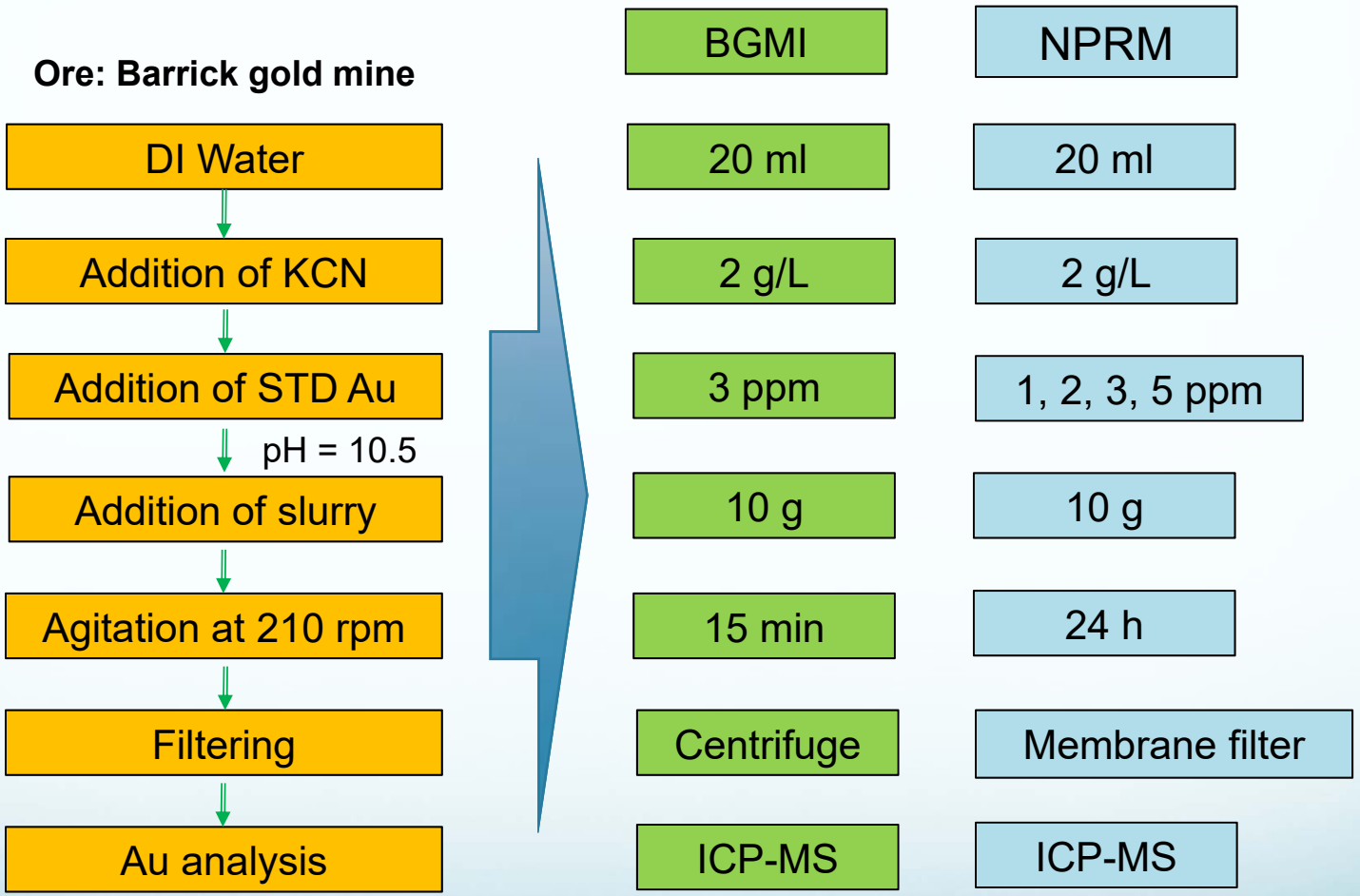
Analysis of Gold Ores by Two Pre-Robbing Test Methods

Ore: Barrick gold mine

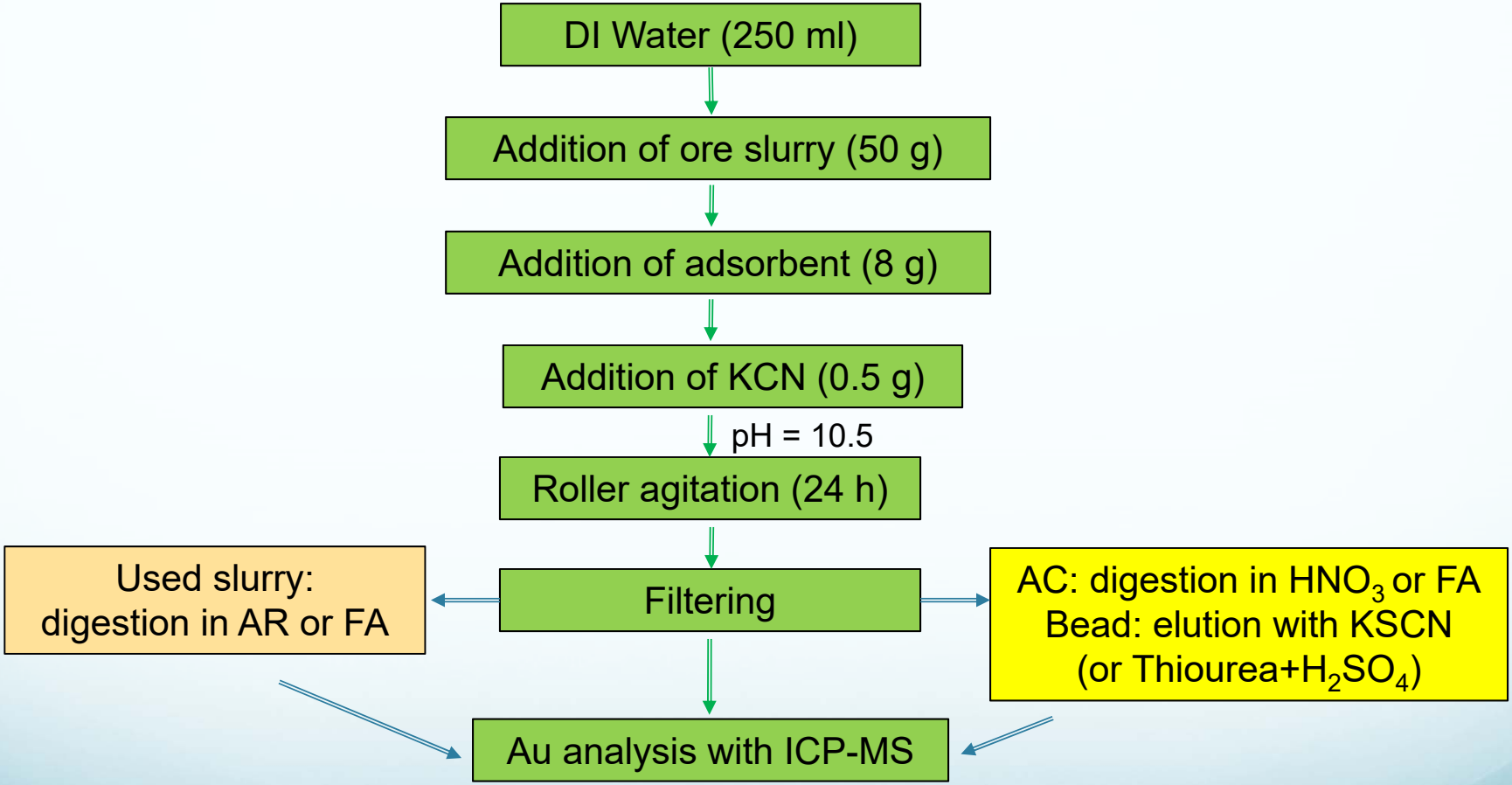


Pre-Robbing potential: BGMI = 52 %, NPRM = 76 % ➔ Moderately Preg-Robbing Ore

* BGMI: Barrick Gold Mines Incorporated, NPRM: New Preg-Robbing Method

Reference: W.R. Goodall, J.D. Leatham, P.J. Scales, Minerals Engineering 18 (2005) 1135-1141.

Gold Recovery from Adsorbent-in-Leach (AIL) Tests of Preg-Robbing



* AC: activated carbon, AR: aqua regia, FA: fire assay

Reference: AuTec Standard Operating Procedure, February 18, 2015

Gold Recovery Results from AIL Preg-Robbing Tests

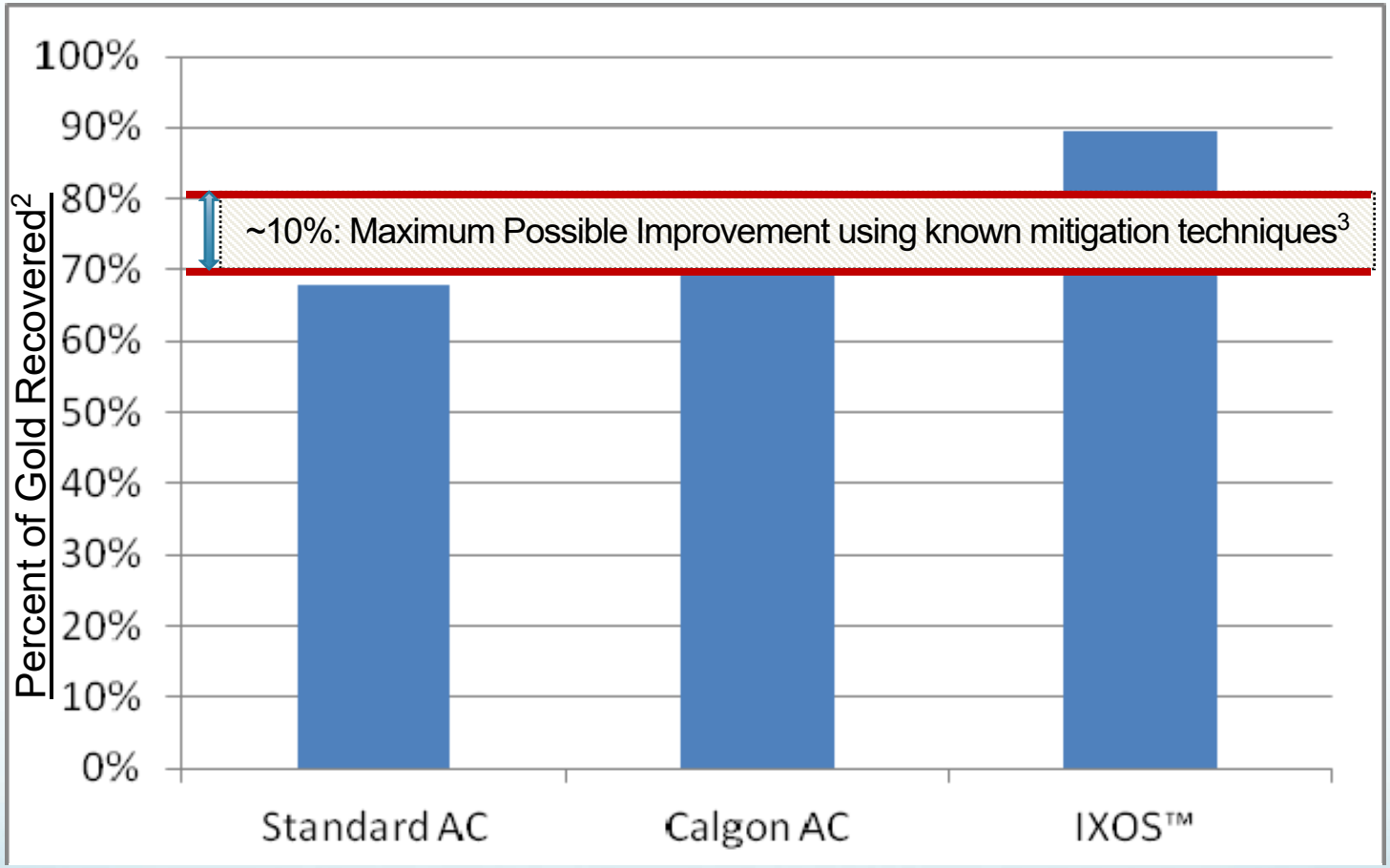
Gold Recovery Analysis

Sample		Fresh Slurry (FA)	Spent Slurry (FA)	Solution (ICP)	Adsorbent (ICP)	Recovery-Digestion or elution	Recovery- FA
		(mg)	(mg)	(mg)	(mg)	(%)	(%)
IXOS®-AuC	**Lab 1**	**0.227**	**0.051**	**0.0008**	**0.201**	**88.6**	**77.1**
	Lab 1-R1	**0.183**	**0.054**	**0.0011**	**0.169**	**92.4**	**70.1**
	Lab 1-R2	0.183	0.058	0.0011	0.159	86.8	68.0
	MTI 1	0.181	0.058	0.0010	0.148	81.8	67.7
Activated Carbon	**AC-Customer 1**	**0.227**	**0.138**	**0.0029**	**0.112**	**49.6**	**37.8**
	AC-Customer 2	**0.183**	**0.073**	**0.0029**	**0.124**	**67.9**	**58.5**
	AC-Customer 3	0.181	0.074	0.0239	0.104	57.5	45.9
	AC-Calgon 1	**0.183**	**0.072**	**0.0026**	**0.127**	**69.5**	**59.5**

IXOS®-AuC shows higher gold recovery than the two activated carbon types: IXOS®-AuC has higher ionic strength for the gold cyanide complex over the carbonaceous matter in the ore.

- Recovery-Digestion (%) = Adsorbent (ICP) / Fresh Slurry (FA) x 100
- Recovery-FA (%) = (Fresh Slurry (FA) – Spent Slurry (FA) – Solution (ICP)) / Fresh Slurry (FA) x 100
- ICP: 6th Wave, Fire Assay (FA): FLSmidth
- Adsorbent loading (W) = 8.0 g, Ore Slurry (W) = 50 g, Temperature (T) = 25 °C, Roller agitation duration = 24 h, Volume of slurry solution (V) = 250 ml, pH = 10.5
- MIP = IXOS®-AuC, ACs = Calgon Gold Plus 6X12, Customer

In Preg-robbing ore, IXOS® Recovered 30% more gold[1]



(1) MIP = IXOS®-AuC, ACs = Calgon Gold Plus 6X12, Standard AC

(2) Gold contents in [Customer] Ore of 3.66mg/kg determined by a fire assay method (FLSmidth). For each adsorbent, 50g of slurry and 8g of adsorbent were mixed in solution. Adsorbent loading (W) = 8.0 g, Temperature (T) = 25 °C, Roller agitation duration = 24h, Volume of slurry solution (V) = 250 ml, pH = 10.5

(3) Most effective non-IXOS® method involves complex process requiring 13 different chemicals for elution!

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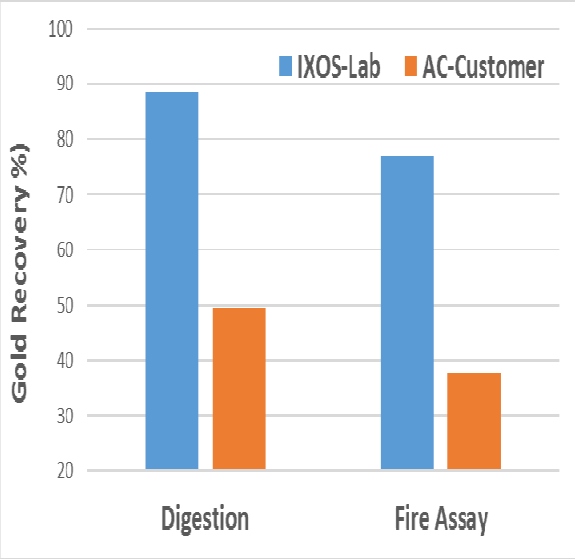
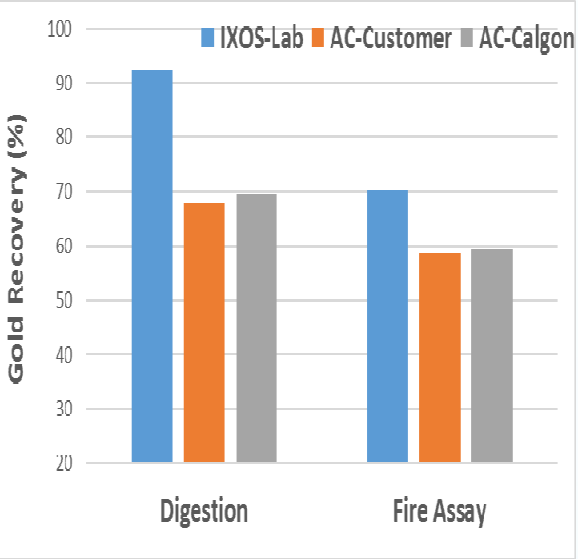
Gold Recovery Results from AIL Tests (ICP vs. Fire Assay)

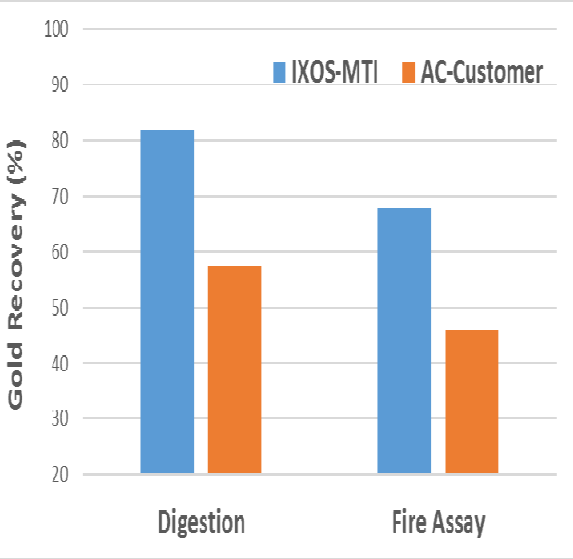
Test 1



Test 2



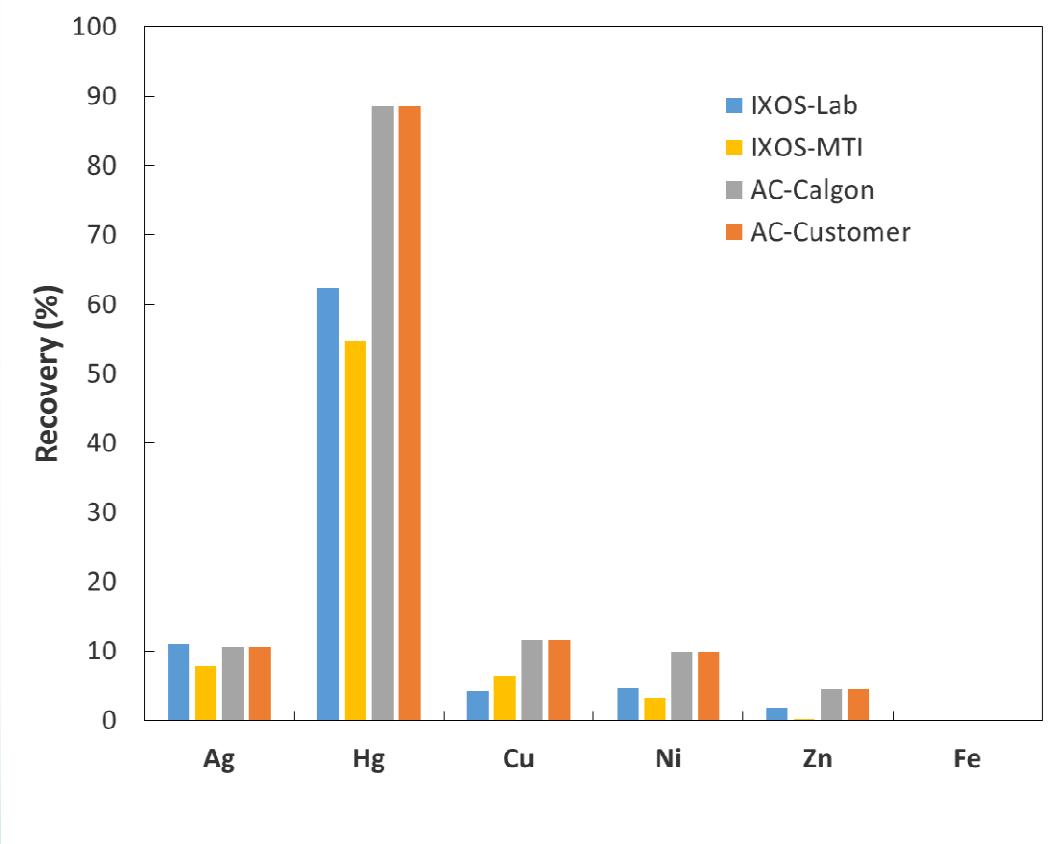
Test 3



- ICP: 6th Wave, Fire Assay (FA): FLSmidth
- Adsorbent loading (W) = 8.0 g, Ore Slurry (W) = 50 g, Temperature (T) = 25 °C, Roller agitation duration = 24 h, Volume of slurry solution (V) = 250 ml, pH = 10.5
- MIP = IXOS®-AuC, ACs = Calgon Gold Plus 6X12, Customer

- IXOS® shows significantly increased Au extraction in preg-robbing ore
- These results are consistent with reuse of IXOS®
- Increased extraction levels are consistent with levels reached using other expensive techniques (roaster, thiosulfate extraction)

Silver and Other Metal Recovery Results from AIL Tests



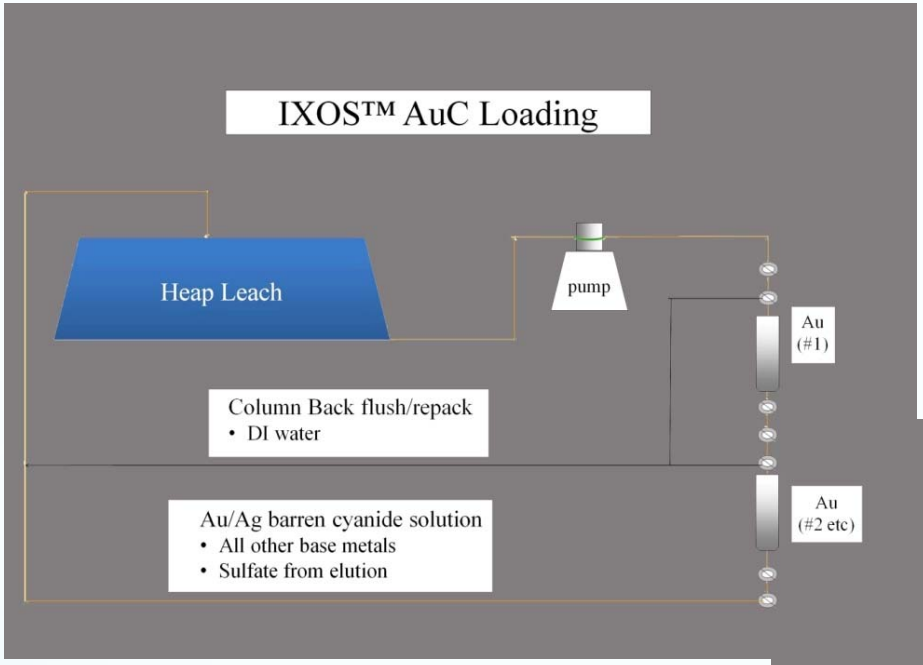
- Silver recovery of the IXOS bead is similar to the two activated carbons.
- Hg, Cu, Ni, and Zn recoveries by IXOS® bead is less activated carbon
- Higher purity and higher Au capacity for IXOS® over activated carbon.

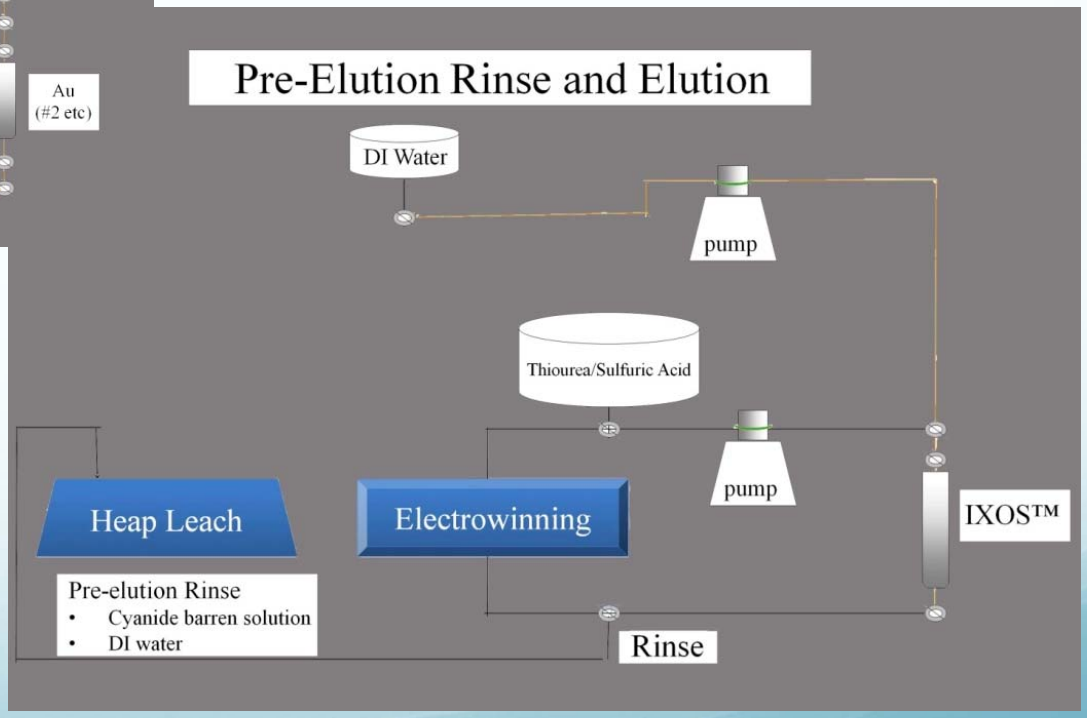
- Adsorbent loading (W) = 8.0 g, Ore slurry (W) = 50 g, Temperature (T) = 25 °C, Roller agitation duration = 24 h, Volume of slurry solution (V) = 250 ml, pH = 10.5
- MIP = IXOS®-AuC, ACs = Calgon Gold Plus 6X12, Customer

Accelerated Aging (column tests)

- IXOS® beads were repeatedly cycled through loading, elution/regeneration.
  - The pH varied from 10.5 (loading) to 1.5 (elution)
  - Temperature swings from ambient to 60°C,
  - Large changes in ionic strength.
- IXOS® beads showed consistent loading capacity across cycles.
- Minimal/no swelling was observed with no measurable attrition.
- Cycle testing completed to 2yr usage.

Simple Loading and Elution





DI water not required in operational system

Key Advantages

- Lower CAPEX
  - High capacity and purity resulting in smaller plant
  - Less complicated circuit with fewer parts
- Significantly lower OPEX
  - Simple low temperature elution
  - NO REGENERATION
  - Eco friendly OPEX savings
    - Lower water usage
    - Recyclable elution chemicals
    - Lower power requirements
    - No toxic airborne emissions

6th Wave

IXOS® Solution Loss Recovery Plant

Example Proposal
for
ANYCO Mines

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Proposal Overview

- 6WIC is proposing to build and install a solution loss recovery (SLR) plant at ABC
- 6WIC will do this at its cost to include building, installation, commissioning, and training of ANYCO personnel for continued operation
  - ANYCO will be responsible for providing the pad, piping to and from the relevant solution streams, and electrical hookup.
- 6WIC and ANYCO will share the recovered gold
- ANYCO will have the option to purchase the final plant after a negotiated period of time
- Program will proceed in two phase
  - Phase 1 pilot plant to validate recovery and optimize design for full size plant
    - Pilot plant to be capable of solution flow up to $20M^3/hr$
  - Phase 2 install plant capable of treating all of the barren solution
- 6WIC has engaged Kappes, Cassiday & Associates for this project. They will handle all aspects of the build and installation under contract to 6WIC.

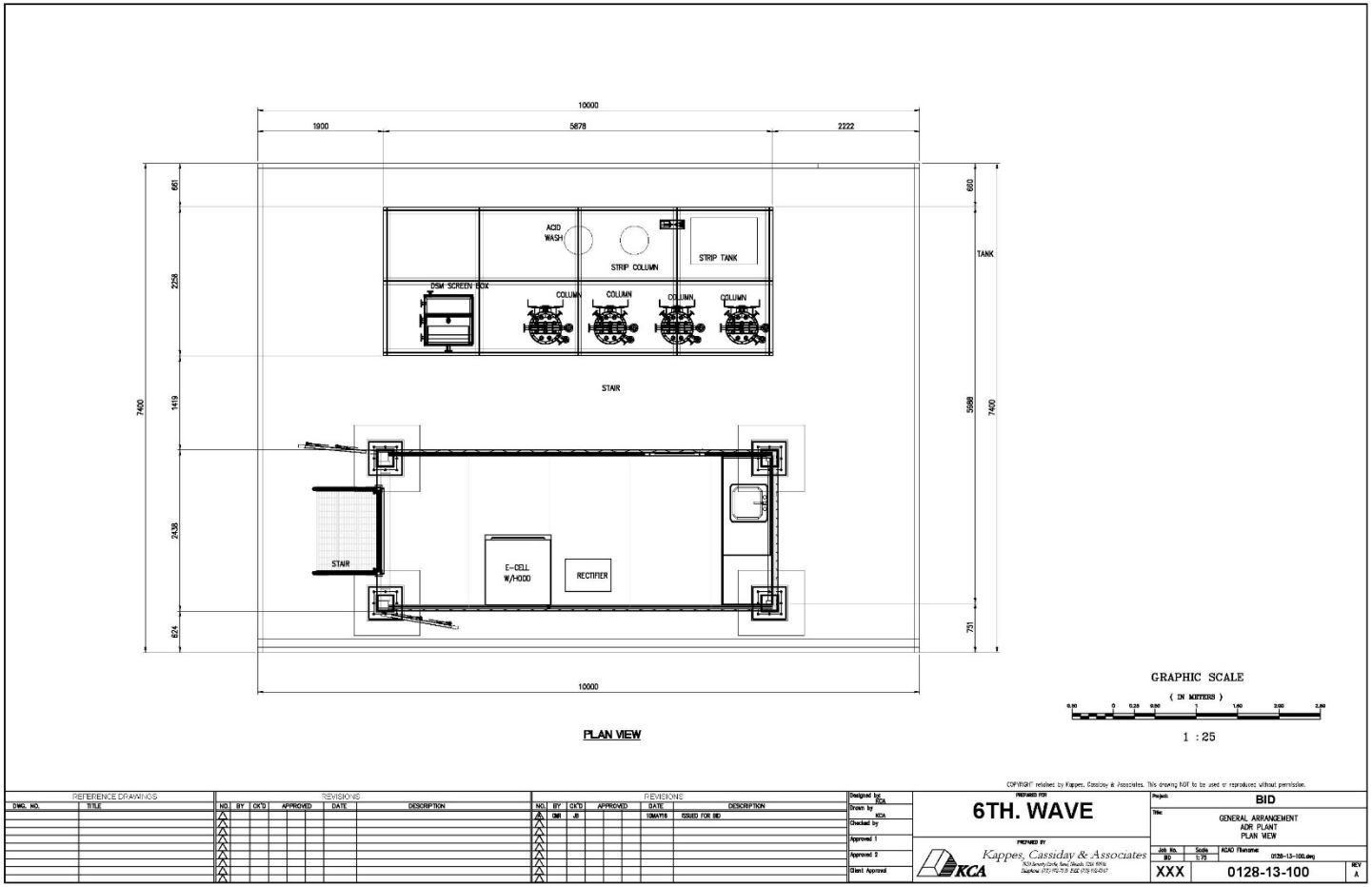
6th Wave

Pilot Plant Design

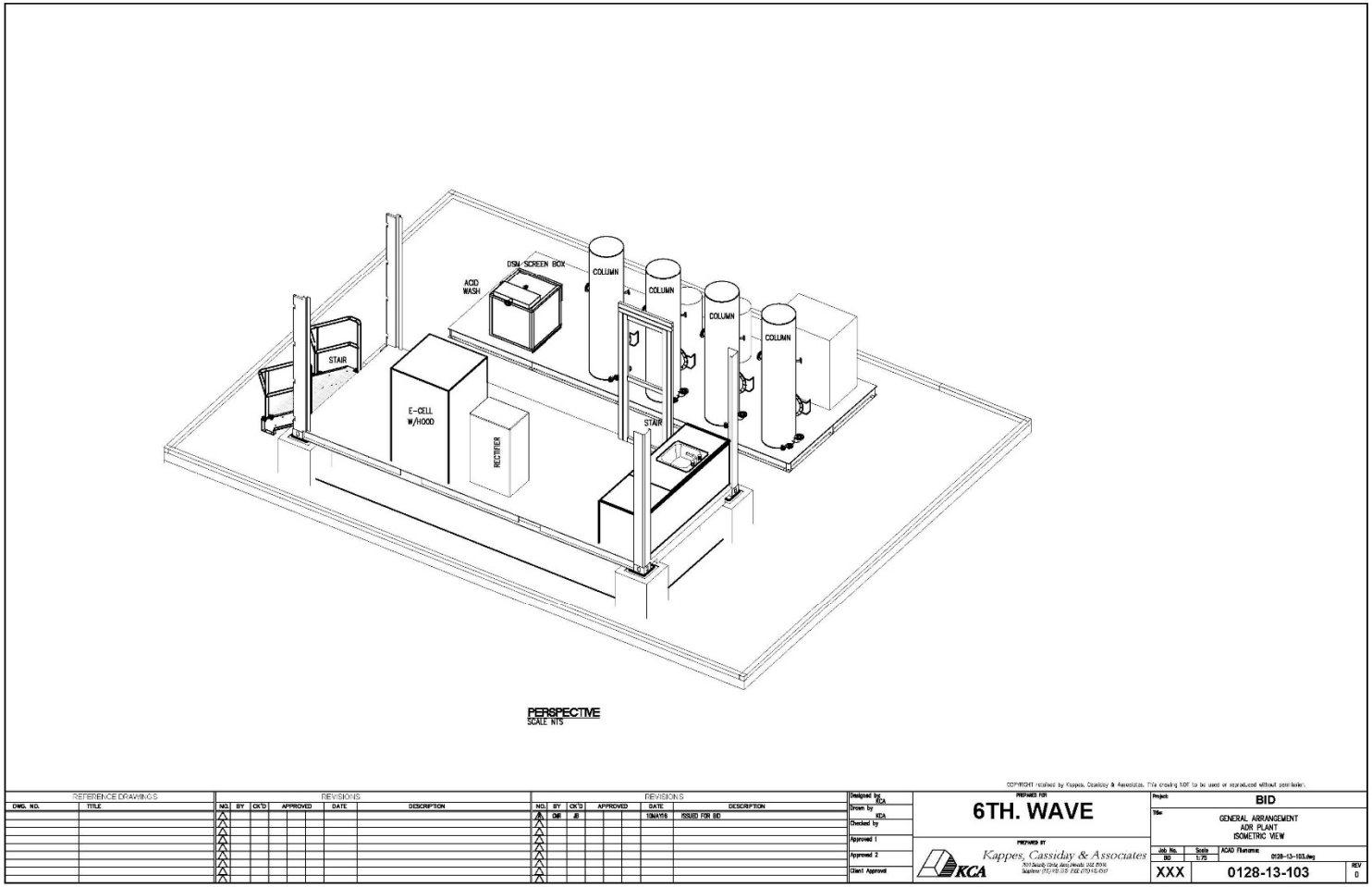
- Plant Components
  - Column Skid (5.5-meter)
    - Adsorption and stripping columns
    - All mechanicals and solution tanks
  - Recovery Module (6-meter shipping container)
    - Lab work area, electrowinning
- Adsorption
  - 4 active adsorption columns, up-flow fluidized beds
  - Carousel operation – counter current
  - Adjustable flow rate designed up to 20m^3/hr
- Desorption
  - Separate single column
  - Continuous flow closed circuit elution
    - Elution with Sulfuric Acid/thiourea solution
  - Single holding tank
- Recovery
  - Direct electrowinning cell in line with eluent

6th Wave

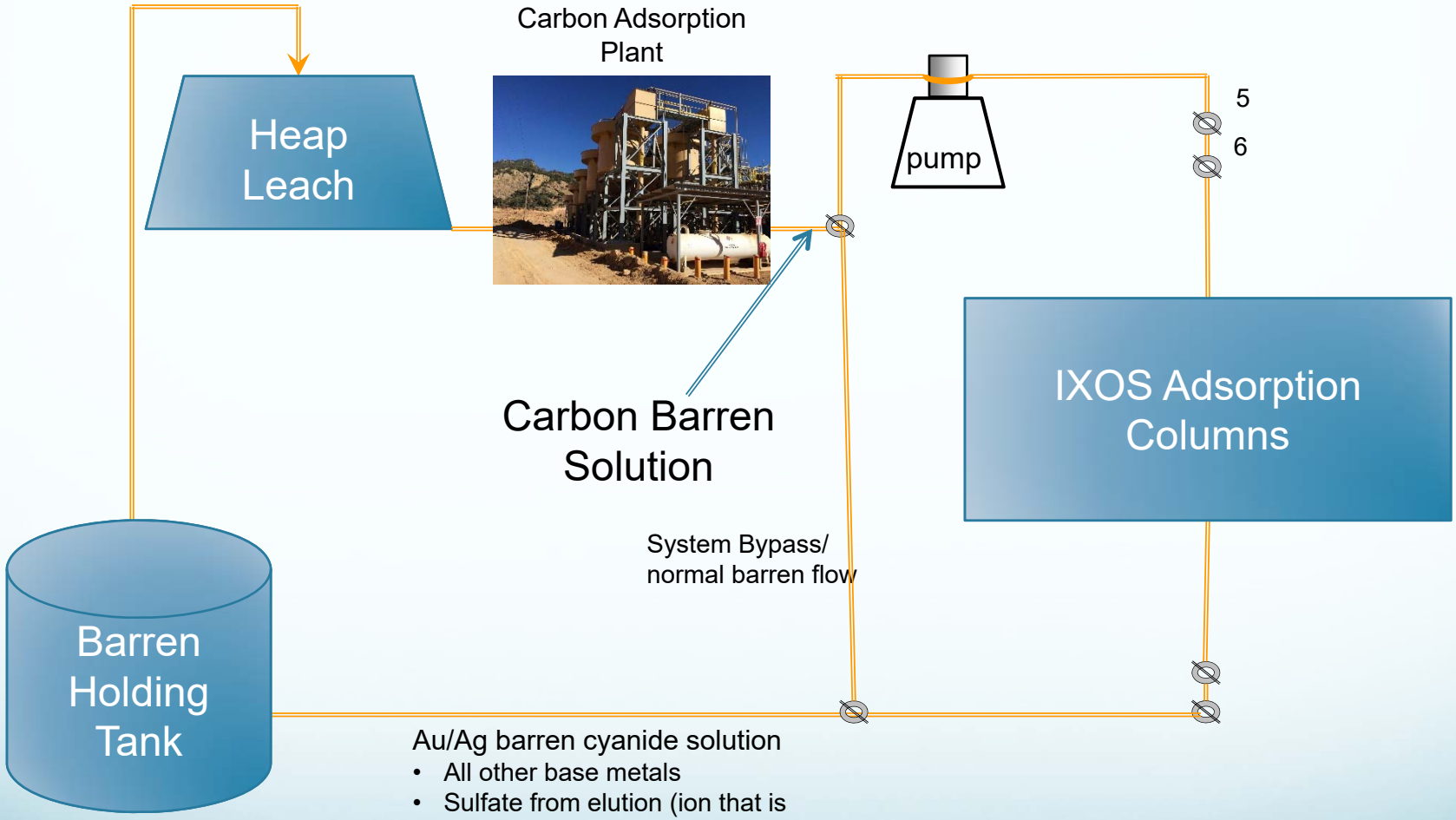
Pilot Plant Layout Top View



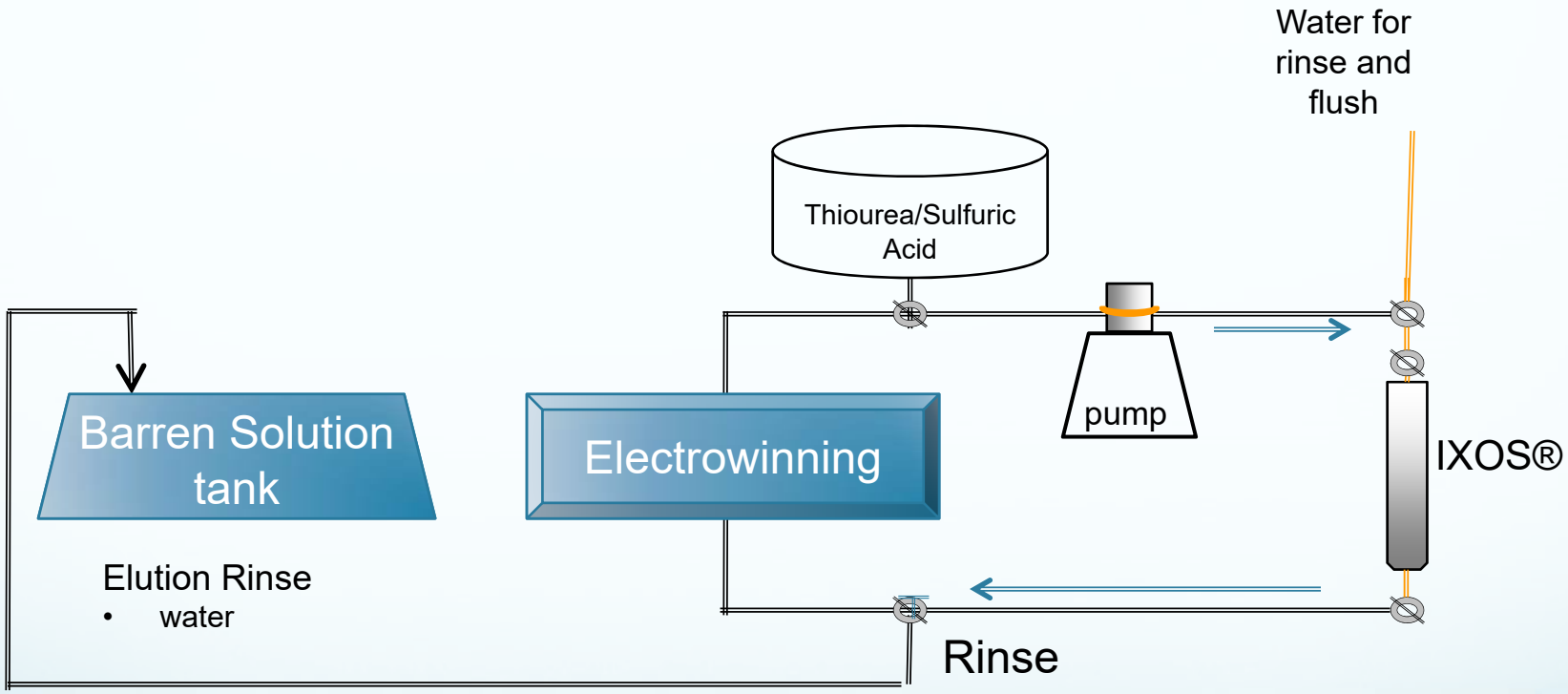
Pilot Plant Plan View



IXOS® Pilot Plant Installation
Top Level Flow Diagram



IXOS® Elution Preliminary Design



ABC Key Operating Facts

- Location — Anywhere
- Mine Type — Open-pit, heap-leach
- Estimated Mine Life — 2014 - 2020
- 2015 Production — 105,000 oz gold
- 2017-18 Av. Production Goal — 110,000
- Secondary Metals — Minor silver component
- Designed Throughput — 16,000 tons/day crushing plant and heap leach processing

Pilot Plant Operating Parameters

Pilot SLR Plant Operating parameters and Value Generation	
IXOS Working capacity for Au (g/kg)	15
Au ppm in solution	0.040
Flow rate (m3/hr; Designed for 10-20)	20.0
Au price (oz)	$1,250
Bed Capacity for IXOS beads (dry kg)	52.5
Au Bed capacity (g)	786.9
Au bed capacity (oz)	27.8
Value per elution	$34,695
Estimated days to Au capacity	31.0
Au average monthly scavenged (30days)	$33,524
Cost of Opperations per 30 day elution period	$969
Net Value per elution	$32,555
Cost/oz Au	$34.93
Cost/ton of ore	0.63

1. Pilot Plant Bed Calculations

Diameter	height	area	vol
cm	cm	cm2	cm3
45	100	1590	158963
vol	IXOS Volume	weight	Dry weight
L	g/cm3	g	kg
159	0.33	52458	52

2. Addsorption condition

PLS	Flow	Flow	Gold flow	IXOS Cap
ppm (mg/L)	m3/hr	L/min	mg/min	mg/g
0.040	20.0	333.3	13.3	15
Bead	IXOS Bed Cap	Fill Time	Time	Time
g	mg	min	hrs	days
39,741	596,109	44,708	745	31

Pilot Plant Operating Costs

Annual ADR Pilot Plant Operating Expenses		
Elution Reagents		$112.12
Power ($0.23 kWh/t)		
Adsorption (24/7)	3kWh	$6,044.40
Elution (3hrs)	7kWh	$58.77
Electrowinning (3hr)	11kWh	$92.35
Labor		$5,000.00
IXOS attrition (0.5%/elution)		$486.67
	Total	$11,794.30

Value Proposition

Estimated Value to Agnico-Eagle for Full Scale SLR plant	
ABC Production (oz/yr)	105,000
Estimated Life of Mine post plant installation (yrs)	6
Solution loss (average)	10%
Available Au for capture (annual)	10,500
Average price of Au	$1,250
Annual Gross Value	$13,125,000
ADR operating costs (per oz Au recovered)	$35
Estimated annual cost of operations	$366,721
Annual Net Value	$12,758,279
Total value over life of mine	$76,549,677
Extended Leaching value added	TBD

Recovery value will be a combination of recovery of Au in real-time and recovery of Au that will never recycle through the leach pad

- This is a raw number based only on the current estimated solution losses.
  - SLR operating costs are probably overestimated.
- At ABC, barren solution is recycled back to the heap.
  - A percentage of the Au left in solution will cycle back into the pregnant solution.
    - This will available for adsorption at some point in the future
  - A percentage will NEVER be recovered.
  - IXOS® has superior adsorption characteristics at low ppb level. This plant will be far more efficient to operate and effective for Au collection after ore production has ended than a carbon plant.