A Leach of Faith:
Moving ASGM Beyond Cyanide

Alternative lixiviants in artisanal and small-scale gold mining: the evidence on recovery, cost, exposure and scale, and what must be in place whatever the reagent

Lixiviant: the leaching solution that dissolves gold out of crushed ore, concentrate or tailings and carries it into solution, where it can then be recovered.

The test: A *'cyanide-free'* label taken on trust is a leap of faith. The test is the same for every lixiviant: regulated operators, sound chemicals management to protect human health and the environment. Evidence, not claims.

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Minamata Convention on Mercury

Source note: Presentation 1 of two. Presentation 2 (Paul Cordy, Cordy Geosciences): How clean is clean? Removing mercury from ASGM tailings.

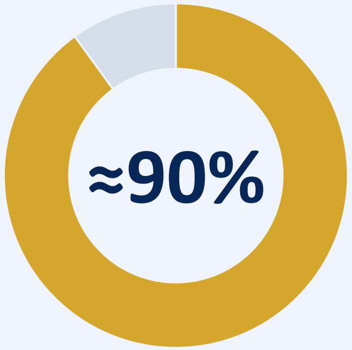
Cyanide is the world's gold lixiviant, and it is growing

Mercury is the ASGM default; cyanide is spreading as grades fall; "safer" proprietary agents are arriving unverified

MERCURY
The ASGM default: cheap, simple, accessible

CYANIDE
Spreading as miners chase lower grades

"SAFER" LIXIVIANTS
Proprietary agents trialed with unknown risks



of mined gold is recovered by cyanidation: one reagent, one industry

Yarar 2002; Marsden & House 2006; Liu et al. 2022

1.31 Mt
sodium cyanide produced in 2026, rising to 1.56 Mt by 2031 (+3.6%/yr)
Mordor Intelligence 2026

US$3.0 bn
market value in 2026, rising to US$4.8 bn by 2035 (+5.6%/yr)
Global Market Insights 2026

~86%
of sodium cyanide volume goes to mining
Mordor Intelligence 2026

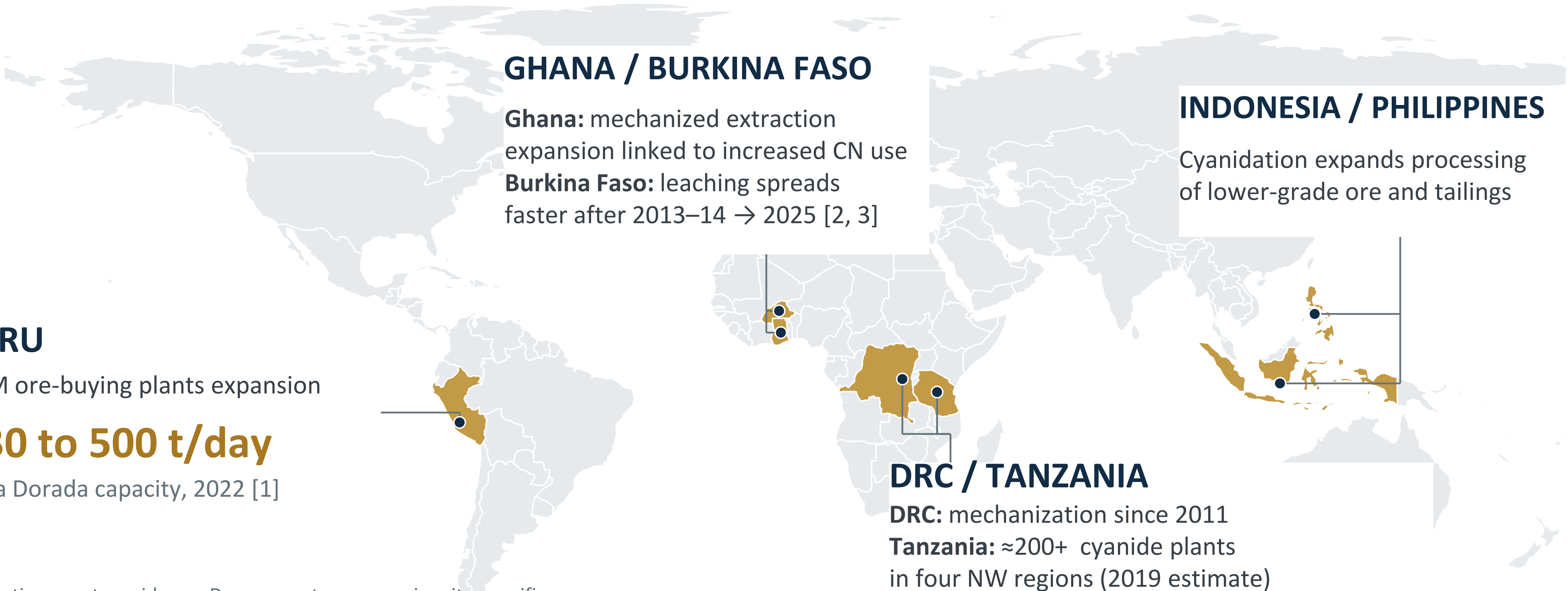
54%
of sales held by five producers (60–66% of capacity)
GMI 2026; Mordor 2026

The growth engine is falling ore grade: cyanidation lets ASGM work lower-grade ore, finer gold and tailings, and analysts report cyanide dosage rising as grades fall.

Source note: Volumes and values: Mordor Intelligence (Jul 2026) and Global Market Insights (Mar 2026), commercial estimates (published ranges US$2.5–3.1 bn; CAGR 3–5.7%). Gold share: Yarar 2002; Marsden & House 2006. Transition dynamics: Verbrugge et al. 2021; Malone et al. 2023.

Semi-industrial mining growth is expanding gold leaching

Documented shifts in mining scale and processing across seven countries: more capital, more tonnes through leaching, more reagent



GHANA / BURKINA FASO

Ghana: mechanized extraction expansion linked to increased CN use
Burkina Faso: leaching spreads faster after 2013–14 → 2025 [2, 3]

INDONESIA / PHILIPPINES

Cyanidation expands processing of lower-grade ore and tailings

[3]

PERU

ASM ore-buying plants expansion

430 to 500 t/day

Veta Dorada capacity, 2022 [1]

DRC / TANZANIA

DRC: mechanization since 2011
Tanzania: ≈200+ cyanide plants in four NW regions (2019 estimate)

Illustrative country evidence. Dosage per tonne remains site-specific.

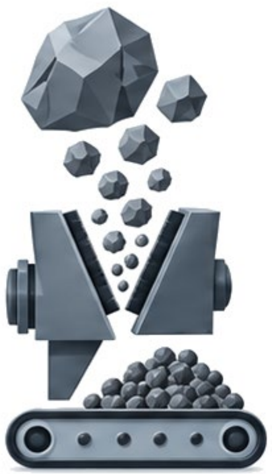
More capital and mechanization → **More ore and tailings through leaching** → **Higher aggregate reagent demand**

Source note: Dynacor 2022 (Peru, Veta Dorada 430 to 500 t/day); Crawford et al. 2016 and Government of Ghana SESA 2025 (Ghana); Verbrugge et al. 2021 (Burkina Faso, Indonesia, Philippines); IPIS 2023 (DRC, Mwenga) and IPIS 2019 (Tanzania, ~200 cyanide plants). Locators are approximate. Map: Natural Earth, public domain.

How cyanide leaching works: the circuit every alternative must fit

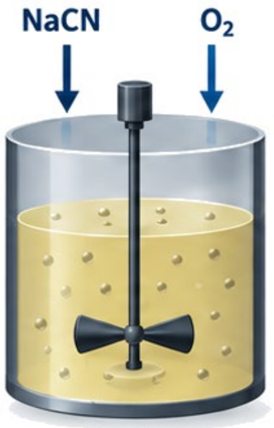
From ore to pregnant eluate: simplified CIP / CIL schematic. Jinchan, GlyCat and cassava all run this same alkaline circuit.

1 Ore prep



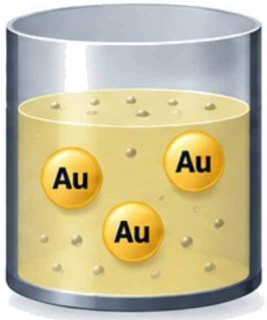
Crush and grind to liberate gold; slurry (or vat) prepared for leaching

2 CN leach



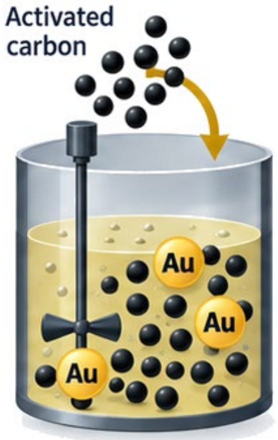
NaCN, O_2 (air), lime (pH 10.5–11)
$4Au + 8CN^- + O_2 + 2H_2O \rightarrow 4[Au(CN)_2]^- + 4OH^-$

3 Au in solution



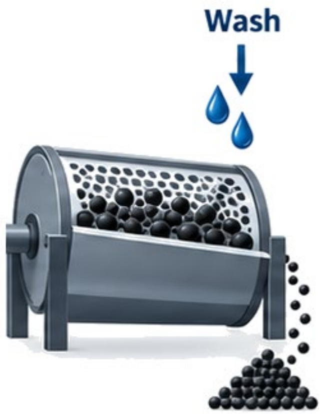
Gold dissolves as the aurocyanide complex $[Au(CN)_2]^-$ (pregnant solution)

4 Adsorption



$[Au(CN)_2]^-$ adsorbs onto activated carbon (CIP / CIL)

5 Loaded carbon



Screen carbon from pulp; water wash, then dilute HCl acid wash to remove scale

6 Elution

Hot caustic + cyanide (Zadra / AARL) strips gold from carbon → pregnant eluate

Source note: Chemistry per Elsner's equation; protective alkalinity (lime, pH 10.5–11) prevents HCN evolution; elution by Zadra or AARL. Not shown: electrowinning or zinc precipitation, smelting, carbon regeneration. In ASGM, vat (percolation) leaching commonly replaces agitated tanks; the chemistry is the same (Marsden & House 2006; Stapper, Dales, Velasquez & Keane 2021).

Seven families of alternative gold-leaching systems

They share chemical characteristics but differ in maturity, process control, waste management and ASGM suitability

Alternative gold-leaching agents (lixiviants) and processing systems

Family	Members	Direct leach or Pretreatment	Typical operating environment	Relative technical maturity	Principal shared control requirement
1 Sulfur-based chemistries	Thiosulfate; Thiourea; Thiocyanate	Direct leach	Alkaline or mixed	Moderate	Reagent stability
2 Halide-based systems	Chloride; Bromide; Iodide	Direct leach	Acidic	Emerging	Corrosion control
3 Amino-acid systems	Glycine; Other amino acids	Direct leach	Alkaline or mixed	Emerging	Stability, solution recovery
4 Biological pathways (*Mainly pretreatment for refractory ore*)	Bio-oxidation; Biohydrometallurgy	Pretreatment	Acidic or mixed	Emerging	Microbial control
5 Advanced solvent systems	Deep eutectic solvents; Ionic liquids	Direct leach	Mixed	Emerging	Solution recovery
6 Oxidation-assisted or hybrid systems	Advanced oxidation processes; Other oxidant-assisted	Leach or pretreatment	Acidic or mixed	Moderate	Oxidant control
7 Proprietary or synthetic formulations (*Verification category*)	Undisclosed compositions	Leach or pretreatment	Variable pH	Variable	Verification

Direct leach or Pretreatment Primary role in the process

Typical operating environment Predominant pH conditions

Relative technical maturity Compared with alternative systems

Principal shared control requirement Key process control focus for the family

Lixiviant (leaching) systems may share chemical characteristics, but they differ substantially in maturity, process control, waste-management requirements and suitability for the Artisanal and Small-scale Gold Mining (ASGM) sector.

Source note: Infographic 1 of the planetGOLD alternative-lixiviants series (Report 1); classes after Zhang et al. 2022 (Table 1) and Aylmore 2016.

Fourteen questions, asked of every option

A due-diligence screen answered with cited evidence, not a numerical score (Report 1 §5 and §6)

15	Options scored
14	Criteria
3	Rating levels
210	Traceable ratings

1. Define the options

- Candidates from the literature review and a supplier screen
- Grouped into seven chemical families
- Cyanidation kept as the benchmark row

2. Set the criteria

- Performance and ore fit (1–2)
- Cost, operability / supply (3–5)
- Safety, environment (6–8);
- ASGM fit (9–13);
- Maturity (14)

3. Rate on the evidence

- Peer-reviewed reviews and primary studies first
- Scale and independence recorded for every source
- Supplier and operator claims logged as claims

4. Read the result

● strong
◐ conditional
○ weak

- Coarse by design: unweighted, no numerical index
- Readiness ranked for a supervised central hub

Same questions for every option, every rating traceable. The result ranks readiness for a central hub is a due diligence screen – not a scoring model.

Source note: Report 1 (Dales & Cordy 2026, revised draft 3) §5 (fourteen criteria, harmonized with the proposal and the 3E lens of Liu et al. 2022) and §6 (suitability matrix; traceability tables; full matrix on backup B5, criteria on B6). Evidence base: Liu et al. 2022; Zhang et al. 2022; Djokić et al. 2026; Malone et al. 2023.

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High recovery does not mean ASGM-ready

Readiness by technology family, graded and evidence register; color is a screening grade, never a safety rating

Technology family	Technical promise	Maturity	Process complexity	Delivered cost	Control burden	ASGM suitability	Positioning
Cyanide (baseline)	Strong	Mature	Moderate	Strong (low)	Low (high concern)	Only if governed	Benchmark: govern, do not assume
Thiosulfate	Strong	Moderate	Limited (high)	Moderate	Limited (high)	Moderate	Most credible near-term alternative, in controlled hubs only
Glycine and amino acids †	Moderate	Emerging–moderate	Moderate	Moderate	Moderate	Moderate	Lower-risk pilot pathway in contained hubs
Bio-oxidation	Moderate	Moderate	Limited (high)	Moderate	Limited (high)	Low to moderate	Pretreatment for refractory ore; central facilities
Thiourea	Moderate–strong	Limited	Limited (high)	Low (high cost)	Low (high concern)	Low	Technically interesting, weak ASGM fit
Thiocyanate	Moderate	Emerging	Limited (high)	Low (high cost)	Limited (high)	Low	Promising chemistry, not yet mature
Halides	Strong	Limited	Limited (high)	Low (high cost)	Low (high concern)	Low	Highly engineered central facilities only
Advanced oxidation	Emerging	Emerging	Limited (high)	Insufficient evidence	Limited (high)	Low	Future R&D, not deployable
DES and ionic liquids	Emerging–moderate	Emerging	Limited (high)	Low (high cost)	Limited (high)	Low	Emerging research only
Proprietary agents (GDAs) *	Moderate	Moderate (mixed)	Moderate	Moderate	Limited (high)	Low to moderate	Held at the gate: verify composition before any use

Laboratory recovery is not field performance. The most credible pathway is controlled, centralized processing, not miner- or village-level chemical use.

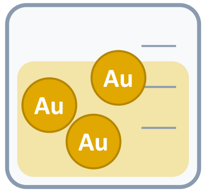
** Cyanide-bearing on independent assay (Deng et al. 2026). † GlyCat (glycine + cyanide) is rated within this family; its control requirements are those of cyanide at reduced concentration.*

Four options worth piloting, each with one condition

Selected on independent evidence and ASGM applicability; the rest are research chemistries or engineered-plant chemistries

Thiosulfate

$S_2O_3^{2-}$ · Cu–NH_3 or Ca system



Benefit Beats cyanide where cyanide fails: 90.5% vs 61.7% on carbonaceous, preg-robbing ore (Ethiopia, laboratory).

Limitation Reagent bill 2–6× cyanide; gold needs resin recovery; ammonia effluent. Ran at Goldstrike 2014–23, then reverted to cyanide.

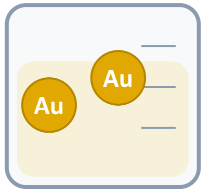
Maturity

One commercial plant, 2014–23; none today

Instrumented, supervised hub only

Alkaline glycine

$NH_2CH_2COO^-$ + oxidant · cyanide-free



Benefit No cyanide at any point; low toxicity; the carbon columns already on site recover the gold.

Limitation Slow: about half of cyanide's recovery on real ASGM tailings (45% vs 87%, Cameroon, laboratory). Needs an oxidant.

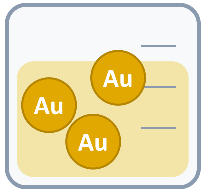
Maturity

Pilot and demonstration scale (TRL 6–8)

Contained hub pilots on real ASGM feed

GlyCat

Glycine + cyanide at 20–35% of dose



Benefit 65–80% less cyanide at comparable recovery: Bulyanhulu CIL and Bayan Airag heap (operator-reported).

Limitation Still cyanide: custody, WAD monitoring and destruction apply. Large-mine data, unaudited; no hub trial yet.

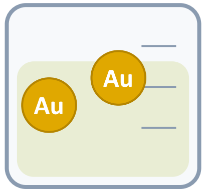
Maturity

Commercial at large mines since 2023–24

Where cyanide is already used

Bio-oxidation

Bacterial pretreatment of sulfide ore



Benefit Unlocks refractory sulfide ore before any leach; mature at industrial scale (TRL 8–9).

Limitation A pretreatment, not a lixiviant: slow, acidic, needs microbial control; the leach that follows still needs a reagent.

Maturity

Commercial at large mines; central plants

Central-plant pretreatment only

Maturity scale: laboratory · pilot · commercial at large mines · proven on ASGM feed (green). None of the four reaches the last segment.

Faster leaching ≠ higher recovery ≠ safer process. None is proven on ASGM feed; each is a hub technology with its own control requirement. Ore-specific test work first.

Source note: Selection from the readiness matrix (Report 1 §6). Thiosulfate: Chaka & Rupprecht 2024; Nevada Gold Mines 2025. Glycine: Mohamed et al. 2025. GlyCat: Draslovka/Barrick 2024, Draslovka 2023 (operator-reported). Bio-oxidation: Surimbayev et al. 2026 (TRL). Halides, thiourea, thiocyanate and solvents are eliminated for ASGM: acid chemistry, corrosion, toxicity, cost.

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Is Jinchan cyanide in disguise?

What the label says, against what independent laboratories find

WHAT THE LABEL SAYS

- *"Cyanide-free", "eco-friendly", "non-toxic"*
- Drop-in substitute for sodium cyanide: same circuit, same carbon
- *"Ordinary cargo":* no dangerous-goods rules for transport or storage
- High recovery, on the supplier's own test data

WHAT INDEPENDENT LABORATORIES FIND

- **A cyanide circuit:** pH 10–12, carbon or zinc recovery (Zhang et al. 2022; Deng et al. 2026)
- **Free cyanide in the reagent before it touches ore:** 7,300 mg/L CN^- in a 100 g/L solution; 41 mg/L still in the leachate (Deng et al. 2026)
- **Slower than cyanide:** 91.7% vs 97% at 24 h in Ghana; 48 h to catch up, at 1.6× the dose (Beyuo et al. 2016)
- **Hungrier:** 1.3–2.3× more reagent per ton of ore in the Ghana and Turkish tests (Beyuo et al. 2016; Yılmaz & Sayın 2024)

The most dangerous property for ASGM: more reagent can mean less gold. Above about 400 ppm, adding Jinchan reduced gold yield (Beyuo et al. 2016). Where dosing is by eye, *"add more"* makes it worse and loads cyanate and ferrocyanide into the tailings (Deng et al. 2026).

ANSWER: presume cyanide-bearing or cyanide-generating until an independent assay says otherwise. A confidential composition means no risk assessment is possible; "ordinary cargo, no restrictions" is an evasion flag.

Source note: Deng et al. 2026 (Hydrometallurgy 244:106799; independent laboratory speciation, Curtin); Beyuo et al. 2016 (Gold Fields Ghana, laboratory); Yılmaz & Sayın 2024 (Turkish ores, laboratory); Zhang et al. 2022 (review). Supplier claims are marketing material, not performance evidence.

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Five samples settle it

Before any program touches a proprietary agent: sample the circuit, speciate at an independent laboratory

1 Unused reagent
as sold, from a retail pack
Is cyanide in the product?

2 Prepared leach solution
reagent dissolved, before ore
Does cyanide form on mixing?

3 Pregnant solution
after leaching, carrying gold
What is carrying the gold?

4 Barren solution
after gold recovery
What must be destroyed?

5 Tailings / residue
solids leaving the circuit
What is left behind?

WHAT THE LABORATORY MEASURES IN EVERY SAMPLE

Free cyanide (CN^-)
The acutely toxic form: HCN gas below pH 9.

WAD cyanide
Weak-acid dissociable: free cyanide plus weakly bound copper, zinc and nickel complexes, regulatory measure.

Total cyanide
Every form, including stable iron complexes, which release free cyanide in sunlight within minutes.

Also
Cyanate, thiocyanate, ammonia and metals: the by-products that show what the reagent really is.

Rules: an independent, accredited laboratory, not a colorimetric field kit · preserve samples (pH above 12, cold, dark) · report the method with every result

Cyanide found: govern the reagent as cyanide.
Not found: the claim has been tested; the reagent is still not endorsed until recovery, effluent and cost are shown on real ASGM feed.

Source note: Report 1 assay protocol (full detail on backup B3); cyanide classes and effluent limits after Stapper, Dales, Velasquez & Keane 2021 (planetGOLD BMP) and World Bank 1995 (free 0.1, WAD 0.5, total 1.0 mg/L); photodissociation of iron–cyanide complexes: Johnson et al. 2002.

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The product's own documents say *"cyanide-class"*

Patent, stock-exchange filings and safety data sheet, read together with the independent chemistry

THE PATENT ON THE PACK

- **WO2012079283A1:** ferrocyanide fused with urea and alkali at 600–1,000 °C.
- **Stated LD_{50} 50 mg/kg** (mice): GHS acute oral Category 3, toxic.
- **Every patent in the class** uses the same cyanide-salt roast (Zhang et al. 2022, Table 6).

THE MANUFACTURER'S FILINGS

- **Product class:** "environment-friendly cyanide-class reagent"; active ingredient contains cyano groups (Senhe listing documents, 2024–26).
- **No national or industry standard** for the class; not a hazardous chemical in China.
- **Exported as "chemical preparations"** (HS 3824.99), not "cyanides" (HS 2837): invisible to cyanide import controls.

THE CHEMISTRY IN SERVICE

- **At the recommended dose** (0.3–0.8 g/L) the reagent gives about 20–60 mg/L free cyanide before any ore contact: a low-strength cyanide circuit, near the 50 mg/L WAD limit for open ponds.
- **"Chelated, cannot ionize" fails:** free cyanide was measured in the beaker (Deng et al. 2026), and iron–cyanide complexes release it in sunlight within minutes (Johnson et al. 2002).
- **The safety data sheet itself** prescribes hypochlorite and ferrous sulfate for the wastewater: cyanide destruction chemistry.

IMPLICATION: treat Jinchan, CNFREE, CNLITE and generic gold dressing agents as cyanide-class reagents for handling, storage, effluent, worker training and Minamata Annex C. Their marketed advantage is regulatory, not metallurgical.

Source note: planetGOLD technical note (Sept 2026), Jinchan global evidence review. Patent WO2012079283A1 (number printed on the packaging); Guangxi Senhe BSE listing documents (2024–26, read in translation); Jinchan SDS TBR-C-202402-0120-1; Deng et al. 2026; Johnson et al. 2002; Zhang et al. 2022. Where the class is sold and used: slide 15 and backup B4.

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Glycine cuts cyanide; it does not yet replace it

Two products are sold as "glycine": one is cyanide-free and slow, the other contains cyanide by design

ALKALINE GLYCINE: cyanide-free

- Glycine, alkali and an oxidant. No cyanide at any point.
- On real ASGM tailings: ~45% recovery in 10 h vs 87% for cyanide in 24 h on the same material (Cameroon; Mohamed et al. 2025, laboratory).
- No acutely lethal reagent to store or destroy; the oxidant is the remaining hazard, and it also consumes the glycine.

GLYCAT: glycine + cyanide, by design

- Laboratory: 0.5–1 M glycine with 500 ppm cyanide gave 90% gold where 500 ppm cyanide alone gave 46%: about 80% less cyanide for the same gold (Barani et al. 2021).
- At scale (operator-reported, unaudited): Bulyanhulu CIL, 80% cyanide cut at comparable recovery; Bayan Airag trial heap, 65% cut, 78% recovery.

WHAT IT MEANS FOR A SMALL-SCALE HUB

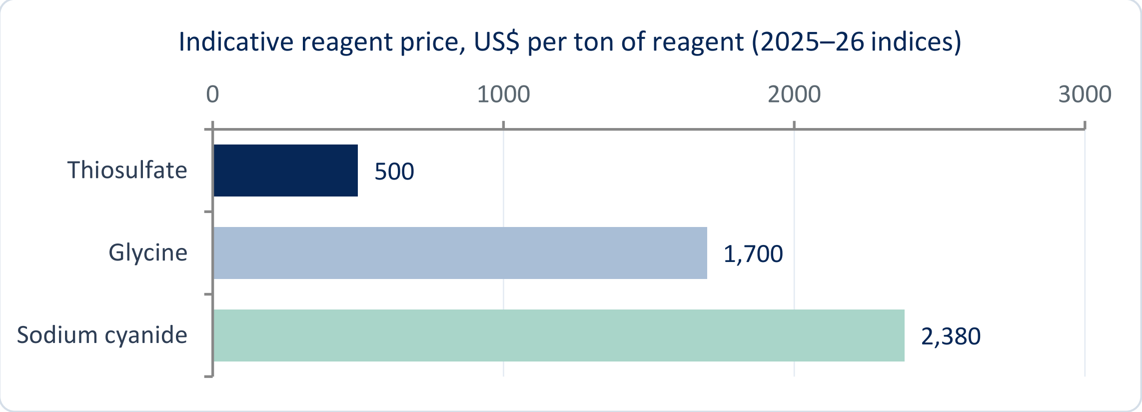
- ✓ On-site carbon columns recover the gold: 13.2 g Au/kg carbon in 4 h (Oraby & Eksteen 2015, laboratory)
- ✓ Not dangerous goods; a permitted food additive (FDA 21 CFR 172.812; EU E640)
- ✓ Cheaper per ton of reagent: about US$1,700 vs US$2,380 for cyanide (2025–26 indices)
- ✗ About half the recovery of cyanide on real ASGM tailings (Mohamed et al. 2025)
- ✗ Needs an oxidant, which is the remaining hazard and degrades the glycine as it works (Oraby et al. 2020)
- ? Consumption on ASGM feed not established; recyclability unvalidated (Fashu et al. 2026)

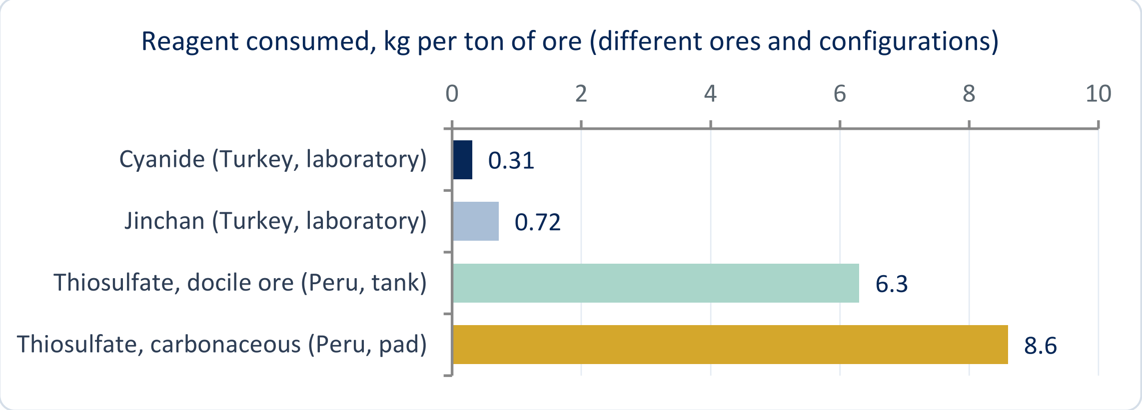
ANSWER: yes, at large-mine scale GlyCat cuts cyanide 65–80% at comparable recovery (pending independent audit). It is cyanide reduction, not replacement: custody, control and destruction still apply. Stand-alone glycine is the cyanide-free option, and it is slow.

Source note: Mohamed et al. 2025 (Cameroon tailings, laboratory; unequal leach times, 10 h vs 24 h); Barani et al. 2021 (laboratory); Draslovka/Barrick 2024 and Draslovka 2023 (supplier/operator-reported); Oraby & Eksteen 2015; Oraby et al. 2020; Fashu et al. 2026; price indices IMARC and ChemAnalyst 2025–26. Amino-acid chemistry: backup B1.

Thiosulfate: mature chemistry, instrumented plants only

The most mature non-cyanide lixiviant and the right tool for carbonaceous ore; not a yard reagent





THE VERDICT, LINE BY LINE

- ✓ Beats cyanide where cyanide fails: 90.5–91.5% vs 61.7% on Ethiopian carbonaceous ore (Chaka & Rupprecht 2024, laboratory).
- ✓ The only non-cyanide lixiviant run at full industrial scale on whole ore: Barrick Goldstrike, 2014–2023.
- ✗ Goldstrike converted back to cyanide in 2023 (US$30 M) for higher recovery and lower cost; no commercial plant runs it today (Nevada Gold Mines 2025).
- ✗ Consumes 6.3–8.6 kg/t: about US$3–8 per ton of ore against US$0.7–3.6 for cyanide (Tremolada 2018; 2025–26 indices).
- ✗ Gold will not load on the carbon ASGM centers own: needs resin or electrowinning; ammonia and high-COD effluent with no standard destruction circuit (Aylmore 2016).

ANSWER: of age for carbonaceous or preg-robbing ore, in an instrumented, supervised plant with resin recovery and effluent treatment. Not for a yard, and no longer proven at any operating plant.

Source note: Prices: IMARC / ChemAnalyst 2025–26 indices (thiosulfate US$475–890/t; NaCN US$1,700–3,300/t by region), indicative. Consumption bars compare different ores, scales and configurations (Yılmaz & Sayın 2024, laboratory; Tremolada 2018, Peru tank and pad): indicative, not like-for-like. Ecuador thiosulfate–glycine: Redrovan et al. 2025.

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Every alternative changes the hazard; yet vulnerable populations stay the same

"Cyanide-free" is a label, not a safety finding: women and children have the highest solution contact and the least protection

Reagent	Acute hazard	Effluent and residue	Manageable in a hub?
Cyanide	HCN gas; ingestion; acutely lethal	Proven destruction circuits (SO_2/air, peroxide, hypochlorite)	**Yes, only if governed**
Thiosulfate	Low acute toxicity; ammonia in the copper–ammonia system	No standard circuit; heavy COD load	**Heavy burden**
Alkaline glycine	Low acute toxicity; food-grade reagent	Biodegradable; residues untested on mercury tailings	**Lightest of any option**
GlyCat	Cyanide present at 20–35% of normal dose	Cyanide destruction still required	**Manageable in a hub**
Jinchan / GDAs	Undisclosed; cyanide-bearing or -generating	Cyanate and ferrocyanide in leachate	**Cannot be assessed**
Thiourea · halides · polysulfides	Suspected carcinogen (thiourea); chlorine gas; H_2S on pH excursion	Acid or halogen effluent; gas control	**No**

WHO HANDLES THE PULP

Women: concentrated in ore dressing, panning and processing: the highest solution contact, the least protective equipment (Hinton, Veiga & Beinhoff 2003; Dales personal observation 2024-26)

Children: an identified exposed group at and around processing sites (Kohio et al. 2025; Stapper et al, 2021).

Communities: water and soil beside processing yards: Burkina Faso, 9% of ASGM-area water samples over the WHO free-cyanide guideline, peak 2.42 mg/L (Kohio et al. 2025)

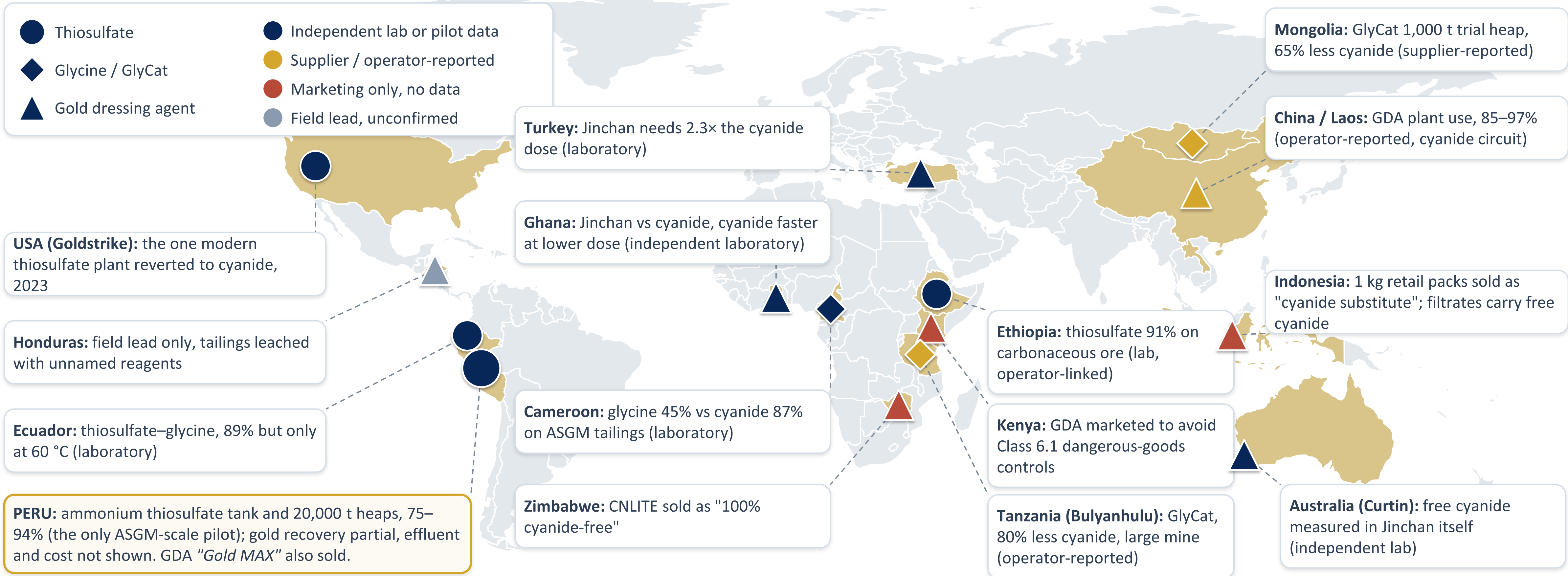
Kenya (Kakamega–Vihiga): cyanidation plants operate beside mercury processing; soil and sediment mercury, chromium and nickel exceed guidelines; cyanide itself has not been measured (Ondayo et al. 2023). Every alternative swaps one waste profile for another, often a less regulated one.

A reagent evaluation that ignores who physically handles pulp is incomplete. PPE, training and rotation for pulp handlers apply to every reagent, branded or not.

Source note: Hazard and effluent columns: Aylmore 2016; Aylmore & Muir 2001; Zhang et al. 2022; Stapper, Dales, Velasquez & Keane 2021; Deng et al. 2026. Exposure: Kohio et al. 2025; Ondayo et al. 2023; Hinton, Veiga & Beinhoff 2003; Report 1 (hazard synthesis; gender). Colors follow the readiness-matrix legend (slide 7).

Every case dissolves gold; none crosses the wall

Principal finding or risk in each place; marker shape is the technology, marker color is the strength of the evidence



THE WALL: no ASGM-relevant case has shown gold recovery from solution, effluent management and delivered cost on ASGM feed. Only the large-mine GlyCat cases cross it, on supplier data.

Source note: Report 1 country cases; detail and evidence grades on backups B4 and B10. Map: Natural Earth 1:110 m, public domain; locators are approximate; no position on contested boundaries. Peru: Tremolada 2018 (practitioner report). Tanzania and Mongolia: Draslovka/Barrick 2024, Draslovka 2023.

From chemical substitution to controlled processing systems

Safety and stewardship come from the system, not from the reagent

UNSUITABLE MODEL

Individual miner or village-level chemical use

Uncontrolled reagent handling
Chemicals bought and stored informally; dosing by eye; spills

No process monitoring
No pH, concentration, temperature or recovery measured

No effluent treatment
Liquors and wash water go straight to soil and streams

Mixed mercury and chemical contamination
Mercury use continues; chemical residues add to it

Higher worker and community exposure
Poisoning risk, ecological damage, long-term health impacts

PREFERRED MODEL

Licensed, centralized processing hub

Ore and tailings characterization Sampling and mineralogy guide process design and reagent choice

Gravity-first recovery Capture what gravity can before any chemical process

Mercury screening and removal Detect and remove mercury before any chemical contact

Controlled lixiviant use, where justified Least hazardous option, right dose, trained supervision

Reliable gold recovery from solution Proven methods: carbon, resin, precipitation, electrowinning

Effluent treatment and residue containment Treat all effluents; contain residues in engineered facilities

Traceable, responsibly produced gold Documented processes support market access and finance

The transition is not to replace cyanide; it is to move chemical processing into controlled systems. Centralized, supervised plants protect people, communities and the environment.

Source note: Infographic 6 of the planetGOLD alternative-lixiviants series, synthesized from Report 1 and planetGOLD program framing; control framework after Stapper, Dales, Velasquez & Keane 2021; gravity first: Gunson & Veiga 2020. The model the WGC, Ghana and the AGC committed to in 2026 (Gold Processing Initiative).

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From ore characterization to a processing decision

Ten steps, none optional and none reagent-specific: a "cyanide-free" label skips none of them

1 Characterize the ore
Sample, test, define mineralogy and gold deportment

2 Optimize gravity recovery
Take what gravity can; minimize gold reporting to leach

3 Screen for mercury
Contaminated material: remove mercury first (Presentation 2)

4 Decide on pretreatment
Refractory or preg-robbing ore: central plant only

5 Select and independently test the lixiviant
Bench tests: recovery, reagent use, cost; assay any proprietary agent

Free-milling, mercury-free, no pretreatment: continue to step 5

Mercury present or refractory ore: remove mercury and pretreat in a central plant before any leach

6 Confirm gold recovery from solution
Carbon, resin, precipitation or electrowinning proven on this liquor

7 Assess worker safety and process control
Hazards, PPE, training, SOPs, monitoring, emergency response

8 Confirm effluent treatment and residues
Treatment circuit, containment, long-term stewardship

9 Confirm the licensed operating model
Permits, reagent logistics, economic viability

10 Pilot in a controlled facility, or reject
Licensed facility only; record and publish results

✓ Controlled, licensed facility available: proceed to a controlled pilot

✕ No controlled facility: not suitable for deployment

Lower toxicity does not mean inherently safe: process control, residue management and governance remain essential, whatever the reagent.

Source note: Infographic 4 of the planetGOLD alternative-lixiviants series; framework synthesized from the Report 1 literature review and planetGOLD program framing. Mercury removal before any leach: Minamata Convention Annex C 1(b)(iv); Veiga et al. 2020.

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What the evidence means, and where we go from here

Three conclusions for decision-makers, and the first moves for each audience

1. No alternative lixiviant is ASGM-ready across the range of ores, settings and operating realities.
2. The credible pathway is controlled, centralized processing with strong governance and environmental safeguards.
3. Decisions must rest on independent evidence and be context-specific, not driven by marketing claims.

OPERATORS

- Gravity first: pre-concentrate before any leach and cut the mass needing chemistry.
- A contained, alkaline circuit with the recovery train (carbon or resin) specified before the first ton.
- Reagent custody: licensed supply, locked storage, dosing by titration; PPE, training and rotation for whoever handles the pulp.

REGULATORS

- License the chemistry, not the brand: Jinchan, CNFREE, GlyCat and cassava fall under cyanide rules; watch imports under HS 3824.99 as well as HS 2837.
- Set the numbers: free 0.1, WAD 0.5, total 1.0 mg/L in effluent, WAD below 50 mg/L in any open pond, and a laboratory that can measure them.
- Permit and inspect centralized plants; apply Minamata Annex C to cyanide-generating agents on mercury-bearing tailings.

SUPPORT PROGRAMS

- Assay before you endorse: the five-sample independent speciation of any proprietary agent.
- Invest in centralized, supervised plants and borrow the Cyanide Code's verification and corrective-action loops in a subsidized form.
- Demonstrate the whole flowsheet, leach + recovery + effluent + delivered cost, on real ASGM feed before scaling anything.

Sequence: responsible cyanidation first; alternatives only where leach, recovery, effluent and delivered cost have been demonstrated on real ASGM feed. Replacing the reagent does not replace the management system.

Source note: Infographic 7 (executive synthesis); Report 1 §6 and conclusions. Full recommendations and priority evidence gaps: backups B11–B12; controls by audience: B11. Next: Presentation 2, How clean is clean? Removing mercury from ASGM tailings (Paul Cordy, Cordy Geosciences).

Backup slides

Supporting detail, reference only: not part of the 20-minute talk

Source note: Backup slides retain the full tables, traceability and reference lists behind the main deck; type in dense tables is smaller than the main-deck minimum and is intended for reading, not projection.

Suggested reading, prioritized

Attached papers and the key reviews first, then the primary studies cited on the slides

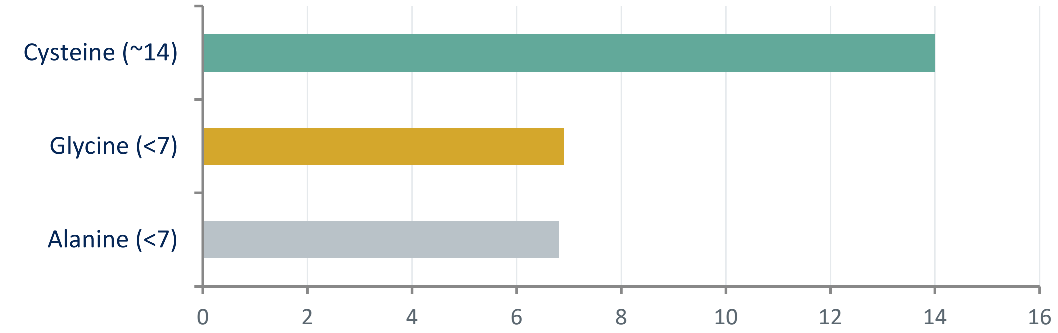
Reference	Why read it	Link
Deng, Schwehr, Yang & Oraby (2026) A comparative study of cyanide, Jinchan and GlyCat™ for gold ore leaching. Hydrometallurgy 244:106799.	The independent speciation evidence behind Question 1 and the GlyCat comparison (laboratory).	doi.org/10.1016/j.hydromet.2026.106799
Aylmore (2016) Alternative lixiviants to cyanide for leaching gold ores. In Gold Ore Processing, 2nd ed., pp. 447–484.	The reference review of all alternative chemistries, conditions, consumption and cost.	doi.org/10.1016/B978-0-444-63658-4.00027-X
Zhang, Cui, Wang, Liu & Lyu (2022) A review of gold extraction using alternatives to cyanide: the novel eco-friendly synthetic gold lixiviants. Minerals Engineering 176:107336.	The key review of the Chinese synthetic reagent class: sixteen lixiviant classes, the patent recipes (ferrocyanide + urea + alkali), operator-reported plant results, and the admission that composition and mechanism remain unclear.	doi.org/10.1016/j.mineng.2021.107336
Stapper, Dales, Velasquez & Keane (2021) Best Management Practices for Cyanide Use in the Small-Scale Gold Mining Sector. planetGOLD.	The control framework behind Objective 2: the test every lixiviant must pass.	planetgold.org
Surimbayev, Bolotova, Akcil & Ghorbani (2026) Gold mining tailings as a sustainable secondary resource. Mineral Processing and Extractive Metallurgy Review.	Technology-readiness ratings for every alternative; why non-cyanide routes still need industrial validation.	doi.org/10.1080/08827508.2026.2693551
Li, Sun, Kou, Wang & Liu (2025) Development of a gold leaching reagent as an alternative to cyanide. Int. J. Miner. Metall. Mater. 32(4):835–850.	What the synthetic "eco-friendly" reagent class is made of, and why its composition is contested.	doi.org/10.1007/s12613-024-2957-x
Chaka & Rupprecht (2024) Thiosulfate leaching in carbonaceous gold-bearing ores in Ethiopia. Scientific Reports 14.	The African carbonaceous-ore case for thiosulfate (laboratory).	doi.org/10.1038/s41598-024-69646-3
Mohamed, Oupoungam, Boyraz, Alp & Sinon (2025) Glycine and cyanide leaching of artisanal gold mining tailings. Physicochem. Probl. Miner. Process. 61(3).	The only direct glycine-vs-cyanide test on ASGM tailings (Cameroon; unequal leach times).	doi.org/10.37190/ppmp/205177
Kohio, Sossou, Karoui & Yacouba (2025) Environmental cyanide pollution from artisanal gold mining in Burkina Faso. IJERPH 22(7):1125.	Measured community exposure to cyanide around ASGM processing.	doi.org/10.3390/ijerph22071125
Reno, Aulia & Dian (2026), supplier-affiliated Sodium cyanide replacement with polymerized cyanide GOLDIX. E3S Web of Conferences 693:02007.	An example of how the cyanurate class is presented; note the free cyanide it measures.	doi.org/10.1051/e3sconf/202669302007
Teng, Huang, Long & Fang (2010/2012), patent Mineral-dressing agent for noble metal. WO2012079283A1 / CN102321807B (the patent number printed on Jinchan packaging).	The ferrocyanide–urea formulation and the LD_{50} of 50.1 mg/kg, disclosed in the patent on the packaging.	patents.google.com/patent/WO2012079283A1

Source note: Full reference list with DOIs: backup slides and speaker notes. Every figure on the slides traces to a row of the evidence register (backup B2) or the full assessment matrix (backup B5).

Glycine is one amino acid among many, and not the strongest

Two different things are compared in marketing and in the literature: how fast an amino acid dissolves gold, and whether it survives a circuit

Gold dissolved from pure gold, matched conditions (mg/L): 1983 data, indicative



Cysteine dissolves gold about twice as fast as glycine or alanine (cysteine ≈14 mg/L; glycine and alanine <7 mg/L). Korobushkina et al. 1983, as summarized by Fashu et al. 2026; bar lengths indicative.

So why does industry use glycine?

- Every other amino acid polymerizes or degrades in service; cysteine is faster but unstable, and costly (Sarvar et al. 2023).
- Glycine is the only amino acid stable enough to survive a real circuit (Sarvar et al. 2023; Fashu et al. 2026).
- It is cheap (about US$1,700/t, industrial grade) and a permitted food additive; research follows availability, not performance (Fashu et al. 2026).

Glycine wins on durability, not speed: a research-agenda finding, not a deployment one.

Complexing ability toward gold (experimental ranking): asparagine > glycine > histidine > cysteine > phenylalanine > valine > aspartic acid > alanine (Sarvar et al. 2023)

Dissolution of deprotonated acids at high pH (FTIR): cysteine > alanine > glycine > histidine (Tapfuma et al. 2024, as summarized by Fashu et al. 2026). Rankings differ between studies; that is itself the honest finding.

Source note: Report 1 (amino-acid chemistry). Sources: Fashu et al. 2026 (Metals 16:724); Sarvar et al. 2023 (J. Cleaner Prod. 391:136123); Korobushkina et al. 1983; Tapfuma et al. 2024 (Miner. Eng. 209:108633).

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Conditions, scale and independence behind every number on the slides

Every quantitative comparison on the main slides traces to one of these rows

Study	Material	Conditions	Result used on slides	Scale	Independence
Deng et al. 2026	Au–Ag ore 1.41 g/t; Au–Cu ore 2.15 g/t, 1.24% Cu; Cu flotation tailings 2.1 g/t	Bottle-roll, 48 h, 30% solids, pH 10–10.5 (lime), ~25 °C; Jinchan 1–10 kg/t; GlyCat 0.5–4 kg/t each; NaCN 3.5–10 kg/t	Jinchan 100 g/L solution: 7,300 mg/L free CN^-, 12,000 CNO^-, 2,000 $Fe(CN)_6^{4-}$; leachate 41 mg/L free CN (NaCN 660); Jinchan slowest kinetics; tailings 7% vs 22% (CN) vs 36% (GlyCat)	Laboratory	Independent of Jinchan; GlyCat co-developer
Beyuo et al. 2016	Gold Fields Ghana (Tarkwa) ore	Agitation leach; NaCN 230–250 ppm; Jinchan 200–600 ppm; 24–48 h; pH 11.5	NaCN 97% at 24 h vs Jinchan 91.7% at 400 ppm at 24 h, ~97% only after 48 h; >400 ppm reduced yield; 17 mg/L free CN in Jinchan liquor (102 for NaCN); lime 1.27 vs 1.99 kg/t	Laboratory	Independent
Yılmaz & Sayın 2024	Çukuralan and Kaymaz ores, Turkey	40% solids; 300 mg/L reagent	Jinchan 0.72 kg/t (90.9%) vs NaCN 0.31 kg/t (92.0%); Kaymaz 1.27 vs 0.95 kg/t	Laboratory	Independent
Chaka & Rupprecht 2024	Legadembi carbonaceous ore, Ethiopia (~1.25 g/t)	Bottle-roll 48 h, 50% solids; 9 g/L S_2O_3, 13.6 g/L NH_3, 0.8 g/L $CuSO_4$, pH 10–11.5; NaCN 0.5 g/L	Thiosulfate 91.54% (abstract) / 90.54% (Table 3) vs cyanide 61.70%; no consumption data	Laboratory	Operator-linked author
Redrovan et al. 2025	Guayzimi ore, Zamora Chinchipe, Ecuador (10 g/t Au); not described as ASGM	0.7 M S_2O_3, 1.75 M glycine, 5 mM Cu, $KMnO_4$ every 2 h, pH 9.3, 60 °C, 6 h, 15% solids, 100 g	89.3% in 6 h (cyanide 89.8% in 24 h; ammoniacal thiosulfate 58% in 6 h)	Laboratory	Independent
Tremolada 2018	Peruvian carbonaceous and docile gold ores	Ammonium thiosulfate; stirred tank 120 h; heaps 10,000–20,000 t, 45 d	6.3 kg/t (tank, docile, 93.6%); 7.4 (tank, carbonaceous, 90.8%); 6.5 (heap, docile, 81.2%); 8.6 (pad, carbonaceous, 75.2%)	Pilot / heap	Practitioner, not peer-reviewed
Mohamed et al. 2025	Kombo Laka ASGM tailings, Cameroon (14 g/t Au, 8 g/t Hg)	Cyanide 1.5 g/L NaCN, 24 h; glycine 3 g/L + 3 g/L $KMnO_4$, 10 h; pH 10.5, L/S 3, room temp.	Cyanide 87% vs glycine 45.6%, unequal leach times; at 6 h: 68% vs 29%; Hg removal ≤30% for both	Laboratory	Independent
Barani et al. 2021	Pb–Cu–Zn polymetallic gold ore	Cyanide 200–1,500 ppm ± 0.5–1 M glycine; up to 72 h	500 ppm CN: 46% → 90% with glycine; dose 500 vs 1,500 ppm without glycine (~67% lower), ~80% less cyanide consumed as summarized by Deng et al. 2026; poor selectivity (Cu, Pb, Zn rise)	Laboratory	Independent
Draslovka / Barrick 2024; Draslovka 2023	Bulyanhulu CIL (1.1 Mtpa, ~5.8 g/t, baseline 4.3 kg/t NaCN); Bayan Airag Cu-bearing Au–Ag ore	Commercial CIL after Jan–Mar 2024 pilot; 1,000 t trial heap	80% CN reduction, "comparable" recovery, WAD "undetectable" (no detection limit stated); heap 78% recovery, 65% CN cut	Commercial	Supplier / operator
Nevada Gold Mines 2025	Goldstrike double-refractory carbonaceous ore	Calcium-thiosulfate RIL, 2014–Q1 2023	US$30 M conversion back to cyanide CIL completed Q1 2023: higher recovery, lower operating cost	Commercial	Operator disclosure (NI 43-101)
Reno et al. 2026	Sumbawa oxide ore, Indonesia (1.55 g/t)	1.5 kg/t reagent, 40% solids, pH 10.5, H_2O_2 to 11 mg/L DO, 24 h	GOLDIX 575 77.5% vs NaCN 70.1%; filtrate free CN 38–70 ppm (GOLDIX) vs 200 (NaCN)	Laboratory	Supplier / operator
Zhang et al. 2022 (compilation, Table 5)	Chinese mine ores and residues (Xiajiadian, Siergou, Hongyuan, Dabaiyang, Paishanlou); Phabon, Laos; Pataz, Peru (Sandioss)	Plant and pilot leaches, 17–48 h, pH 10–12.5; Jinchan 0.3–0.9 kg/t (30 kg/t on a roasted residue); carbon or zinc recovery	Jinchan 85–97% vs NaCN 89–97% at equal or lower dose; "cyanide in leach solution <0.004 mg/L" (method not stated); CG505 0.18 mg/L CN in solution, 1.14 mg/L in cake	Plant / pilot (as reported)	Operator- / vendor-linked, Chinese-language primary studies

Source note: Scale: laboratory = kg-scale bottle-roll/agitation; pilot = 10,000–20,000 t heaps; commercial = operating plant. Independence = author affiliation as declared. Last row: vendor-side plant reports compiled by Zhang et al. 2022, for questions on the Chinese literature.

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Independent assay protocol for any proprietary "cyanide-free" agent

What "assay first" means in practice: five samples along the circuit, speciated by an independent laboratory

Sample	What it answers	Analytes	Why it matters in a yard
1 · Unused reagent (as sold)	Does the product itself contain or release cyanide on dissolution?	free · WAD · total CN; CNO^-; $Fe(CN)_6$; SCN^-; thiourea; NH_3/NH_4^+; metals (Fe, Cu, As, Hg)	Deng et al. 2026 found 7,300 mg/L free CN^- and 2,000 mg/L ferrocyanide in a 100 g/L Jinchan solution.
2 · Prepared leach solution	What is the working concentration of cyanide species at the dose actually used?	free · WAD · total CN; pH; CNO^-; SCN^-	Sets the exposure level for whoever mixes and doses.
3 · Pregnant solution	Which complex carries the gold, and what else is in solution?	Au, Ag, Cu, Fe, As, Hg; free · WAD · total CN; CNO^-; SCN^-; NH_3	Tells you whether carbon/CIL will work and what the recovery train must handle.
4 · Barren solution	What is discharged or recycled after recovery?	free · WAD · total CN; CNO^-; SCN^-; NH_3; COD; metals	Determines destruction/treatment requirement and effluent compliance (free 0.1 · WAD 0.5 · total 1.0 mg/L).
5 · Tailings / residue	What stays on the ground, and how does it behave with mercury?	total CN, WAD CN (leachate test); metals incl. Hg; $Hg(CN)_2$ speciation where Hg present	Annex C interface: cyanide-generating agents on mercury-bearing tailings form soluble Hg–CN complexes (Veiga et al. 2020).

Rules of the protocol: sampling and preservation to a cyanide-speciation laboratory (not a colorimetric field kit); silver-nitrate titration on site for free cyanide only; an independent laboratory with no supplier relationship; results published with the program's endorsement decision. Confidential composition means no independent risk assessment.

Source note: Report 1 (assay protocol); analytical framework after Stapper, Dales, Velasquez & Keane 2021 (free/WAD/total cyanide classes; World Bank 1995 effluent guidelines); speciation example from Deng et al. 2026; Hg–CN interface from Veiga et al. 2020.

Research, trade and use, graded by evidence type

Where the gold dressing agents are being tested, sold and used, and how strong the evidence is for each entry

Country / region	What was found	Evidence type	planetGOLD
China	Domestic market leader; named industrial customers (China National Gold, Shandong Gold, Zijin, Zhaojin); plant substitution studies at Xiajiadian, Siergou, Hongyuan and others compiled by Zhang et al. 2022 (Table 5; operator-linked); classed as an ordinary chemical, "no approval needed to buy, store or transport"; eight producers with >250 kt/yr combined capacity.	**Regulatory filing / patent**	—
Laos · Guinea · Russia	Sole-supply industrial customers named in securities filings: Vangtat Mining (Laos, 3,275–3,640 t/yr); Ningbo Zhongce's Kankan subsidiaries (Guinea, 16,884 t demand 2025); Arktos → Terimalchik mine (Russia, 50 t in 2023 → 1,200 t in 2025). Laos also has operator-reported plant results at Phabon Gold Mine (Guo et al. 2015; Kang et al. 2019, via Zhang et al. 2022).	**Regulatory filing / patent**	—
Indonesia	Jinchan retails in 1 kg and 25 kg packs on Lazada, Shopee, Tokopedia as "pengganti sianida (non-toxic)"; five named Jakarta distributors; CNFREE marketed against Indonesia's NaCN controls since 2012; GOLDIX laboratory study (Reno et al. 2026, supplier-affiliated) measures free cyanide in its tailings.	**Distributor / marketplace**	Phase 1
Peru	Equivalent chemistry sold as Gold MAX "lixiviante ecológico" (Royal Chemical, Lima; stated LD_{50} 50 mg/kg); four university theses validate it at pH 12, 0.5 g/L, 48 h at La Rinconada, Arequipa, Puno, Cusco; marketed to miners on social media. Another GDA (Sandioss) bench-tested on Pataz ore (Heras et al. 2018, via Zhang et al. 2022).	**Distributor / marketplace**	Phase 1
Kenya	AuLeach GDA marketed for "Kakamega & Migori" beside NaCN: "cyanide-free", clears customs "as standard industrial cargo", avoids Class 6.1 processing at Mombasa, "rapid NEMA EIA approvals". A 2025 NEMA EIA for a Kakamega vat-leach plant specifies conventional NaCN.	**Distributor / marketplace**	Phase 1
Zimbabwe	CNLITE Africa (Harare) markets CNLITE as "100% cyanide-free", LD_{50} >5,000 mg/kg, 96–98% recovery at 0.3–0.6 kg/t; 2026 Mazowe mercury-free trials name hypochlorite and cyanidation, not GDAs; 2019 NAP silent.	**Distributor / marketplace**	Phase 2
Tanzania	Jinchan marketed for vat leaching; AMGC (c. 2019) investigation of the environmental and health impact of GDA in small-scale mining, likely the only intergovernmental field study; not retrievable.	**Intergovernmental (not retrieved)**	Phase 2
Ghana	Gold Fields Ghana laboratory comparison (Beyuo et al. 2016): cyanide faster at lower dose (97% vs 91.7% at 24 h; parity only at 48 h); Jinchan liquor 17 mg/L free CN. Vendor (CAMAL) claims TAS96 GDA replaced NaCN at a 300 t/d plant, unaudited.	**Peer-reviewed**	Phase 2
Honduras	On the vendor's brochure list. Voice memos (Aug 2026): experimental tailings leaching with unnamed lixiviants at Macuelizo (Minas y Cuevas concession, legacy heap-leach site); informal miners use cyanide without permits. Reagent unconfirmed; follow up.	**Field lead (unconfirmed)**	Phase 2
Turkey · Kazakhstan	Independent bench tests (Yılmaz & Sayın 2024; Malyshev et al. 2025): parity on oxide ore, 1.3–2.3× consumption, slower kinetics; official distributor and registered trademark in Kazakhstan (jinchan.kz).	**Peer-reviewed**	—
Suriname · Guyana · Colombia · Sudan · CAR · Nigeria · Philippines · others	Named on the manufacturer's user-country or brochure lists (27–30+ countries); no distributor, import or regulatory record located. Sudan's Sai Island banned cyanide "mixers" (Nov 2024) without naming GDAs.	**Vendor claim**	Phase 1–2 / GEF-8

REGULATORY POSITION: no registration, approval, ban, import restriction, seizure or agency statement on Jinchan or any GDA was found in any of the 27 claimed markets; ICMI and the reagent industry have published no position.

Source note: Condensed from INCAS/planetGOLD technical note (10 Sept 2026), Table 4, with sources therein: Senhe listing documents; Beyuo et al. 2016; Yılmaz & Sayın 2024; Malyshev et al. 2025; Reno et al. 2026; distributor pages (United Chemical; CNLITE Africa; Royal Chemical); AMGC c. 2019; Chinese and Laos plant reports via Zhang et al. 2022. Vendor lists are recorded as claims.

Full assessment matrix: 14 criteria

Report 1 §6.1, reproduced without change: ● strong or favorable · ◐ moderate or conditional · ○ weak or unfavorable

Option	1 Recovery	2 Ore fit	3 Process simplicity	4 Cost	5 Supply	6 Worker safety	7 Environ. manageability	8 Detox / effluent	9 Low-skill / no lab	10 Field robustness	11 Regulatory acceptance	12 Scalability	13 ASGM suitability	14 Readiness / maturity
Cyanidation (baseline)	●	●	◐	●	◐	○	◐	◐	◐	◐	●	●	◐	●
Thiosulfate	◐	●	○	◐	◐	◐	◐	◐	○	○	◐	◐	○	◐
Glycine / GlyCat	◐	◐	◐	◐	◐	●	●	◐	○	○	◐	◐	○	◐
Glycine–thiosulfate / CN–glycine hybrid	◐	◐	○	◐	◐	◐	◐	◐	○	○	◐	◐	○	◐
Thiourea	◐	◐	○	○	○	○	○	○	○	○	○	○	○	○
Thiocyanate	◐	◐	○	○	○	◐	◐	○	○	○	○	○	○	○
Polysulfide / alkaline sulfide	◐	◐	○	◐	◐	○	○	○	○	○	○	○	○	○
Halides (Cl / Br / I)	●	◐	○	○	○	○	○	○	○	○	○	○	○	○
Chlorination / hypochlorite	◐	◐	○	◐	◐	○	○	○	○	○	○	◐	○	◐
Cassava / cyanogenic (governed as cyanide)	○	◐	◐	●	●	○	○	○	◐	◐	○	○	◐	○
Proprietary GDAs (Jinchan / CNFREE / CNLITE)	◐	◐	◐	◐	●	○	○	○	○	◐	○	◐	○	○
Novel synthetic (Li-type NESGL)	◐	○	○	○	○	◐	◐	○	○	○	○	○	○	○
Bio-oxidation (pretreatment)	◐	●	○	◐	◐	◐	●	◐	○	○	◐	◐	○	◐
Bioleaching / biogenic	○	◐	○	◐	◐	◐	●	◐	○	○	○	○	○	○
DES / ionic liquids	◐	◐	○	○	○	◐	◐	○	○	○	○	○	○	○

LEGEND ● strong / favorable ◐ moderate / conditional ○ weak / unfavorable

More dots = more favorable for ASGM deployment; the baseline row rates cyanide on the same scale, so ○ on worker safety is weak for cyanide by design. Ratings are screening judgments, not precision scores; criteria and traceability on B6–B8.

Mapping to the seven families on slide 5: sulfur-based = thiosulfate, thiourea, thiocyanate, polysulfide; halide-based = halides (Cl / Br / I), chlorination; amino-acid = glycine / GlyCat; oxidation-assisted or hybrid = the glycine–thiosulfate / CN–glycine hybrid (advanced oxidation processes are not scored in Report 1 §6.1); biological = bio-oxidation, bioleaching; advanced solvent = DES / ionic liquids; proprietary or synthetic (verification category) = cassava / cyanogenic, proprietary GDAs, novel synthetic NESGL; cyanidation is the baseline.

Source note: Report 1 (Dales & Cordy 2026, revised draft 3, 3 Sept 2026) §6.1 master matrix; evidence: Liu et al. 2022; Djokić et al. 2026; Zhang et al. 2022; and the per-criterion tables (§6.2–6.4, backups B7–B8).

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The fourteen assessment criteria and the four-tier classification

Each criterion is a due-diligence question, not a single number; applied identically to every option (Report 1 §5, §6.5)

#	Criterion	What is assessed
1	**Metallurgical effectiveness / gold recovery**	Achievable recovery on representative feed, not best-case laboratory foil or concentrate.
2	**Ore and mineralogical suitability**	Free-milling vs refractory; sulfides, copper, preg-robbing carbon.
3	**Process complexity and control**	Number of reagents; Eh–pH window; oxidant management; monitoring burden.
4	**Capital and operating cost**	Reagent + oxidant + recovery train + effluent capex/opex; delivered, not headline reagent price.
5	**Reagent availability and supply-chain reliability**	Local availability, shelf life, transport, storage, import control.
6	**Worker health and safety**	Acute/chronic toxicity, gas generation, corrosivity, exposure controls.
7	**Environmental risk and manageability**	Effluent, residues, ecosystem exposure, spill behavior.
8	**Detoxification / effluent / waste management**	Whether an engineered destruction or recovery step is required and feasible.
9	**Technical skills and laboratory requirement**	Operator competence and analytical support needed to run it safely.
10	**Field robustness**	Tolerance of variable feed, weak process control and interruption.
11	**Regulatory acceptance**	Standing under mining, chemicals and environmental regimes; licensing.
12	**Scalability**	From village kit to centralized hub without loss of control.
13	**Suitability for ASGM conditions**	The composite of the above under informal, low-infrastructure operation.
14	**Technology readiness and commercial maturity**	Laboratory / pilot / demonstration / commercial, and independence of the evidence.

FOUR-TIER ASGM CLASSIFICATION

Tier 1, conditional controlled-pilot candidates: thiosulfate and glycine, in supervised centralized hubs only (Liu et al. 2022; Eksteen et al. 2018; Mohamed et al. 2025).

Tier 2, longer-term R&D: glycine–thiosulfate hybrids, thiocyanate, bio-oxidation as pretreatment, AOPs, DES / ionic liquids (Djokić et al. 2026).

Tier 3, cautionary / proprietary, verify before any use: Jinchan, CNFREE, CNLITE, generic GDAs and the Li-type NESGL; cassava and cyanogenic routes governed as cyanide (Zhang et al. 2022; Guo et al. 2022; Li et al. 2025; Torkaman et al. 2021).

Tier 4, not suitable for dispersed ASGM: thiourea, halides / chlorination, polysulfide, stand-alone bioleaching (Liu et al. 2022).

The tiers are Report 1 §6.5 and broadly match the readiness matrix on slide 7; two placements differ: Report 1 puts thiocyanate and bio-oxidation in Tier 2 (longer-term R&D), whereas slide 7 positions thiocyanate as not yet mature for deployment and bio-oxidation as a hub pretreatment.

Source note: Report 1 (Dales & Cordy 2026, revised draft 3) §5 (assessment framework; the reviewer's fourteen dimensions mapped onto the proposal's nine criteria and the "3E" lens of Liu et al. 2022) and §6.5 (four-tier classification).

Traceability: recovery, ore fit, maturity, cost and supply

Report 1 §6.2 (criteria 1, 2, 14) and §6.3 (criteria 3, 4, 5), with the evidence each rating rests on

Option	Reported recovery	Ore fit	Maturity	Evidence
Thiosulfate	~70–95%, often 80–90% optimized	Carbonaceous, preg-robbing, Cu-bearing	Commercial at one site (Goldstrike) 2014–23; reverted to cyanide Q1 2023 ‡	Djokić et al. 2026; Liu et al. 2022; Xie et al. 2021; Nevada Gold Mines 2025
Glycine / GlyCat	~45% stand-alone on ASGM tailings vs 87% CN; 46% → 90% at 500 ppm CN as CN–glycine hybrid ‡	Cu-gold; alkaline	Commercial (Bulyanhulu) as CN reduction; operator-reported	Mohamed et al. 2025; Barani et al. 2021 (2022 figures unverified); Eksteen et al. 2018
Thiourea	~80–95% laboratory	Some refractory / acid-oxidized	Pilot; 1980s antimony-concentrate circuit (NSW)	Djokić et al. 2026; Borda & Torres 2022; Zhang et al. 2022
Halides	~85–98% on concentrates	Oxidized concentrates	Cl commercial (concentrates); Br / I laboratory	Djokić et al. 2026; Liu et al. 2022
Proprietary GDAs	90.8% on Carlin concentrate (Jinchan); 85–97% Chinese plant reports; 91.7% at 24 h in Ghana	Concentrate, alkaline / carbon	Marketed; plant use in China (operator-reported); independent laboratory data only (Ghana, Turkey, Curtin) ‡	Guo et al. 2022; Zhang et al. 2022; Beyuo et al. 2016; Deng et al. 2026
Novel synthetic (Li)	87.56% roasted concentrate; 66.15% untreated	Roasted sulfide concentrate	Bench	Li et al. 2025
Bio-oxidation	85–98% with activation (as pretreatment)	Refractory sulfides	Commercial as pretreatment	Djokić et al. 2026; Liu et al. 2022

Option	Indicative reagent cost (US$/t)	Key cost / control driver	Supply / control note
Cyanide (baseline)	NaCN ~2,700	<5% of processing cost at 0.2–0.5 kg/t ore; mature CIP/CIL recovery	Controlled import; concentrated global supply
Thiosulfate	$Na_2S_2O_3$ ~500	Consumption via degradation erodes the cost edge; needs resin/IX recovery	Widely available
Thiourea	~1,500	High reagent cost + acid handling	Available; carcinogen-controlled
Halides: iodine	I_2 ~30,000	Reagent cost is the entire obstacle	Specialty supply
Chlorine	Cl_2 ~250	Cheapest reagent, worst EHS	Gas handling infrastructure required
Polysulfide	Na_2S ~400	Cheap, alkaline; H_2S risk; high effluent COD	Available
Glycine	Commodity scale (~1,700 industrial grade, 2026 index)	Slow kinetics need oxidant; recyclable (claimed; unvalidated over repeated cycles)	Industrial-scale commodity (Draslovka)

Reagent prices from Liu et al. 2022 (Table S11, after Aylmore 2016) and 2025–26 indices; cost share from JXSC 2025 and Liu et al. 2022. Prices are indicative reagent-only figures and exclude oxidant, recovery-train and effluent capex, the costs that usually decide the outcome.

Source note: Report 1 §6.2–§6.3. ‡ Entry updated for this presentation against evidence verified in 2026 (Goldstrike reversal to cyanide, Nevada Gold Mines 2025; independent GDA laboratory data, Deng et al. 2026; Barani et al. 2021 figures checked against the paper); Report 1 draft 3 predates these checks.

Traceability: hazards, effluent, ASGM fit, and evidence limitations

Report 1 §6.4 (criteria 6, 7, 8, 13), and the limits of the evidence behind the whole assessment

Option	Principal hazard	Detox / effluent requirement	Net ASGM read
Cyanide	Acute toxicity; HCN gas below pH 9.3; $Hg(CN)_2$ on Hg tailings	Engineered destruction (SO_2/air, H_2O_2) or recovery	Governable only under stewardship; not for uncontained use
Thiosulfate	Low acute toxicity; ammonia hazard in Cu–NH_3 system	High-COD effluent needs treatment	Centralized only
Glycine / GlyCat	Low toxicity; contains cyanide by design (GlyCat)	CN-reduced tailings; IX recovers >95% metals, weak Hg uptake	Medium-term, hybrid; not stand-alone
Thiourea	Suspected carcinogen; acidic	Effluent treatment required	Weak fit
Halides / chlorination	Cl_2 / Br_2 toxic, corrosive	Gas capture and neutralization	Engineered facility only
Polysulfide	H_2S generation on pH excursion	High-COD detox	Unacceptable in an open ASGM setting
Cassava / cyanogenic	Generates CN^- by hydrolysis	Same as cyanide	Govern as cyanide; not a non-cyanide method
Proprietary GDAs	Cyanide-bearing / -generating; misleading labeling	Presumed same as cyanide; SDS itself prescribes hypochlorite and ferrous sulfate	Verify by assay before any consideration

EVIDENCE LIMITATIONS BEHIND THE ASSESSMENT

Scale: most non-cyanide results are laboratory bottle-roll or agitation tests on kilogram samples; the only pilot data are Peruvian thiosulfate heaps (practitioner report) and the only commercial data are Goldstrike (thiosulfate, reverted) and GlyCat plants (supplier/operator-reported, unaudited).
Independence: the Chinese plant literature on the gold dressing agents is operator- or vendor-linked and does not state cyanide analytical methods; developer-authored glycine papers (Curtin) and the Draslovka/Barrick material are labeled as such.
Comparability: leach times, doses and ores differ between the studies compared (Cameroon glycine 10 h vs cyanide 24 h; Ghana Jinchan 24 vs 48 h); ratings are screening judgments, not a numerical index.
Gaps: no third-party assay of a gold dressing agent as sold; no ecotoxicology; no glycine consumption on ASGM feed; no independent audit of GlyCat plant data; no thiosulfate recovery or effluent treatment at hub scale; residue behavior of every alternative on mercury-bearing tailings untested.

Source note: Report 1 §6.4; evidence: Liu et al. 2022; Malone et al. 2023; Mohamed et al. 2025; Zhang et al. 2022; Kuyucak & Akcil 2013. The absolute rule stands: no cyanide, GDA, NESGL or cyanogenic agent on mercury-bearing tailings without prior mercury removal (bridge to Report 2 and Presentation 2).

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Alternative lixiviants: the key finding in one line

Principal advantage, principal limitation and ASGM implication by technology family

Laboratory or optimized recovery is not equivalent to field performance.

Technical promise is not the same as ASGM suitability.

Technology family	Principal advantage	Principal limitation	ASGM implication
Thiosulfate	Lower toxicity; strongest near-term alternative.	High reagent consumption and solution instability; no plant operating today.	Most credible near-term candidate, but only in controlled hubs.
Glycine / amino acids	Low toxicity; alkaline chemistry; promising for copper-gold ores.	Slower kinetics; oxidant needs; still emerging.	Promising for contained pilots, not direct field deployment.
Thiourea	Fast gold dissolution.	Acidic, unstable and costly; suspected carcinogen.	Technically interesting but weak ASGM fit.
Thiocyanate	Lower acute toxicity than cyanide.	Experimental; acidic and oxidant-intensive.	Not yet mature for deployment.
Halides	Rapid kinetics and strong performance on some concentrates.	Corrosive systems and higher EHS burden.	Only plausible in highly engineered facilities.
Bio-oxidation / biohydrometallurgy	Useful for refractory ores and lower-energy pretreatment.	Slow and operationally demanding.	Best framed as pretreatment rather than direct replacement.
Proprietary gold dressing agents and synthetic lixiviants	Commercial interest and easier retrofit claims.	Cyanide-bearing on independent assay; composition undisclosed.	Use only with independent verification, composition disclosure and cyanide-class controls.
AOPs, deep eutectic solvents and ionic liquids	Interesting emerging research directions.	Scale-up, cost and maturity constraints.	R&D relevance only at present.

KEY TAKEAWAY: no single alternative is ASGM-ready today. Suitability depends on control, monitoring and evidence, not just chemistry.

Source note: Infographic 5 of the planetGOLD alternative-lixiviants series, reconciled with Report 1 §6 and the evidence on slides 9 to 13 (thiosulfate: Goldstrike reversal; thiocyanate: acidic operation; proprietary agents: cyanide-bearing on assay).

Where the evidence stops: seven countries, one wall

Every documented case dissolves gold; no ASGM-relevant case has shown recovery from solution, effluent management and delivered cost on ASGM feed

Country case (scale · independence)	Gold dissolved	Recovered from solution	Effluent managed	Cost established	ASGM scale
Ghana: Jinchan vs NaCN (cyanide faster, at lower dose) Beyuo et al. 2016 · laboratory · independent	SHOWN	NOT SHOWN	NOT SHOWN	NOT SHOWN	NOT SHOWN
Ethiopia: thiosulfate, ~91% on carbonaceous ore Chaka & Rupprecht 2024 · laboratory · operator-linked author	SHOWN	NOT SHOWN	NOT SHOWN	NOT SHOWN	NOT SHOWN
Ecuador: thiosulfate–glycine, 89.3% at 60 °C Redrovan et al. 2025 · laboratory · independent	SHOWN	NOT SHOWN	NOT SHOWN	NOT SHOWN	NOT SHOWN
Peru: ammonium thiosulfate tank / heap, 75–94% Tremolada 2018 · pilot to 20,000 t heaps · practitioner report	SHOWN	PARTIAL	NOT SHOWN	PARTIAL	PARTIAL
Indonesia: GOLDIX (cyanurate-class GDA) vs NaCN; Jinchan sold in 1 kg retail packs Reno et al. 2026 · laboratory · supplier-affiliated; marketplace listings	SHOWN	NOT SHOWN	PARTIAL (detox tested)	NOT SHOWN	RETAIL USE, UNDOCUMENTED
Kenya: GDA marketed into Kakamega / Migori to avoid Class 6.1 controls Distributor page (United Chemical 2026); no documented use	?	?	?	?	?
Honduras: field lead, tailings leaching with unnamed lixiviants, Macuelizo planetGOLD Honduras voice memos, Aug 2026 · reagent unconfirmed	?	NOT SHOWN	NOT SHOWN	NOT SHOWN	?
Mongolia: GlyCat trial heap, LSM analogue Draslovka 2023 · 1,000 t trial · supplier-reported	SHOWN	SHOWN	PARTIAL	SHOWN	NOT ASGM

★ **THE WALL:** no ASGM-relevant case gets past recovery from solution. Two countries are field leads or marketing only; five are documented, all laboratory or pilot. Only the large-scale-mining analogue crosses the wall, on supplier-reported data.

Source note: Report 1 (country cases). Mongolia is an instrumented LSM heap trial (Draslovka 2023, supplier-reported), the nearest at-scale analogue, included for contrast, not as ASGM evidence. Bulyanhulu (commercial CIL, operator-reported) is likewise LSM. Chinese and Laos plant results for gold dressing agents (Zhang et al. 2022, Table 5) are cyanide-class reagents in cyanide circuits.

What must be in place, whatever the lixiviant

Four controls for each audience; every item applies to cyanide today and to any reagent that follows it

OPERATORS

Pre-concentrate first
gravity before any leach; cut the mass needing chemistry by an order of magnitude (Gunson & Veiga 2020)

Contained circuit
alkaline, lined, no open discharge; carbon or resin recovery specified before the first ton

Reagent custody
licensed supply, locked storage, dose by titration, for ANY lixiviant, branded or not (Stapper, Dales et al. 2021)

People
PPE, training and rotation for whoever touches the pulp, women and children included

REGULATORS

License the reagent, not the brand
Jinchan, CNFREE, GlyCat and cassava fall under cyanide rules; "ordinary cargo, no restrictions" is a red flag; watch imports under HS 3824.99 "chemical preparations", not only HS 2837 "cyanides"

Set the numbers
free 0.1 · WAD 0.5 · total 1.0 mg/L in effluent (World Bank 1995); WAD below 50 mg/L in any open pond; and a laboratory that can measure them

Annex C, Minamata
no cyanide, or cyanide-generating agent, on tailings to which mercury has been added without first removing it (1(b)(iv)); the bridge to Presentation 2

Inspect the hub, not the hillside
permit and monitor centralized processing plants, where control is possible

SUPPORT PROGRAMS

Assay before you endorse
independent five-sample speciation of any proprietary agent before it enters a program

Centralized, supervised plants
the model the WGC, Ghana and the AGC committed to in July–August 2026 (WGC Gold Processing Initiative)

Borrow the Code's architecture
independent verification, public reporting, corrective-action loops, not its fee model (ICMI 2026)

Demonstrate the whole flowsheet
leach + recovery + effluent + delivered cost, on real ASGM feed, before scaling anything

The assurance model: the Code showed that independent verification, transparency and corrective-action loops can civilize a hazardous reagent in the formal sector. A simplified, subsidized analogue is what reaches ASGM (Stapper, Dales, Velasquez & Keane 2021; Report 1, Cyanide Code and implementation sections).

Source note: Gunson & Veiga 2020; Stapper, Dales, Velasquez & Keane 2021; World Bank 1995 (mine effluent guidelines); Minamata Convention 2013, Annex C 1(b)(iv); World Gold Council 2026 (Gold Processing Initiative MoUs); ICMI 2026; Guangxi Senhe listing documents (customs classification).

What to do now, and what we still need to know

PRACTICAL RECOMMENDATIONS

- **Operators:** gravity pre-concentration before any leach; contained alkaline circuit with carbon or resin recovery specified; titration-based dosing; PPE, training and rotation for pulp handlers.
- **Regulators:** license reagent chemistry, not brands, and watch imports under HS 3824.99 as well as HS 2837; adopt free/WAD/total cyanide effluent limits and fund a speciation laboratory; permit and inspect centralized plants; apply Annex C to cyanide-generating agents.
- **Support programs:** require the five-sample independent assay before endorsing any proprietary agent; invest in centralized, supervised plants; replicate the Code's verification and corrective-action loops in a subsidized form.
- **Sequence:** responsible cyanidation first; pilot alkaline glycine or GlyCat in a hub only with the whole flowsheet (leach + recovery + effluent + delivered cost) demonstrated on real ASGM feed.
- **Communicate:** treat "cyanide-free", "non-toxic" and "ordinary cargo" as claims to be tested, and say so publicly; put the labeling question formally to ICMI and to the reagent industry; neither has a published position.

PRIORITY EVIDENCE GAPS: FUTURE RESEARCH

- **Proprietary agents:** assay of retail-purchased Jinchan, CNFREE and CNLITE at an accredited laboratory (free/WAD/total cyanide, ferrocyanide, cyanate, thiourea); no published third-party analysis of product as sold exists; reconcile the three circulating recipes; ecotoxicology; residue behavior on mercury-bearing tailings.
- **Alkaline glycine on ASGM feed:** recovery from solution on site carbon, glycine and oxidant consumption per ton, recyclability over repeated cycles, delivered cost, at matched leach times against cyanide.
- **GlyCat:** independent audit of the Bulyanhulu and Bayan Airag data; a small-scale hub configuration trial with WAD-cyanide monitoring.
- **Thiosulfate:** resin recovery and ammonia/COD effluent treatment at pilot-hub scale on carbonaceous ASGM ore; consumption and cost on ASGM feed; lessons from the Goldstrike reversal.
- **Exposure and field use:** cyanide speciation in water, soil and biomonitoring at ASGM processing sites; confirm GDA use in program countries (Honduras/Macuelizo lead; Indonesia, Kenya, Peru, Tanzania, Zimbabwe; the AMGC Tanzania report); gender-disaggregated exposure data.
- **Mercury interface:** behavior of every alternative on mercury-contaminated tailings: the question Presentation 2 takes up.

PRIORITY ACTIONS: ore characterization, gravity-first recovery, mercury screening, controlled piloting, and independent verification of proprietary products.

Source note: Next: Presentation 2, How clean is clean? Removing mercury from ASGM tailings (Paul Cordy, Cordy Geosciences). Report 1 (draft 3, July 2026) carries the full 14-criterion matrix and the annotated evidence base; all supplier figures are labeled as such.

Where alternative technologies fit in an ASGM transition pathway

A technology positioning ladder showing increasing technical and management complexity

HIGHER TECHNICAL AND MANAGEMENT COMPLEXITY

TECHNICAL AND MANAGEMENT REQUIREMENTS INCREASE

Not necessarily increasing environmental performance

Advanced oxidation processes, ionic liquids and deep eutectic solvents	7	Emerging R&D pathways; not currently deployable in ASGM.
Halides, thiourea and thiocyanate	6	Technically interesting but higher EHS and process-control burden.
Bio-oxidation pretreatment	5	Pretreatment for refractory ores; slow and operationally demanding.
Thiosulfate systems	4	Most credible near-term alternative; ore-specific and more complex to control; no plant operating today.
Glycine or amino-acid systems	3	Lower-toxicity potential; slower leaching; suited to contained pilots.
Controlled chemical processing in licensed facilities	2	Centralized model with monitoring, containment and trained operators; responsible cyanidation belongs here.
Gravity concentration and direct smelting	1	Most immediate mercury-reduction pathway; lowest chemical complexity.

The ladder indicates **increasing control and management requirements**. Rung 2 is where responsible cyanidation sits; every rung above it needs the same system plus its own controls.

KEY TAKEAWAY: ASGM transition should begin with gravity-first processing and move toward controlled hubs, not immediate miner-level chemical substitution.

Source note: Infographic 3 of the planetGOLD alternative-lixiviants series; positioning consistent with Report 1 §6.5 (four-tier classification) and the readiness matrix on slide 7. Rung 4 annotated with the Goldstrike reversal (Nevada Gold Mines 2025).

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How clean is clean? Removing mercury from ASGM Tailings

Paul Cordy

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Annex C

(b) Actions to eliminate:

(iv) Cyanide leaching in sediment, ore or tailings to which mercury has been added without first removing the mercury;

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Practical mercury removal from tailings

- Minamata compliance demands Hg removal with little guidance
- Cyanidation is exploding, Hg contaminated tails are ubiquitous
- As with gold mining, multi-stage separation
- Source: Journal articles, NGO reports, Expert interviews

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Practical mercury removal from tailings

- All old technologies, with new research into ASGM field application
- Clay rich, old acid generating tailings reduce recovery
- Typical tailings have 100-1000 ppm of Hg or more, 200-300 ppm or less is more usual

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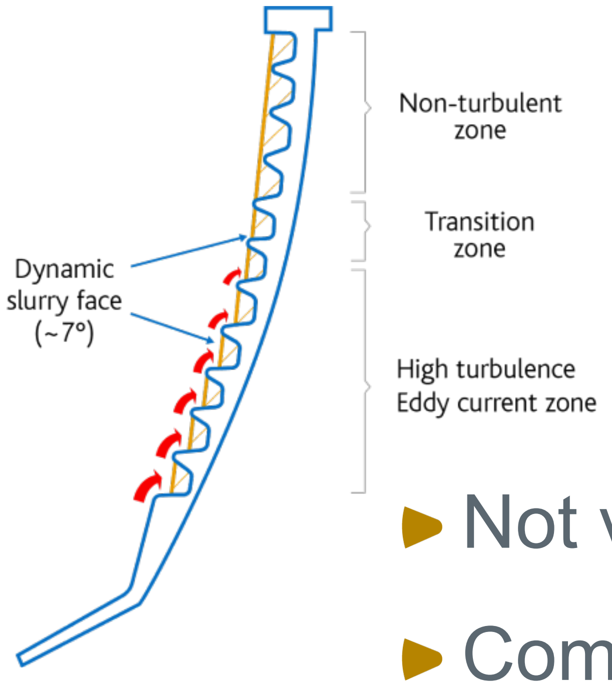
Assessment framework

- Deployment readiness
- Effectiveness/recovery (% range)
- Tailings compatibility
- Cost
- Equipment/reagent availability & supply chain
- Ease of adoption at ASGM scale
- Health & environmental risk
- Gender dimensions
- Evidence confidence
- Governance and implementation capacity

Gravity concentration



- Not very efficient <15%
- Common in gold plants
- New centrifuge design more effective
- Costly relative to recovery

Seprosystems.com 2026

Gravity

Deployment Readiness	Widely used for gold and mercury
Recovery (% range)	**< 15% for mercury**
Tailings compatibility	Universal
Estimated cost ($/T)	ASGM accessible
Availability	Broadly available
Ease of adoption	Easily adopted, artisanal scale proven
Health & env risk	Low, chemical free
Gender dimensions	**High cost relative to recovery**
Evidence confidence	Robust history of field implementation
Governance and implementation	Possible anywhere energy and space is available.

Foam floatation

- Historic, proven, widespread and relatively financially accessible process in mining
- Routinely used for extraction of gold and other fine grained hydrophobic minerals like sulphides
- Fatty acids and sulfur-based organics (Xanthate), stick to gold, mercury and the foam
- Mercury recovery values of up to 75% and over 90% silver for gold and silver can be recovered by this method

Foam floatation

Deployment readiness	Widely used for gold
Recovery (% range)	75-99%
Tailings compatibility	Universal, great with sulphides
Estimated cost ($/T)	Modest cost
Availability	Common in ore processing plants.
Ease of adoption	**Easily adopted, especially, with small scale cyanidation**
Health & env risk	Non toxic exist, **toxic = efficient**
Gender dimensions	No apparent use case
Evidence confidence	Ubiquitous industrial mining process
Gov+ implementation capacity	Allowed in most countries. Scalable

Copper-Silver plates

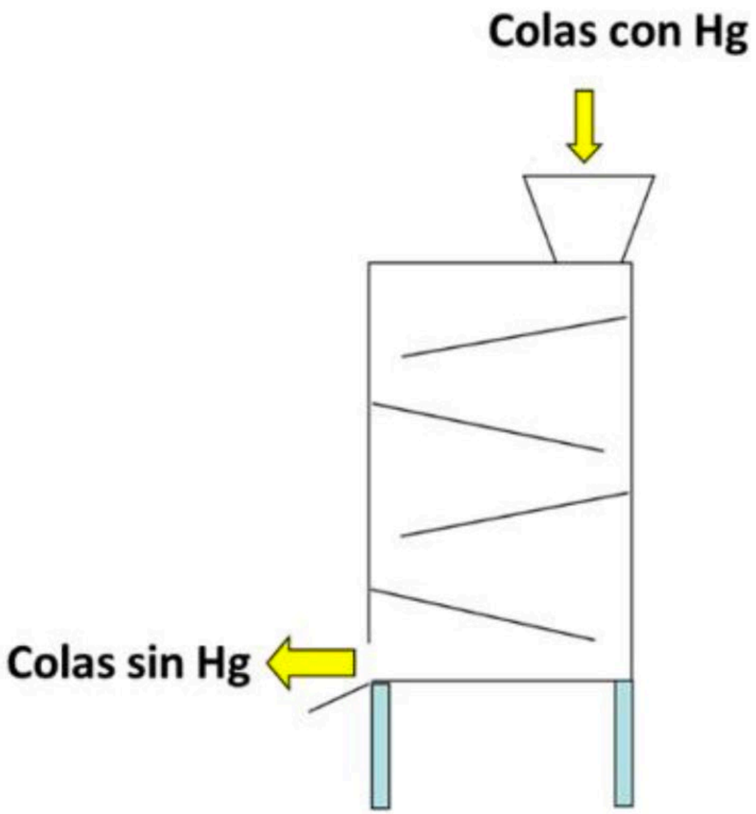


Figure 3 Silver-Covered Copper Plates in a ZigZag Arrangement

Pure Earth 2024

- cheap, effective, and easy to build in ASGM context
- Up to 85% efficiency was possible using real Colombian tailings
- Lower recovery from older acid generating tailings
- Commercially successful in Costa Rica
- Scalable, reactivate with vinegar

Copper /silver plates

Deployment readiness	Field tested and widely applicable
Recovery (% range)	60-95%
Tailings compatibility	Old acidic or muddy tailings are bad
Estimated cost ($/T)	Accessible to anyone
Availability	Ubiquitous in cyanide operations
Ease of adoption	**Easily adopted and locally produced**
Health & env risk	Low, if electroplating carefully
Gender dimensions	Naturally down-scalable, transportable
Evidence confidence	Robust lab and field research
Gov+ implementation capacity	Best in formal cyanidation facilities. Scalable

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Thermal desorption (retort)

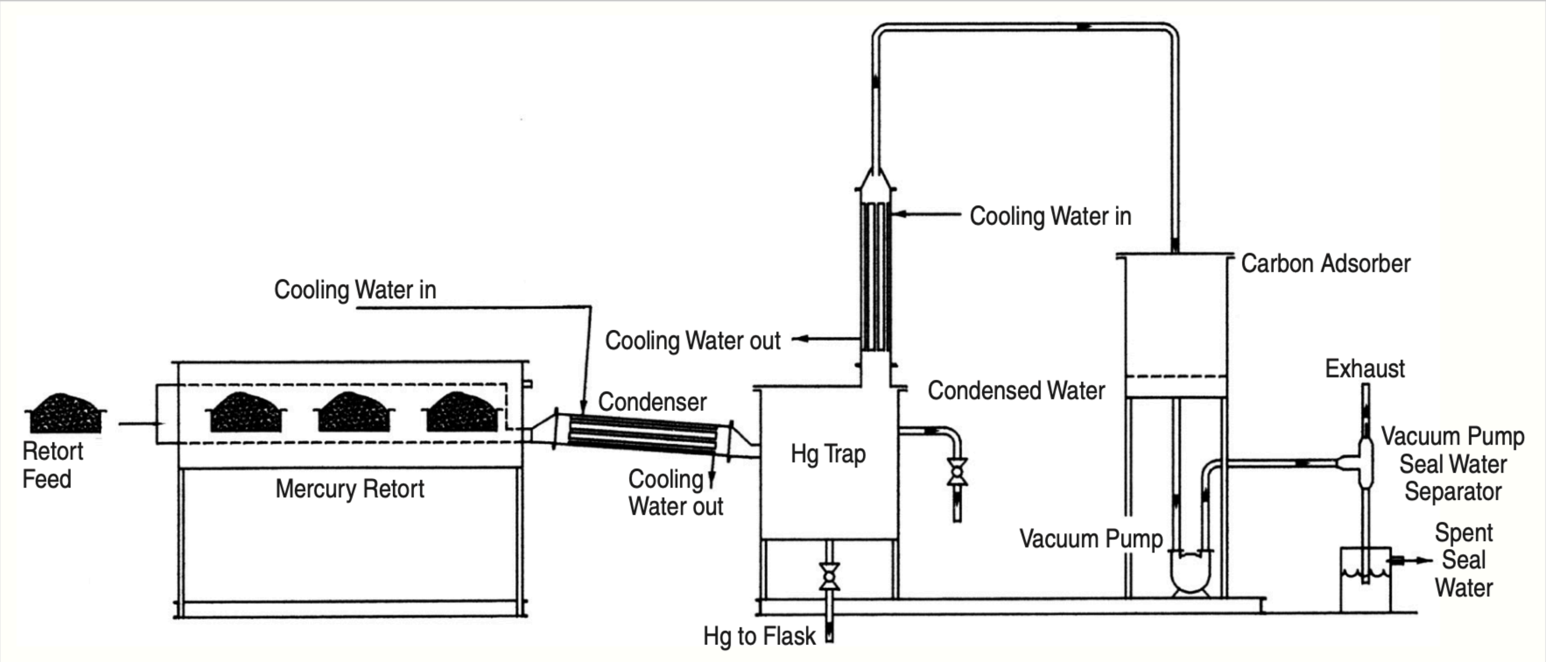

Figure 2. A simplified retort schematic.

Washburn et al. 2003

- Field tested and widely used for gold
- Easily adopted, proven artisanal and industrial designs
- 90-99% efficient
- Also can liberate more gold by degrading sulphides
- 400 and 600 °C under 0.20 to 0.25 atmosphere

Thermal desorption (retort)

Deployment readiness	Ancient, simple, proven, scalable
Recovery (% range)	90-99%
Tailings compatibility	Universal, also liberates gold
Estimated cost ($/T)	500 -1000 USD per tonne
Availability	Broadly available, **common in soil remediation and mining**.
Ease of adoption	Easily adopted, artisanal designs proven
Health & env risk	Some fugitive mercury vapour
Gender dimensions	**Locally built artisanal solutions**
Evidence confidence	Widely used for roasting amalgam, sulphides, soil decontamination.
Gov + implementation capacity	Can meet emissions and disposal standards

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Artisanal Zinc retort

Propane heated, water cooled

- Eliminates open air burning of gold and mercury loaded zinc
- Water cooled, vapour sealed by submersion of bottom edge

Oseas Garcia 2012

Solar retort

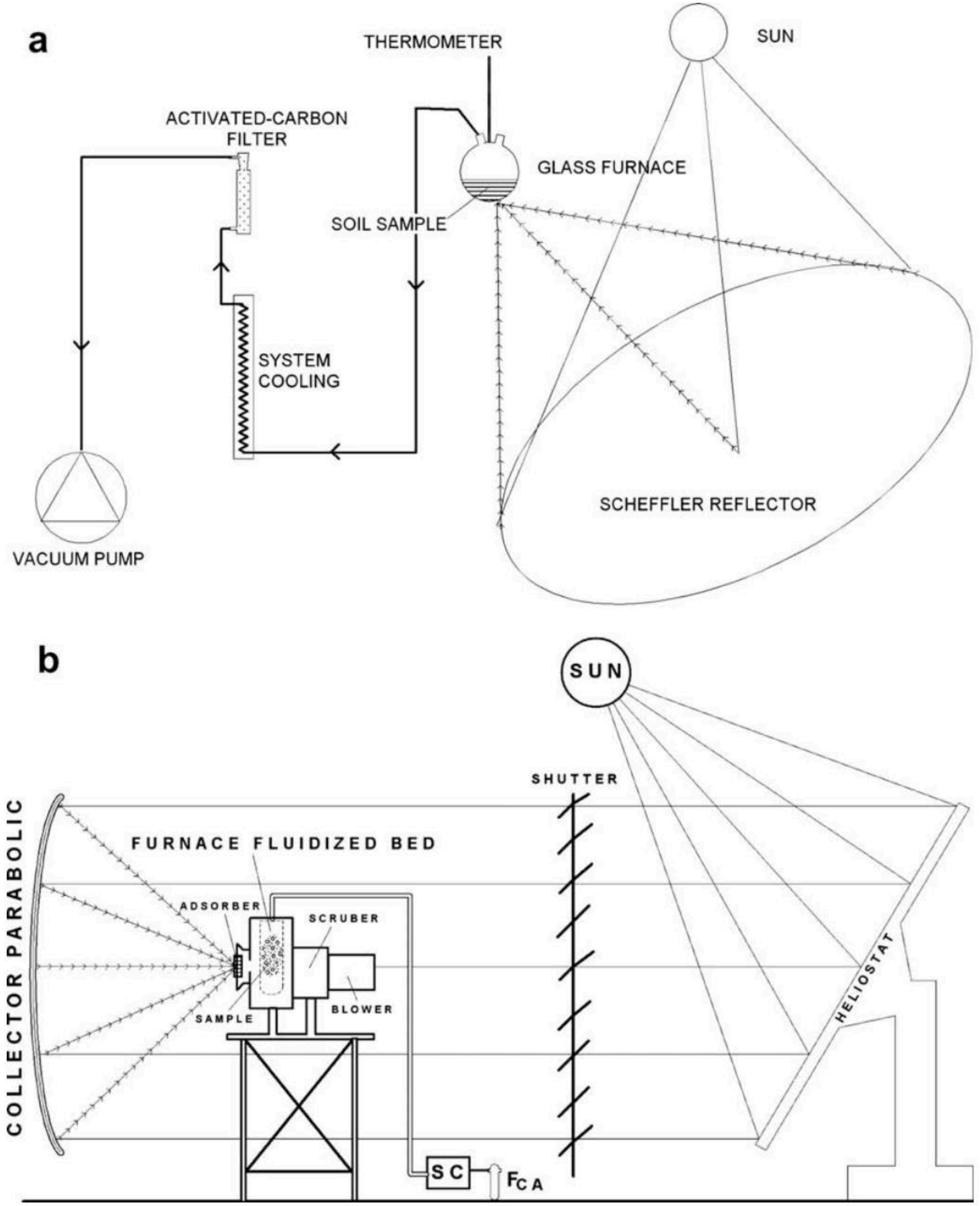


Fig. 1. (a) Scheme of operation of the low-temperature solar furnace (LT-UPC). (b) Scheme of operation of the middle-temperature solar furnace (MT-PSA). SC: system cooling, F_{CA}: activated-carbon filter.

Navarro et al. 2009

Precipitation

- Removal of residual mercury from lixiviation process streams
- Cyanide dissolves mercury ~30% less effectively than gold
- Sulfides (Na_2S, CaS, ZnS), sulfur-based organic substances (Xanthate) highly effective at precipitating mercury
- No reduction in gold extraction efficiency
- 95-99% removal
- Widely available

Precipitation

Deployment readiness	Common use in cyanidation processes
Recovery (% range)	95-99%
Tailings compatibility	**In CN solutions only**
Estimated cost ($/T)	Cheap, common options exist
Availability	Widely available
Ease of adoption	Normal CN agitated tank facilities should suffice
Health & env risk	Normal industrial chemicals risk
Gender dimensions	**Could be applied in micro-cyanidation**
Evidence confidence	**Widespread industrial use and research**
Gov + implementation capacity	Common use in cyanidation processes

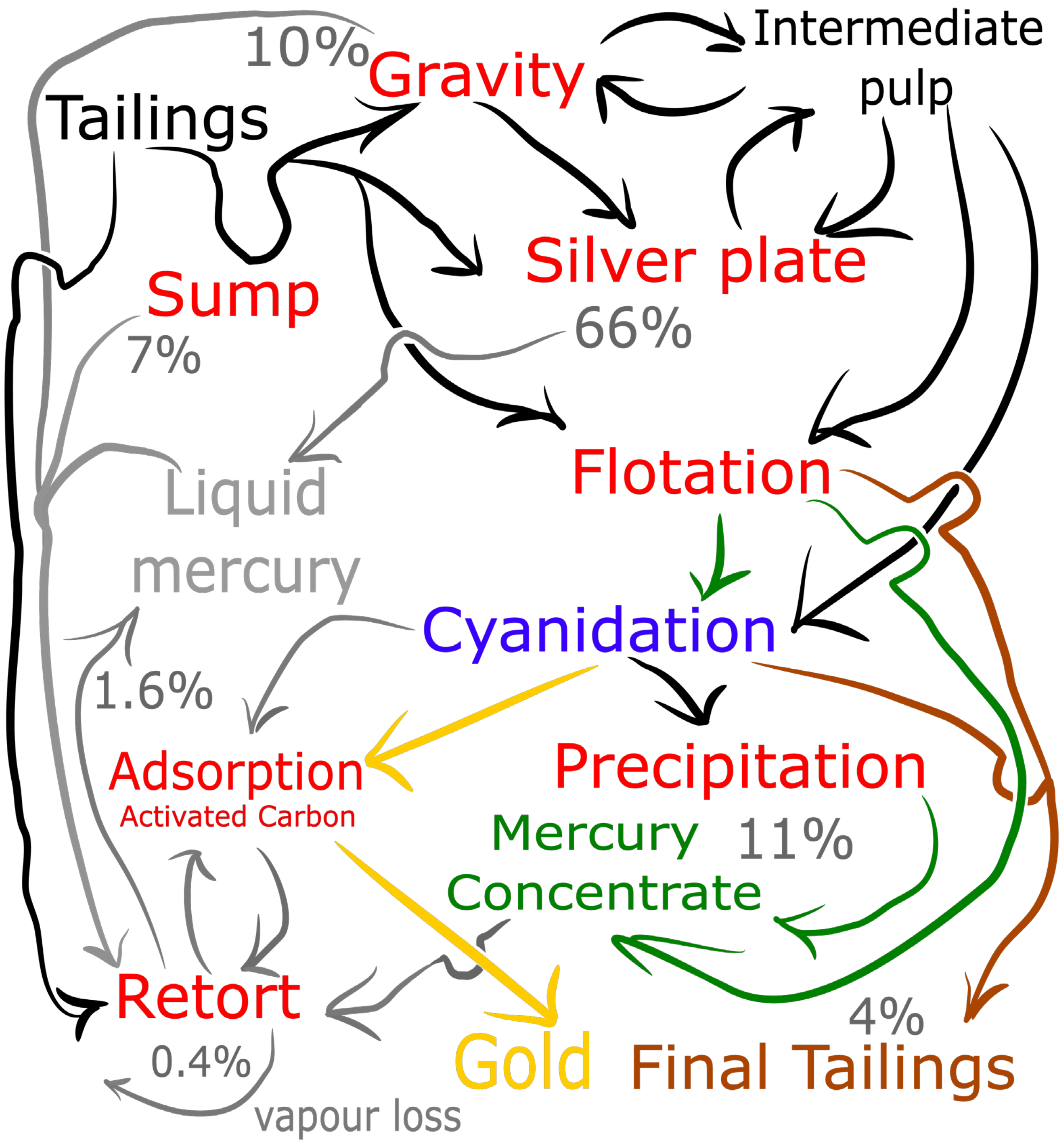
Activated carbon

- Oldest, simplest and most effective way to remove mercury vapour, droplets and ions from air or water
- Filters industrial flue gas streams and wastewaters
- Made by burning wood in an oxygen poor environment
- Molecular scale cracks and crevices whose electrostatic and size properties attract, trap and hold metals
- Sulfur-impregnated carbon can typically remove 99.99% of residual mercury from air
- Granular activated carbon is used to capture gold and mercury from cyanide solutions

Adsorption with Activated Carbon

Deployment readiness	Common artisanal and industrial use
Recovery (% range)	95-99%
Tailings compatibility	Universal
Estimated cost ($/T)	Cheapest and simplest
Availability	Made easily by burning wood, coconut shells, etc
Ease of adoption	Widely used for air filtration and in cyanidation
Health & env risk	Safe and non-toxic
Gender dimensions	Accessible
Evidence confidence	Widespread practical use
Gov + implementation capacity	Widespread use in artisanal and industrial processes

Sump


Intermediate pulp
10%
Gravity
Tailings
Silver plate
Sump
66%
7%
Flotation
Liquid mercury
Cyanidation
1.6%
Adsorption
Activated Carbon
Precipitation
Mercury Concentrate
11%
Retort
4%
0.4%
Gold
Final Tailings
vapour loss

Thank you.

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