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Review

An examination, solution, and transformative strategy to replace mercury and cyanide salts in artisanal small-scale mining (ASM) - Southern Ecuador

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Abstract

Artisanal and small-scale gold mining (ASGM) is widely recognized by the scientific community and numerous organizations for its significant contribution to global mercury (Hg) pollution. Mercury, a potent neurotoxin, is used to extract gold (Au) from crushed and milled ore, making ASGM the largest anthropogenic source of deadly environmental and atmospheric mercury contamination.

After extensive research and collaboration with experts dedicated to mitigating the health risks posed by mercury and its detrimental effects on global biodiversity, this paper advocates for a broader approach to this critical issue. This approach includes targeting ore processing centers, which collectively process an estimated 85-90% of the ore from approximately 18-20 million impoverished artisanal miners in about 80 countries annually using mercury.

This paper examines several current non-mercury methods employed by artisanal miners to recover gold and proposes a transformative strategy aimed at revolutionizing the use of mercury and cyanide salts in both artisanal and small-scale mining (ASM) and large-scale mining (LSM) operations worldwide.

Ecuador’s Portovelo-Zaruma mining district is an ideal location to introduce and demonstrate the use of Manipueira, an extract from the cyanogenic bitter cassava plant (*Manihot esculenta Crantz*), as a replacement for mercury and cyanide salts as lixiviants. This strategy aims to sustainably recover more gold, more quickly, from ore and tailings wastes. The district's high density of artisanal miners, numerous gold mines, proximity to ore processing centers, and local availability of the bitter cassava plant make it particularly well-suited for this initiative.

By implementing these strategies, substantial improvements in gold recovery rates can be achieved while effectively mitigating the environmental and health challenges associated with mercury and cyanide use.

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1. Introduction: Artisanal mercury pollution is poisoning life on Earth

Artisanal and small-scale gold (ASG) miners worldwide contribute significantly to the global gold supply, but the use of mercury in gold recovery poses severe environmental and health risks. The 18 to 20 million estimated artisanal miners includes 4 - 5 million women and 600,000 children under the age of 15, all largely suspected of suffering from undiagnosed mercury poisoning each year. Collectively, these miners produce an estimated 20-25% of the world's total annual gold supply which is valued at around USD $30 billion (Linda McGrew, 2016; UNEP Global Mercury Partnership report, 2023,). Most of the gold extracted from ore using mercury ends up in jewelry, computers, iPads, iPhones, and other electronic devices.

Globally, the ASM sector is responsible for the annual release of 2,000 tonnes of mercury to the environment (UNEP News, 2018) while Yuyun Ismawati, co-founder of an Indonesian environmental group, Nexus3 Foundation and a recipient of the 2009 Goldman Environmental Prize reports, "illicit manufacturers in Indonesia produce more than 10,000 tonnes of mercury a year" (Richard C. Paddock, 2019).

According to the United Nations Industrial Development Organization, almost 100 percent of all mercury used in artisanal gold mining is released into the environment, constituting a danger on all fronts – economic, environmental and human health (UNIDO Booklet).

"Mercury is everywhere (L. J. Esdaile & Justin M. Chalker, 2018) (**Fig.** 1)*: in the rain, snow, our food, our waters, the central nervous system (WHO, Mercury and Health Fact Sheet, 2017)* (**Fig.** 2)*, the brain (WHO, Mercury and Health Fact Sheet, 2017)* (**Fig.** 3), *and even in the human placenta (Phylicia Ricketts et al., 2017)* (**Fig.** 4)*!"*

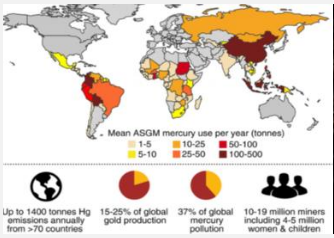


Fig.,1. Estimated annual mercury use in ASGM

Fig., 2. Central nervous system

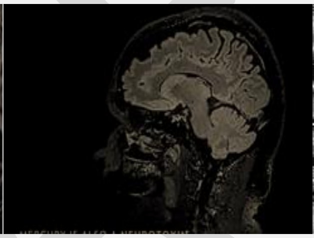


Fig., 3. Brain

Fig., 4. Placenta

Atmospheric mercury pollution is documented to stay airborne up to one year (Oxford University earth scientists, 2021) impacting all people on Earth including unborn children who are especially at the greatest risk (Bose-O'Reilly S, et al 2010). Mercury precipitates back to Earth in the form of rain, ice, and snow polluting the land, contaminating the waters, poisoning the fish we consume, threatening our health (**Fig.** 5), and destroying our Planet's health.

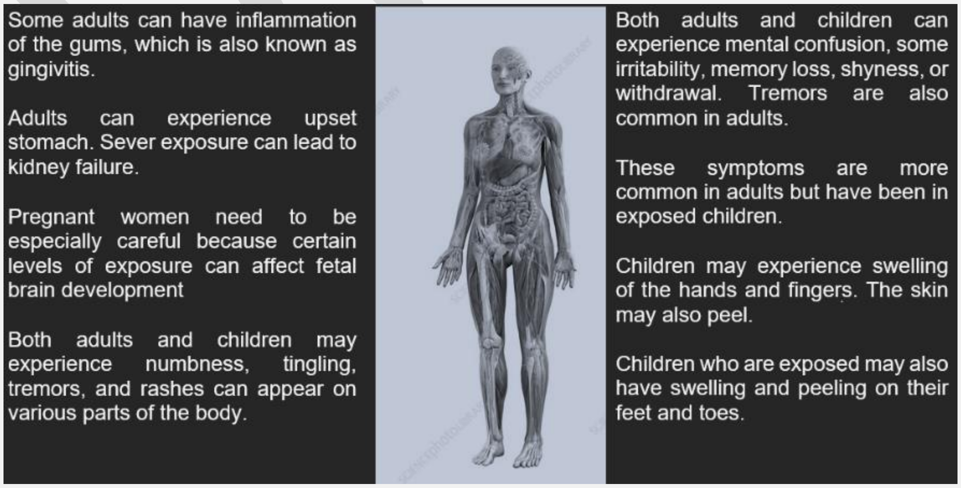


Fig., 5. Mercury Poisoning Symptoms

The *Lancet* Commission on pollution and health, found that pollution was responsible for an estimated 9 million deaths (16% of all deaths globally), and for economic losses totaling US$ 4.6 trillion (6.2% of global economic output) in 2015 (Richard Fuller, et al 2022).

2. Artisanal Gold Ore Processing

2.1 Chilean Mill Ore Crushing and Processing (**Fig**. 6)

Fig., 6. Chilean Mill

Typically, a group of 5 or 6 artisanal miners spend 3 – 4 weeks mining 40 – 80 tonnes of ore bearing gold which they package in 45 kilogram (kg) bags and truck to their local ore processing center. The next 48 – 72 hours is spent nonstop production concentrating the ore to 10 - 15 kg for processing using mercury (**Fig.** 7).

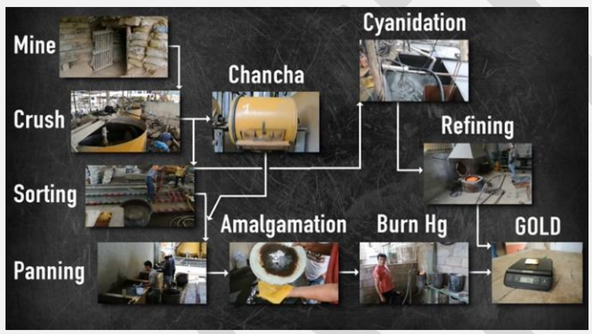


Fig., 7. Gold Recovery Processing Circuit

Once the ore is manually broken (**Fig.** 8), it's shoveled into a jaw crusher (**Fig.** 9) then into a chilean mill (**Fig.** 10) where a pair of revolving cement wheels rotate on top of the solid to liquid 6-14% ratio (S:L) slurry on a curved surface crushing it, liberating (freeing) gold, and reducing the particle size to 150 – 200 mesh (89-75 microns).

Fig., 8. Breaking

Fig., 9. Jaw Crusher

Fig., 10. Chilean Mill

Water continuously flows through the mill during processing flushing the concentrate through a 0.2 millimeter (mm) nylon screen onto a sluice (**Fig.** 11) causing the heavier gold particles to sink onto the carpets (balletas) which are manually picked up and rinsed in a barrel (**Fig.** 12) every hour sorting the gold and to minimize gold losses. However, the lighter smaller gold particles are washed away to tailings wastes with typical gold losses up to 70% (P.Torkaman et al, 2021). Copper plates covered with mercury (**Fig.** 13) are also used to extract gold from the slurry concentrate.

Fig., 11. Sluicing

Fig., 12. Rinsing

Fig., 13. Copper Plates

The concentrate is panned (**Fig.** 14) using a stone and rubbing in a circular motion for 5 – 6 hrs. with mercury to amalgamate (bond) with the liberated gold (**Fig.** 15), an acquired talent for an artisanal miner to recover more than 70%. Stone rubbing reduces the particle size, homogenizes the mercury which increases the amount of amalgamated gold as mercury does not amalgamate with surface gold (**Fig.** 16) which can be recovered using cyanide.

Fig., 14. Panning

Fig., 15. Liberated Gold

Fig., 16. Surface Gold

Panning produces a dense 50 – 50% mercury gold amalgam (UNIDO, A Practical Guide) which is scrubbed with brown sugar (**Fig.** 17) as miners believe it will make the gold shiner and recover more gold. The amalgam is placed in a gauze, squeezed by hand (**Fig.** 18) to remove excess mercury (P. Torkaman & M. M. Veiga, 2023) and torched above 460º centigrade vaporizing the mercury to the environment (**Fig.** 19) leaving the gold behind.

Unknowingly, they only recover 20 – 30% of the gold with the rest being lost to tailings wastes which the center owners keep for payment in lieu of cash for the use of their facilities, much to the chagrin of the miners as they are aware the wastes contain unknown quantities of gold (Marcello M. Veiga et al, 2014).

Fig., 17. Scrubbing

Fig., 18. Squeezing

Fig., 19. Torching

The inhalation of mercury by artisanal miners and the gold smiths who refine the gold dorés or buttons (gold products) still containing 2 - 5% mercury (Paul Cordy et al, 2013; L. J. Esdaile & Justin M. Chalker, 2018) further releases mercury vapors to the local environment causing damage to the central nervous system, digestive system, immune system, lungs, thyroid, kidneys, and causing memory loss, insomnia, tremors, neuromuscular changes, headaches, and paralysis (WHO Mercury and Health Fact Sheet, 2017).

2.2 Chancha Barrel Whole Ore Mercury Processing

After crushing, 100 – 150 kg of ore is shoveled into steel drums *a.k.a.* trommels (**Fig.** 20), ball mills (**Fig.** 21) or chancha barrels (**Fig.** 22) along with the remaining slurry left in the bottom of the chilean mill which contains a high concentration of gold, *a.k.a.,* las ollas. Whole ore chancha barrel processing is recognized as the planet's deadliest form due to severe mercury environmental impact.

Fig., 20. Trommel

Fig., 21. Ball Mills

Fig., 22. Chancha Barrels

The drums contain 180 kg steel rods and stream/river rocks (**Fig.** 23) which pulverize the crushed ore during an 8 hour rotation period in a mixture of 200 liters of stream water, 1kg mercury per 20kg crushed ore (L. J. Esdaile and Justin M. Chalker, 2018), soap, urine, coca cola (**Fig.** 24), toothpaste, bleach, brown sugar, and other household items miners believe will enhance gold recovery and make it shinier (Brandon Nichols, 2016).

Once completed, the slurry concentrate is hand poured into a barrel (**Fig.** 25), sluiced, sorted, panned using mercury, and torched to recover the gold as was the situation when processing ore using Chilean Mills.

Fig., 23. Steel Rods Stream Rocks

Fig., 24. Coca Cola

Fig., 25. Slurry Concentrate

Artisanal miners add up to 500 gms of mercury to only recover 1.5 gms of gold (Peter W.U. Appel, PhD & Leoncia Na-Oy, 2012; Global Environment Facility, 2014), the remaining gold is lost to tailings wastes which are generally processed using cyanide salts. These mercury laden gold and silver (Ag) rich tailings may contain between 50 and 5,000 mg mercury per kg and up to 14% gold by mass (L. J. Esdaile & Justin M. Chalker, 2018). As much as 20 gm of gold can be isolated for every tonne of tailings (M. M. Veiga et al, 2009).

These 2^{nd}, 3^{rd}, and 4^{th} generation artisanal miners need their money immediately. They earn between USD $4-$5 dollars per day and typically have 5 – 6 dependents. They cannot afford the time, nor the money required to leach their wastes using sodium cyanide salt at USD $3 – 5 /kg. Additionally, they have no access to the salt as the sale is regulated and restricted to certified suppliers of the International Customer Management Institute (ICMI). The Chinese supply the salt to the centers much to the dismay of the community with each center using an average of 2.05 tonnes/month and an average of 2.4 kg of mercury/month costing USD $385/kg (P. Torkaman et al., 2021).

Furthermore, the Carbon in Pulp (CIP) leaching process requires expensive activated charcoal and may take 2 – 3 weeks or more to obtain while the Merrill-Crowe leaching process alone could take 30 days or more (Pariya Torkaman, 2023).

The miners agree mercury is dangerous to their health, the environment, their community well-being and have no knowledge or the wherewithal to implement change as that's not in there control, only the center owners can make the change and up until now, there's been no incentive for them to replace mercury use as processing the artisanal miners tailings is their main source of income but not all the Members as a number of facilities lack storage ponds and leaching equipment.

3. Gold Recovery Using Non-Mercury Methods

The choice of leaching agent in gold extraction depends on factors such as ore type, environmental considerations, availability, and economic feasibility. While cyanide remains the most widely used, alternatives like thiosulfate, thiourea, and bioleaching are gaining traction due to their environmental benefits and effectiveness for certain ore types. Further research and technological advancements will likely enhance the viability and adoption of these alternative leaching agents.

Cyanide, gravity concentration, biological and chemical leaching processes as well as the relevant technical supports have been introduced to replace mercury in numerous countries although the use of a plant-based extract solution as a lixiviant to replace the use of mercury and cyanide salts in ASM has an extremely limited audience, if any at all.

It's not just about eliminating the use of mercury; it's also about fostering coexistence between artisanal miners and ore processing center owners (Marcello M. Veiga et al., 2022; Marcello M. Veiga and Omotayo Fadina, 2020). This coexistence model allows artisanal miners to focus on mining activities while ore processing is managed by centers or companies. This approach offers a solution for formalizing miners, increasing economic benefits, and reducing pollution.

3.1 Manipueira – Modified Merrill-Crowe Gold Cementation Process (MMCP)

Preliminary experimental research conducted at the Norman B. Keevil Institute of Mining Engineering, University of British Columbia (UBC) spearheaded by Dr. Marcello M. Veiga, P.Eng., Professor Emeritus using Manipueira as a lixiviant in a solution containing 267 $^{\pm}$ mg/L ionic CN^- at pH 10.5, showed promising results leaching 50% of the ore gold in 24 hrs. It was observed that the lower solid to liquid 20% ratio (S:L) recovers more gold as the solution contains more CN^- (P. Torkaman et al, 2021).

Additional observations concluded some gold in the Manipueira solution was suspected of being preg-robbed (the phenomenon whereby the gold cyanide complex, $Au(CN)_2^-$, is removed from solution by the constituents of the ore) due to the suspended starch which must be removed by flotation first, not filtration, as it inhibits the gold particles extraction.

The standard Merrill-Crowe process (MCP) was modified (MMCP) by eliminating both filtration, the main cost associated with operating and vacuum systems to simplify the process, and by replacing sodium cyanide as a lixiviant with Manipueira. By using cloth bags filled with zinc (Zn) shavings (or aluminum (Al)) in the pulp agitation process, 99.4% of gold was precipitated on the zinc shavings in 2 (two) hours when the agitation was reduced to avoid aeration compared to 84% gold recovery using the standard MCP (P. Torkaman & M. M. Veiga, 2023).

Additional experiments conducted using the MMCP leached 99.6% of the gold from mercury contaminated tailings wastes and 99.3% of the gold from ore concentrates in 2 hours (Marcello M. Veiga & Pariya Torkaman, 2021).

Unlike current artisanal leaching protocol, all the hydrogen cyanide in the Manipueira extract solution is consumed during the process mitigating releases to the environment as the pH is properly maintained. If the miners can't smell almonds, the scent of CN^-, the process isn't working. At pH 11, over 99% of the free cyanide exists in solution as CN^-, while at pH 7 or less, over 99% of the cyanide exists as hydrogen HCN (The Cyanide Code, Cyanide Facts).

Thirty - forty percent of the plants weight is the Manipueira solution (P. Torkaman et al, 2021) and the plant can produce up to 1,550 mg of aqueous (aq.) free cyanide ($HCN_{aq.}$) per kg fresh root (Burns A. E. et al., 2012), the plants natural defense system when the integrity of the cellular structure is compromised. The bitter cassava plant does not contain cyanide.

An estimated 120 million tonnes of cassava wastewater globally is recklessly discarded to the environment annually by flour makers. Manipueira, which stinks when fermented, attracts insects, creates human health threats, causes biodiversity destruction, contaminates the soil, drinking water, irrigation water contaminates the crops, and pollutes the rivers. Flour mills face a serious problem of disposing large amounts of Manipueira (300 L/tonne of the root or more) (Nitschke, M., & Pastore, G. M., 2003) which represents a risk for domestic animals, and it is a sanitation problem.

According to the WHO (Simeonova et al., 2004), bitter cassava dried root cortex, leaves, and whole tuber, can produce up to 2360, 300, and 380 mg of free cyanide per kg, respectively.

"The symbiosis of artisanal ore processors and flour makers is a win-win situation to reduce environmental pollution, human health threats, and mitigating an unintended consequence of harvesting the bitter cassava plant" (P. Torkaman et al., 2021).

3.11 The Chemistry

It is well documented that more than 2,000 plants species including edibles such lima beans, bamboo, flax, and the bitter cassava plant **Fig.** 26), used to make starch (**Fig.** 27), toasted cassava, porridge, dough, beer, and other foodstuff all contain cyanogenic glycosides (**Fig.** 28), natural plant toxins (Islamiyat Folashade Bolarinwa, et al, 2016).

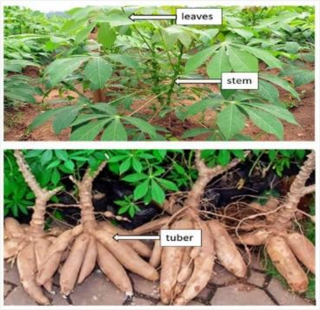


Fig., 26. Bitter Cassava Plant

Fig., 27. Starch

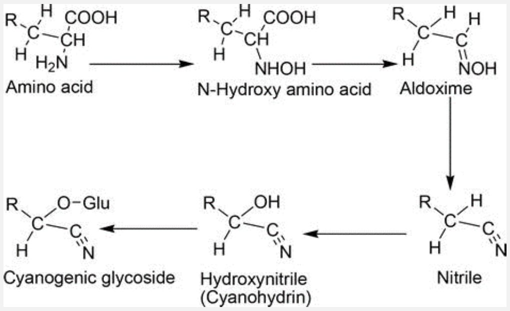


Fig., 28. Cyanogenic Glycoside

These glycosides can be converted to aqueous free cyanide *a.k.a.,* hydrocyanic acid (HCN) by enzymatic hydrolysis of linamarin (**Fig.** 29), a cyanogenic glucoside only present in bitter cassava (Ewa Jaszczak et al., 2017), when exposed to linamarase, an enzyme normally expressed in the cell walls of bitter cassava plants. Under neutral conditions, acetone cyanohydrin decomposes to acetone and hydrogen cyanide (HCN), a rapid acting lethal agent (WHO Hydrogen cyanide fact sheet).

The disruption of the plant cell structure by predators or by flour manufactures peeling and processing the roots coalesces the glycosides with the corresponding β-D-glucosidase enzymes producing sugars and cyanohydrin that spontaneously decomposes into hydrocyanic acid (HCN) and a ketone in a pH 5.5 – 6 solution (Islamiyat Folashade Bolarinwa et al., 2016) .

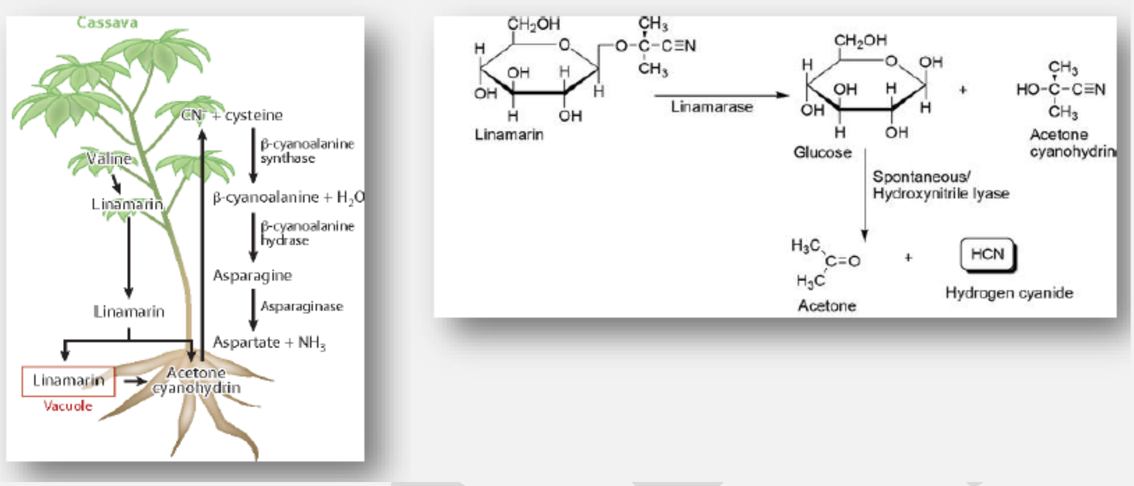


Fig., 29. Enzymatic Hydrolysis of Linamarin

3.2 Organic Aqua Regia (OAR)

Organic Aqua Regia (OAR) is a non-toxic, environmentally friendly solvent that mimics the properties of traditional aqua regia, which is a mixture of nitric acid and hydrochloric acid used for dissolving gold and other precious metals. Traditional aqua regia is highly corrosive and dangerous to handle, making it unsuitable for many applications, especially in artisanal and small-scale gold mining.

In traditional aqua regia, gold dissolves through the following reactions:

1. **Nitric Acid Reaction:**

$3NO_3^- + 3H^+ \rightarrow 2H_2O + NO + NO_2 + O$

2. **Chloride Ion Reaction:**

$3Cl^- + O \rightarrow Cl_3^-$

3. **Formation of Tetrachloroaurate:**

$Au + Cl_3^- + 4HCl \rightarrow H[AuCl_4] + 3H_2O$

OAR formulations are proprietary and are designed to provide a safer and greener alternative for metal dissolution, leveraging organic acids and other biodegradable components. A simple hypothetical reaction and not a formula for an organic solvent could be:

Au + Organic Complexing Agent + Oxidizer→ Gold-Complex

This makes OAR a preferable option for applications requiring metal recovery, such as gold mining and electronics recycling, where safety and environmental considerations are paramount. The main advantages are that it is non-toxic, is recyclable, extracts gold faster than cyanide, does not use water, and does not require carbon or electrowinning. Additionally, the ore requires no crushing and minimal grinding, both of processes reduces operating costs as crushing and grinding are the most expensive.

After years of research conducted at the Norman B. Keevil (Chairman Emeritus of Teck Resources) Institute of Mining Engineering, UBC in conjunction with Newlox Gold Ventures Corp. (Newlox) and Chiba University in Japan, tests results using an OAR formulation yielded greater than 90% gold recovery (Newlox Press Release, October 2020).

Extensive R&D work was completed at UBC during the primary process design and subsequent optimization processes. The result was that Newlox Gold's wholly owned subsidiary, Oro Roca, S.A., built an environmental processing facility in Costa Rica using the designs provided by UBC which specifically addresses the environmental and metallurgical qualities of the reclamation material identified. The Company's environmental reclamation plant is operational and processes 80 tonnes per day (**Fig**. 30).

Fig., 30 Reclamation Plant

Newlox's tailings remediation coexistence model enables the artisanal miners to create a valuable revenue stream from their waste material while simultaneously reducing the environmental impact of their operations. In Costa Rica, the local artisanal miners are organized into legal cooperative companies.

Newlox has tailings supply agreements with all the local mining cooperatives. Tailings are purchased on a per-truckload basis, samples are analyzed in-house prior to purchase. Upon agreement of the price, the ore is processed using their UBC designed state-of-the-art technology and their proprietary OAR reagent. The recovered gold profit is equally split after deducting operating expenses.

Newlox recently announced the completion of construction at the Boston Clean Gold Project with a processing capability of 150 tonnes per day (Newlox Gold Ventures Corp. Release, 2023) and announced the agreement to acquire 100% of the Antioquia Community Coexistence Project in San Roque, Department of Antioquia, Colombia (Newlox Press Release, 2023).

3.3 Balso and Malva Plant Extract Solution

In Tadó, Dept. Chocó, Colombia, small-scale alluvial gold miners produce Green Gold using the Balso (Ochroma pyramidale) and Malva (Hibiscus furcellatus) leaves which they crush by hand (**Fig.** 31), mix with water to make a foamy liquid (**Fig.** 32) which is added to the gold pan (*a.k.a.* batea) lowering the solution surface tension allowing the fine alluvial gold to float and be recovered instead of using mercury (William E. Brooks et al, 2015).

Fig., 31., Hand crushing Balso leaves

Fig., 32. Foamy liquid

3.4 Gravity Borax® Method (GBM)

The mercury free gravity borax method (GBM) *a.k.a.* the Filipino method for sustainable gold recovery was purportedly developed in the 1950s by an artisanal miner in the province of Benguet on the island of Luzon, the main island in the northern portion of the Philippines (911 Metallurgist, Fact Sheet I.). However, according to Pure Earth (Transforming The Chichiqueros Gold Mining Community In Peru's Rainforest Into A Mercury-Free Model, 2017) *(f.k.a)* Blacksmith Institute, the GBM has been in use in the Philippines for a century.

The GBM uses an environmentally benign, low-cost, and naturally occurring Borax® powder (sodium borate decahydrate) as a flux to replace the use of mercury. However, this process can only be used on concentrates with high grades of gold (>5% Au) and with no sulfides (Veiga and Gunson, 2020). Additionally, the process requires a gold melting furnace which is expensive and requires skills to operate.

When Borax® is mixed with the crushed gold ore concentrate in a plastic bag containing water then heated in a crucible to 1150 – 1450º Celsius, this process causes chemical reactions in the molten state which easily dissolves (oxidizes) the metal impurities in the mixture forming a slag, purifying the gold sustainably, and with no toxic tailings wastes.

In Sorata Bolivia, the GBM was introduced to several groups of artisanal miners by scientists who conducted educational mercury-amalgamation vs. the GBM for gold recovery competitions. The winner being the GBM which extracted up to 5 (five) times more gold (Peter W. U. Appel et al, 2015) (**Fig.** 33). On the lower left side of the photo is the gold button recovered using borax smelting weighing 0.5 g, and above is the 0.1 g button recovered using amalgamation. On the upper right side of the photo is the 0.4 g gold button recovered using borax smelting, and below is the 0.3 g gold button recovered using amalgamation.

Fig., 33. Results of competition showing gold recovered using borax smelting and amalgamation.

ASG miners using borax has been successfully tested and operational in the Philippines, Indonesia, Tanzania, Bolivia, Sudan Africa, Kenya, and Zimbabwe for decades. In a small area of Luzon, approximately 15,000 ASG miners use this method exclusively and typically reporting 3 (three) times more gold recovery than by using mercury (**Fig.** 34) and without producing any toxic tailings wastes (Peter W.U. Appel, PhD & Leoncio Na-Oy, 2012).

It is reasonable to estimate that over the past 70+ years, approximately 30,000 ASG miners out of an estimated 18 million across an approximate 7 of 80 countries worldwide have collectively transitioned to using the sustainable GBM.

Gold recovery using amalgamation vs. borax smelting.

Location	Amalgamation	Borax smelting
Suerte 1, Bolivia	0.1 gram	0.5 gram
Suerte 2, Bolivia	0.4 gram	0.5 gram
Gaang 1, Philippines	1.2 gram	3.2 gram
Gaang 2, Philippines	2.3 gram	4.8 gram
Gaang 3, Philippines	1.8 gram	4.2 gram
Gaang 4, Philippines	7.2 gram	22.5 gram
Kias, Philippines 1	0.4 gram	1.1 gram
Kias, Philippines 2	0.8 gram	1.3 gram

Fig., 34. Gold recovery using amalgamation vs. borax smelting

3.5 Sodium Cyanide Gold Leaching

In 2019, the global total production capacity of sodium cyanide (NaCN) is about 1.92 million tons, and the total output is about 1.45 million tons. The average annual growth rate of output from 2015 to 2019 is about 1.8%. The mining industry uses approximately 6% of the total cyanide produced (CN FREE, 2020).

Gold in a sodium cyanide solution in the presence of oxygen and water forms $[Au(CN)_2]^-$ with the overall chemical reaction:

$4Au + 8NaCN + O_2 + 2H_2O \rightarrow 4Na[Au(CN)_2] + 4NaOH$ (James Edward Hoffmann, 2008).

In this reaction, gold reacts with sodium cyanide oxygen (O_2), and water (H_2O) to produce is sodium dicyanoaurate ($Na[Au(CN)_2]$) and sodium hydroxide (NaOH).

It is well known and documented that both the carbon-in-pulp (CIP) gold precipitation process (**Fig.** 34) and the Merrill-Crowe zinc dust gold cementation process (**Fig.** 35) typically recover at least 90% of the tailings gold using sodium cyanide as a lixiviant (Marcello Veiga et al., 2014), proven and documented to recover 3 times more gold than the artisanal miners themselves using mercury. Both leaching processes use a 100 - 110 parts per million (ppm) concentrated sodium cyanide solution at pH 11.

3.6 Carbon in Pulp (CIP) Gold Leaching Process

In the CIP process, the gold is adsorbed onto activated carbon added to the solution. The activated carbon with gold is washed with a hot caustic solution. The gold is precipitated by passing the concentrated cyanide gold solution through an electrowinning cell after being desorbed from the activated carbon.

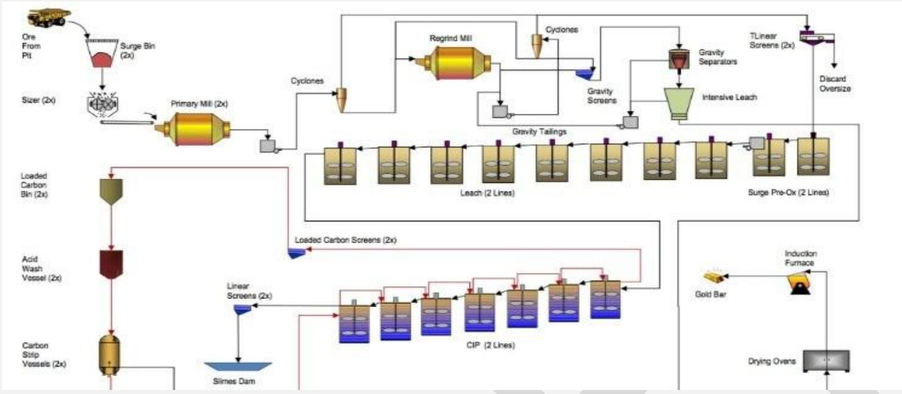


Fig., 34. Carbon in Pulp (CIP) Flowchart

3.7 Merrill-Crowe Gold Cementation Process

In the Merrill-Crowe gold cementation process, zinc dust or shavings are added to the solution which gold preferentially bonds to form a gold zinc amalgam (AuZn) over the gold cyanide (AuCN) compound. This solution is further processed and subsequently the gold is precipitated by torching the zinc gold amalgam releasing toxic zinc oxide (ZnO) fumes to the environment, polluting the atmosphere, and creating human health threats to leave behind the gold.

The Merrill-Crowe Process (MCP) is a widely used technique for gold recovery in both large-scale and artisanal mining operations. During laboratory research conducted at the University of British Columbia, the process was modified (MMCP) to reduce the leaching costs by eliminating both filtration and the use of vacuum systems to simplify the process, and to recover more gold faster by using cloth bags filled with zinc shavings replacing free zinc dust.

Manipueira, which replaced sodium cyanide as lixiviant, recovered 99.4% of gold which was precipitated on the zinc shavings in just 2 (two) hours when the agitation was reduced to avoid aeration (P. Torkaman & M. M. Veiga, 2021). Unprecedented gold recovery and time period.

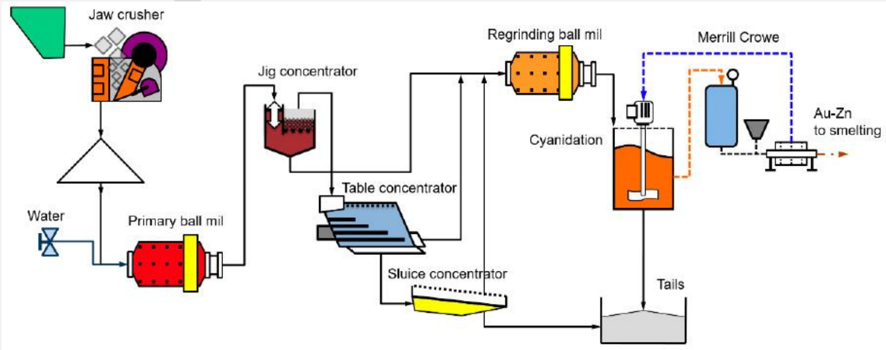


Fig., 35. Merrill-Crowe Flowchart

Miners are subject to metal fume fever *a.k.a.* brass founders' ague, brass shakes, zinc shakes, and other names, from the inhalation of zinc oxide (ZnO) which is characterized by fatigue, chills, fever, myalgias, cough, dyspnea, leukocytosis, thirst, metallic taste and salivation (Ross G. Cooper, 2008).

After leaching, the tailings wastes now containing water soluble potent mercury cyanide complexes, methylmercury, an even deadlier neurotoxin at 17 – 35 times faster human absorption than elemental mercury (Young-Seoub Hong et al., 2012) and with unknown biomagnification effects, mercury droplets, and various heavy metals are discharged directly into the waters

This toxic pollutant creates a serious hazard to human health, provides mobility for mercury, contaminates the riverbanks, the soil, drinking water, and the water used for irrigation compromising food safety (Arjumand Riaz et al., 2017) which leads to contaminated food crops, for example, rice (Stephan Bose-O'Reilly et al, 2016).

4. Not-For-Profit Organizations

4.1 Pure Earth

Pure Earth, a not-for-profit organization, is a leading global organization focused on pollution issues in low-and middle-income countries and has "addressed toxic pollution in over 120 project locations through assessment, remediation, risk mitigation, awareness raising and more" (Sarah, 2024). "These projects have impacted approximately 5 million people with 20% of those being children under six. Families in many of these communities will live longer, have less intellectual impairment, cancer, and other diseases."

Pure Earth, notwithstanding the WHO, "has identified mercury as one of the world's top toxic threats". Because much of the mercury released into the environment is the result of ASGM, Pure Earth's global mercury work focuses on ASGM mining communities around the world."

Pure Earth's 20 years of effort in 50 countries (Global Mercury Program: Success By The Numbers, 2019) to date has trained 1,500 miners to use the Benguet method *a.k.a.* the GBM. "Miners especially women, report increased earnings" using the Benguet method being taught in the Philippines by Leoncio D. Na-Oy. Extrapolating Pure Earth's efforts to convert the ~ 20 million ASG miners in 80 countries to using the mercury free Benguet method at this current rate and budget, will take 10's of thousands of years and with untold costs to eliminate mercury use in ASGM.

4.2 planetGOLD

The planetGOLD programme backed by the Global Economic Facility (GEF) and overseen by UNEP (planetGOLD, Technical Solutions), collaborates with governments, businesses, and ASGM communities in nine nations to enhance mining practices and conditions.

planetGOLD is working to eliminate mercury from the supply chain of gold produced by ASG miners by supporting improvements in raising awareness, access to finance, formalization, and technical solutions and better practices including improved crushing and milling, the use of gravity separation with sluicing and shaking tables, flotation, chemical leaching, and eliminating the worst practices.

"The gap in applicable guidance for cyanide management in the ASGM sector requires urgent attention, especially considering cyanide's accessibility and effectiveness at gold extraction, and in light of the trend in uptake of cyanidation in the small-scale gold mining sector worldwide."

planetGOLD current program is to reduce mercury use in ASGM by 2 tonnes, training 350 miners over 10 years, and enhancing gold prices for responsibly sourced gold, all contributing to Ecuador's Mining Sector Development Plan and promoting responsible mining practices (Ecuador, Supporting miners to improve health and the environment, 2020).

5. Ecuador's Approach to Mercury Management

According to the UNEP report (UNEP, 2012), it was estimated that “Ecuador emitted 20 to 50 tons of mercury to the environment in 1997 from artisanal and small-scale gold mining”.

On August 16th, 2017, the Minamata Convention on Mercury (UNEP, 2017), a legally binding international treaty designed to protect human health and the environment from anthropogenic emissions and releases of mercury and mercury compounds enters into force ratified by 50 Countries.

In 2014, the Indonesia government banned the use of mercury in gold mining. In September 2017, the government deposited it’s instrument of ratification (Indonesia, 2017) to the Minamata Convention of Mercury. The government submitted a National Action Plan in 2022, and has done little to curb its use, clean up contaminated sites, or warn the public of the danger.

According to Ms. Yuyun (Richard C. Paddock, 2019), for years, Mr. Cece was a pioneer in a network of illegal mercury producers, traders and smugglers who used to supply gold miners across Indonesia with mercury to extract gold from crushed ore. “On a single day, operating a furnace he (Cece) constructed in his backyard, he could produce a ton of black-market mercury worth more than USD $20,000, he said.” As long as that financial carrot hangs, the longer and harder it will be to eradicate mercury production in Indonesia. About a third is used in gold mining in Indonesia, she said, the rest smuggled overseas to S. America through Bolivia.

On January 26, 2016, Bolivia, Plurinational State of, deposited it’s instrument of ratification (Bolivia, 2016) to the Minamata Convention on Mercury to become the 22nd party and has done little to curb its use, clean up contaminated sites, prevent the export of mercury, or warn the public of the danger.

In 2015, Ecuador banned the import on mercury. On the 29th of July 2016, the government deposited it’s instrument of ratification (Ecuador 2016) to the Minamata Convention on Mercury to be the 29th party To date, other than submitting a National Action Plan (Ecuador Action Plan, 2020), Ecuador has done little to curb the use of mercury.

5.1 Portovelo-Zaruma Mining District

The estimated number of artisanal gold miners in Ecuador ranges from 32,000 (planetGOLD Ecuador Key Figures, 2021) to 100,000 (Marcello M. Veiga et al., 2009), including approximately 10,000 local in the Portovelo-Zaruma mining district (**Fig.** 36).

Zaruma, in the province of El Oro and twin city with Portovelo, is one of Ecuador’s 5 UNESCO World Heritage sites and located at 1,200 meters elevation high up in the Amazon Andes can be considered as the world’s pinnacle source of deadly global atmospheric and environmental mercury pollution.

Fig. 36. Portovelo-Zaruma mining district, Ecuador

In 2015, 68 (sixty-eight) of a total of 87 (eighty-seven) Chilean Centers of varying stature (**Fig.** 37), are collectively owned by 67 (sixty-seven) Aproplasmin members (Members), a local mining organization, and which are lined up along one-square mile (Robert Gould, 2013) on the Calera and Amarillo riverbanks.

The daily ore processing capacity of these Chilean centers ranges from less than 10 tonnes to over 100 tonnes, producing an average of 6–7 kg of gold per month, with operating costs averaging USD $90,000 per month, including electricity (Adriana O. Gonçalves et al., 2017). The lower-capacity centers, known as chancha barrel whole ore mercury amalgamation centers (Chancha Barrel Centers), are the most inefficient and environmentally destructive form of processing.

Fig., 37. Chilean Processing Centers Situated on the Calera and Amarillo Riverbanks

Collectively, these centers process an estimated 50,000 (fifty thousand) artisanal miners ore annually using mercury and are responsible for the annual discharge of 1.9 million tonnes of toxic tailings waste directly into the Calera and Amarillo rivers (Adriana O. Gonçalves et al., 2017). These toxic wastes contain an estimated 222 kg of mercury, 2,033 tonnes of cyanide (Adriana O. Gonçalves et al., 2017), unknown quantities of methylmercury, potent mercury-cyanide compounds which provide mobility for mercury, and unknown quantities of precious metals including gold and silver.

This pollutant weaves through the Amazon rivers, causing extensive biodiversity loss, polluting riverbanks, contaminating soil, drinking, and irrigation water, and devastating Peru's Puyango-Tumbes river basin 60 km west. Ultimately, it flows into the Pacific Ocean 350 km west, poisoning marine life—especially tuna, where mercury bioaccumulates most heavily, impacting the fish we consume.

These centers are also responsible for the release of an estimated 303 kg of mercury to the atmosphere annually from the miners burning their mercury-gold amalgams to isolate the gold which releases mercury vapors to the environment creating local atmospheric mercury pollution (**Fig.** 38) and which is transported globally by the winds and rivers (Víctor González-Carrasco et al, 2011). As presented in the previous study, independent from the sampling location, average elemental Hg levels measured in air exceeded the current Agency for Toxic Substances and Disease Registry minimum risk level of 300 ng/m3 (ATSDR, 2024).

Atmospheric *Hg concentrations detected in urban central area of Portovelo	Gold Shop
Wet season 214.6±43.7 ng/m3 Dry season 574.2±72.8 ng/m3	Outside > 1,000,000 ng/m3 Inside >2,000,000 ng/m3 immediately after burning Au amalgam.
El Pache, Portovelo gold processing region	**Hg in exhaled air from miners in Portovelo before/ after burning amalgams
Rainy Season 2356.7±1807.6 ng/m3 Dry seasons 3699.5±1225.3 ng/ m3	Before 170-1352 ng/m3 Afterwards 2007-3389 ng/m3

*Minimum public exposure risk level of 200 ng/ m3
** 1000 ng/m3 maximum public exposure of inorganic Hg vapour (*the Agency for Toxic Substances and Disease Registry (a federal public health agency within the United States Department of Health and Human Services)*

Fig., 38. Air Mercury Contamination in the Gold Mining Town of Portovelo, Ecuador

6. Aproplasmin Members and Employees 2015 Survey Data

When extrapolated to represent all 67 Aproplasmin members, data interpretation from a 2015 survey conducted with 20 members and employees suggests that up to 44 centers may use mercury, and as many as 24 centers lack storage ponds for tailings waste. Additionally, 10% or 6 – 7 centers process < 10 tonnes of ore/day, 50% or 34 centers process 10 to 50 tonnes/day, and 14 centers process > 100 tonnes/day (Adriana O. Gonçalves et al., 2017).

Of particular interest are the centers that process < 10 tonnes of ore/day and potentially, up to 47 centers that process ore only from their mine, and the facilities that house no storage ponds for tailings wastes which is discharged directly into the rivers. If they don't use mercury, their gold products in part qualify to become OECD compliant as the pedigree can be tracked addressing the supply chain issue as well..

One advantage of being OECD compliant is that, for the first time, the Members can sell directly to either of the 3 (three) Swiss refineries in Peru thereby avoiding costly local discount brokers and where they will receive a fair market price for both the gold and silver content of the dorés or gold “buttons” unlike the current practice.

7. Transformative Strategy

In 2020, prior to the COVID-19 pandemic, the first author engaged a well-known and respected local consulting professional geologist. This geologist, during the development of the ESG driven climate action initiative, technology, and solution to revolutionize ASM ore processing, communicated with several of the 67 Members who collectively own 68 whole ore mercury amalgamation chilean processing centers (Chilean Centers) which are lined up along one square mile on the Calera and Amarillo riverbanks. Many of these members expressed interest in forming joint venture partnerships (JVPs).

Additionally, several of the 32-member Association of Autonomous Miners Muluncay Society (Society members), a second local mining organization whose members collectively own and operate 32 Chilean Centers situated on the Miranda, Arcapamba, and Botoneros streams, direct tributaries of the Calera river, offered their facilities for sale, including mining concession rights and with current environmental licenses.

Now, in the post-COVID-19 era, which has severely impacted the South American artisanal mining sector, MGRT is positioned to address the challenges posed by the January 1, 2021, enactment of the OECD Due Diligence Guidelines for Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas (CAHRAs), (OECD, Third Edition). This regulation, which bans the importation into Europe of any gold that is not OECD compliant, has effectively removed artisanal miners' gold from the marketplace due to ongoing complexities and compliance challenges.

The situation was further exacerbated when METALOR, a leading Swiss-based supplier of precious metals, announced (METALOR Press Release, 2019) that it would cease all artisanal mining and mine collectors' business. As a result, many South American artisanal miners are now defaulting on their concession fees and environmental licenses, leaving them in a dire financial situation.

Here, we propose a transformative strategy to introduce, implement, and demonstrate the effectiveness of using Manipueira as a lixiviant to replace both mercury and cyanide salts in ASM. This strategy is designed to ensure that investors, miners, and processing center owners can profit from the initiative, innovative technology, and solution. The approach involves a 4-stage process targeting members of both organizations, facilitating the adoption and success of this innovative method.

7.1 Stage I. Chancha Barrel Center

The strategy includes the purchase of one or more whole ore mercury amalgamation chancha barrel processing centers (Chancha Barrel Center) as they are more accessible, less costly and less time-consuming centers to repurpose than a Chilean Processing Center which, in addition to housing numerous chancha barrels for processing whole ore using mercury, contains leaching technology and equipment, up to 12 chilean mills, and storage ponds for tailings wastes. Alternatively, a JVP with the owner(s) of these centers or fabricate a Chancha Barrel Center in Portovelo as, according to our sources, mining related construction in Zaruma is banned primarily due to underground illegal mining destroying the City foundation.

By showcasing the successful use of manipueira and validating our claims of 2 – 3 times more gold recovery, at this smaller scale, the Company aims to pave the way for broader adoption across larger processing facilities. This approach allows for a more cost-effective and efficient demonstration of the technology's capabilities, setting the stage for future repurposing and widespread implementation.

7.2 Stage I. Turnkey Cassava Processing Plant (TCPP)

To support the successful introduction of the use of Manipueira in the less costly and most time efficient manner, the Company will purchase and modify a turnkey cassava processing plant to have permanently housed on the grounds of the repurposed Chancha Barrel Center for production and demonstration purposes.

7.3 Stage II. Merrill-Crowe Leaching Unit

The introduction of Manipueira as a replacement for cyanide salts to the Aproplasmin and Society members can be strategically achieved by purchasing a Merrill-Crowe leaching unit for demonstration purposes. This unit would be housed in the same facility as the TCPP.

7.4 Stage III. Cassava Processing Plant (CPP)

An incentive for a flour manufacturer to enter into a JVP, notwithstanding the benefits derived from using cutting edge technology which includes increased starch production and with an enhanced product quality to generate higher income is to provide funds as an interest-free loan to the JVP. This loan would cover the purchase, engineering, modification, and installation of a Cassava Processing Plant (CPP) with an operating capacity ranging from 2 tonnes to 60 tonnes per hour.

7.5 Stage IV. Chilean Processing Center

By this stage, the Company will have positioned itself in the Portovelo-Zaruma and the Malva mining ecosystems and management believes, that the opportunities presented in 2021 to purchase several of the Society members Chilean Processing Centers or to form JVP still exists according to our sources.

The Company estimates that the costs for engineering, remediation, and repurposing the 10–50 tonne/day Chilean Processing Center into a Manipueira Leaching Center will total approximately USD $1.5 million. This amount includes expenses for due diligence and equipment. The timeline to commissioning and full gold production is expected to be 10–12 months depending on factors such as property acreage, the number of Chilean mills, and chancha barrels.

These centers generate the majority, if not all, of their revenue by processing miners' tailings wastes using cyanide.

8. Stage I.

8.1 Chancha Barrel Center Repurposing

To maximize impact efficiently and introduce the use of Manipueira in both the mining districts the following methodology is proposed:

1. **Education and Outreach:**
    - Distribute comprehensive literature and educational materials detailing the benefits and usage of Manipueira as a lixiviant.
    - Conduct workshops and training sessions to educate miners on the environmental and health advantages of using Manipueira over mercury and cyanide.
2. **Strategic Partnership and Stakeholders:**
    - Identify one or more Aproplasmin and Society members Chancha Barrel Centers, with or without storage ponds for tailings wastes.
    - Negotiate with the Members to purchase the center or to form a JVP.
    - Community.
    - planetGOLD.
    - Pure Earth.
    - ARM (Alliance for Responsible Mining).
    - Government.
3. **Financial Support:**
    - Provide the necessary capital for the purchase of the Chancha Barrel Center or provide the JVP with an interest-free loan* in exchange for subsequent royalties with the capital being used to repurpose the center for the use of Manipueira.
4. **Technical Assistance:**

    - Assemble a skilled engineering team to repurpose the selected center(s), transitioning its operations to utilize Manipueira and integrating state-of-the art technology into chancha processing.
5. **Implementation and Monitoring:**
    - Implement the repurposed center as a demonstration site.
    - Continuously monitor the performance and impact, gathering data to support further adoption among the remaining centers.

The repurposing of a Chancha Barrel Center to a Manipueira Barrel Center entails the remediation of the facility, equipment, and grounds of mercury, removal of the sluice, (**Fig.** 39) and the installation of an APT Gemini Gold Upgrade Table (**Fig.** 40) known to recover up to 97% of the ore gold and to produce a bullion grade gold for direct smelting. The table operating capacity ranges from 30kg (65 lbs.)/hr, 115kg (250 lbs.)/hr, to 0.5 tonnes/hr. Ideal for grain sizes between 30 micron and 2mm (911 Metallurgist, Fact Sheet I.). An APT Gemini Gold Upgrade Table costs USD $25,000 plus shipping and import taxes.

The chancha barrel must be modified and equipped with a pH controller and dosing pump (**Fig.** 41) coupled to a canister containing sodium hydroxide (NaOH) to maintain a constant pH between 10.5 – 11 during the 4 – 5 hrs. of rapid circular rotation and engineered to receive the safe transfer of the Manipueira solution from a hermetically sealed discharge container.

Fig., 39. Sluice

Fig., 40. APT Gemini Gold Upgrade Table

Fig., 41. pH Controller & Dosing Pump

After processing, the concentrate is discharged from the chancha barrel onto the APT Gemini Gold Upgrade Table for capturing the gold.

By showcasing the successful use of Manipueira and the APT Table at this smaller scale, the authors believe will pave the way for broader adoption across additional and larger processing facilities. This approach allows for a more cost-effective and efficient demonstration of the technology's capabilities, setting the stage for future repurposing and widespread implementation.

The strategy presented ensures that the introduction and adoption of Manipueira are well-supported through education, strategic partnerships, financial resources, and technical expertise, paving the way for a sustainable and healthier gold extraction process.

**The BCE (Central Bank of Ecuador) offers a low interest loan program up to USD $500K for BCE certified artisanal miners to acquire cleaner technology or purchase machinery subject to the miner owning a mine (mining concession), having a current environmental permit to operate, has had no legal problems involving his practice, are qualified within the framework of the planetGOLD alliance, and not using mercury (planetGOLD news, 2023).*

The BCE will buy the certified miners gold however, the miners aren't taking the Bank up on its loan program as the miners would have to travel to Quito, Ecuador's Capital, 300 miles (480 km) from the mining district carrying their gold to exchange for cash. The issues are the unprotected travelling distance and that the Bank only pays for the gold content of the dorés or gold buttons, not the silver content.

8.2 Turnkey Cassava Processing Plant (TCPP)

To support the successful introduction of the use of Manipueira in the less costly and most time efficient manner, the strategy proposed is that concurrent with the chancha barrel repurposing, a turnkey cassava processing plant (**Fig.** 42) be purchased to have in place permanently for demonstration purposes and housed on the grounds of the repurposed Manipueira Barrel Center.

The TCPP is a fully integrated system designed to handle the entire process of converting raw cassava tubers into various products such as garri (a popular West African food made from cassava tubers), flour and starch amongst other products. These plants are designed to streamline the entire production process, ensuring efficiency, quality, and scalability.

Fig., 42. Cassava Mobile Processing Unit

The TCPP must be engineered to enable the cassava wastewater produced both, during the grating of the plant roots to a pulp and the pressing of the starch, be collected in a hermetically sealed container, to remove the starch by flotation (P. Torkaman et al, 2021), and secure for subsequent transfer into a sealed container equipped with a pH controller and a dousing pump with a canister of sodium hydroxide (NaOH) to maintain a pH 10.5 – 11 for transport to the Portovelo-Zaruma and the transfer into the modified chancha barrel.

Key Components of a Turnkey Cassava Processing Plant.

1. **Cassava Peeling Machine**
   - Automatically peels the cassava tubers to remove the outer skin, increasing efficiency and reducing labor costs.
2. **Cassava Washing Machine**
   - Cleans the peeled cassava tubers to remove dirt, sand, and other impurities.
3. **Cassava Grating Machine**
   - Grates the cleaned cassava into a fine mash, which is essential for further processing steps like fermentation or drying.
4. **Hydraulic Press or Dewatering Machine**
   - Extracts excess water from the grated cassava mash, which is crucial for producing high-quality products like garri or flour.
5. **Fermentation Tanks**
   - Used for fermenting the cassava mash to reduce cyanide content and develop desired flavors, particularly for products like garri, a popular West African food.
6. **Sifting and Sieving Machines**
   - Ensures the cassava mash or flour is of uniform size and free from fibrous materials or impurities.
7. **Drying Equipment**
   - Could include solar dryers, flash dryers, or rotary dryers, which reduce the moisture content of the cassava products.

In 2021, the global bitter cassava production was estimated at 308 million tonnes with Africa's total production being ~ 203 million tonnes (about 56% of world production), followed by Asia (84 million tonnes) and America with 26 million tonnes (Blue Sense, 2023). In 2022, Ecuador's cassava production was ~ 146,000 tonnes (World Data Atlas, 2022) with 80% being exported to neighboring Colombia. Uhmano Global Cia. Ltda., has agreements with the flour producers in the Manabí Province and is Ecuador's largest exporter of food products. The purchase price for one tonne of the bitter cassava plant is between USD $195 – 220.

"The cassava root (tuber) is carbohydrate-rich, protein-poor and must be boiled, roasted, fermented or otherwise processed to tame compounds that can produce toxic hydrogen cyanide during digestion, rich in nutrients, and extremely healthy to consume" (Marissa Fessenden, 2014) (**Fig.** 43). The tuberous root is hand peeled (**Fig.** 44), placed in a gauze, and mechanically pressed or squeezed by hand to dry the starch and to remove the wastewater known as cassava wastewater *a.k.a.,* Manipueira (**Fig.** 45).

Cyanide exposure of more than 50 μg g^{-1} (microgram per gram) caused symptoms such as headache, weakness, changes in taste and smell, irritation of the throat, vomiting, lacrimation, abdominal colic, pericardial pain and nervous instability (Ifeabunike O.B., et al., 2017). The Ecuadorian bitter cassava plant generates up to

400 mg/liter (ppm) and the Brazilian bitter cassava plant can generate up to 665 ppm of HCN (Burns, A.E., et al, 2021).

Fig., 43. Health Benefits

Fig., 44. Hand peeling

Fig., 45. Manipueira

An estimated 800 million people in 80 countries including 500 million in Africa depend on the root as their main staple (Fran Robson et al., 2023).

9. Stage II.

Merrill-Crowe Leaching Unit

The introduction of Manipueira as a replacement for cyanide salts to Aproplasmin and Society members who exclusively process their own mine's ore and without the use of mercury which in part, qualifies their gold to be OECD compliant, can be strategically achieved by purchasing a Merrill-Crowe leaching unit (**Fig.** 46) for demonstration purposes. This unit would be housed in the same facility as the TCPP at the repurposed Chancha Barrel Center.

Fig., 46. Merrill-Crowe Process

10. Stage III.

Cassava Processing Plant (CPP) Repurposing

An incentive for a flour manufacturer to enter into a JVP, aside from the benefits of cutting edge technology, including increased starch production, enhanced quality, and higher income, is to provide funds as an interest-free loan to the JVP. This loan would cover the purchase, engineering, modification, and installation of a Cassava Processing Plant (CPP) with an operating capacity ranging from 2 tonnes to 60 tonnes per hour (**Fig.** 47).

In the Manabí Province, 230 starch factories permanently employ 1,380 people and all of whom are engaged in cassava (manioc) starch production mainly using semi-mechanized or traditional processing systems (AGSF Working Document, 2004) (**Fig**. 48).

Fig., 47. Cassava Processing Plant

Fig., 48. Traditional Cassa Processing

The MCPP will be engineered such that, during the grating of the plant roots to a pulp and the pressing of the starch, the wastewater produced will be collected in a hermetically sealed container enabled with the ability to remove the starch by flotation (P. Torkaman et al, 2021) and transferred into a sealed container equipped with a pH controller and a dousing pump with a canister of sodium hydroxide (NaOH) to maintain the pH of the solution which will be transferred to the modified chancha barrel for processing.

The MCPP facility will house a small laboratory equipped with testing equipment to ensure quality control and quality assurance.

Modified Cassava Processing Plant (MCPP) Equipment List

1. **Cassava Peeling Machine:**
   - **Purpose:** To peel the outer skin of the cassava roots efficiently in an enclosed and sealed peeling machine.
   - **Example:** Electric cassava peeling machine with stainless steel blades.
2. **Cassava Crushing Machine:**
   - **Purpose:** To crush the peeled cassava roots into a fine pulp, facilitating starch extraction and cassava wastewater collection.
   - **Example:** Cassava grating machine or hammer mill.
3. **Starch Extraction Unit:**
   - **Purpose:** To separate the starch from the cassava pulp.
   - **Example:** Hydraulic press or centrifuge separator to extract and collect starch in a container.
4. **Cassava Wastewater Collection System:**
   - **Purpose:** To collect the liquid (cassava wastewater) from the crushed cassava pulp.
   - **Example:** Custom-made system with filters and collection trays leading to a hermetically sealed container where the starch can be removed by flotation, not filtration to mitigate pre-robbing.
5. **Hermetically Sealed Containers:**
   - **Purpose:** To store the collected cassava wastewater securely, preventing exposure to air and contaminants.
   - **Example:** Stainless steel tanks with hermetic sealing.
6. **NaOH Addition and pH Regulation System:**
   - **Purpose:** To add NaOH to the cassava wastewater to increase and maintain the pH to the desired range (10.5-11).
   - **Example:** Automated pH controller with dosing pump with sensors and NaOH storage tank.
7. **Portable Unit Framework:**
   - **Purpose:** To house and transport all the equipment mentioned above, making the entire system mobile.
   - **Example:** A portable skid or trailer with integrated power supply and storage for easy transportation made locally.

The MCPP will ensure efficient and quality processing of the bitter cassava plant which is engineered for the safe collection and handling of the cassava wastewater which will be transported approximately 148 miles (238km) from the Manabí Province to Zaruma with precise pH regulation. The cost of a small CPP is approximately USD $100,000 plus shipping and import taxes.

11. Stage IV

Chilean Processing Center Repurposing

Based on the repurposing of a 10 - 50 tonne/day remediated whole ore mercury amalgamation chilean processing center (Chilean Processing Center) (**Fig.** 49) and which employs the Merrill-Crowe gold cementation process (**Fig.** 50), utilizing Chilean mills with sluices (**Fig.** 51), and having chancha barrels (**Fig.,** 52) to process whole ore using mercury, the Company has prepared design schematics in flowchart prototyping the world's first Manipueira precious metals pilot plant leaching center (Manipueira Leaching Center) for ore and toxic tailings wastes (**Fig.** 53).

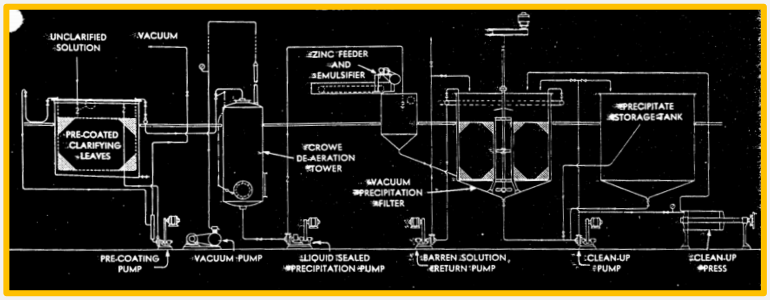
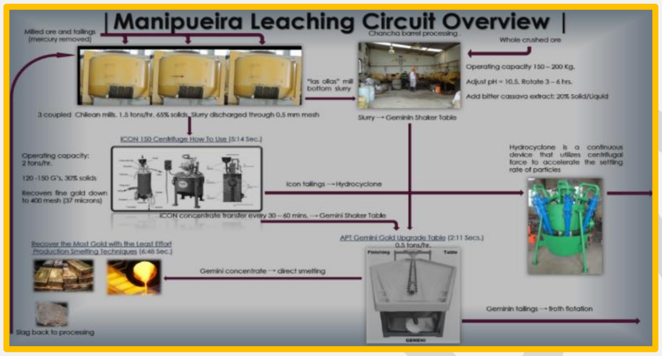


Fig., 49. Chilean Processing center

Fig., 50. Merrill-Crowe Gold Cementation Process

Fig., 51. Chilean Mills

Fig., 52. Chancha Barrels



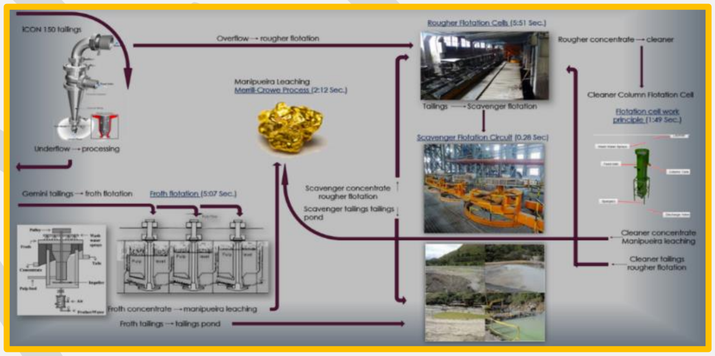


Fig., 53. Manipueira Precious Metals Leaching Center

The pilot plant MMCP protocol eliminates both the filtration process of the manipueira solution, the main cost associated with operating and the vacuum systems to simplify the process and replaces sodium cyanide with Manipueira as a lixiviant.

The pilot plant cutting-edge technology is seamlessly integrated with existing ore processing and leaching circuitry equipment. This technology includes an Icon i150 centrifuge (**Fig**. 54) which is capable of recovering fine gold down to 400 mesh (37 microns) from tailings and milled ore and with an operating capacity of 2 tonnes/hr. and up to 150 G-force and employing hydrocyclonic separation (*a.k.a.* hydrocloning) technology (**Fig.** 55) to classify and separate particles based on size, shape, and density, and to concentrate the gold for subsequent leaching or floatation. Overall, hydrocyclonic separation is an efficient and cost-effective method for pre-processing and concentrating ores in gold mining and other mineral processing applications.

Fig., 54 Icon i150 Centrifuge

Fig., 55. Hydrocyclone Separator

The pilot plant incorporates an APT Gemini Gold Upgrade Table's (**Fig**. 56) known to recover up to 97% of the ore gold and to produce a bullion grade gold for direct smelting to replace both the existing chancha barrel and the Chilean mill sluices. The table operating capacity ranges from 30kg (65 lbs.)/hr, 115kg (250 lbs.)/hr, to 0.5 tonnes/hr. Ideal for grain sizes between 30 micron and 2mm (911 Metallurgist, Fact Sheet I.). An APT Gemini Gold Upgrade Table costs USD $25,000 plus shipping and import taxes.

The chancha barrel (**Fig**. 57) must be modified and equipped with a pH controller and dosing pump (**Fig.** 58) coupled to a canister containing sodium hydroxide (NaOH) to maintain a constant pH 10.5 – 11 during the 4 – 6 hrs. of rapid circular rotation and engineered to receive the safe transfer of the Manipueira solution from a hermetically sealed discharge container.

Fig., 56. APT Gemini Gold Upgrade Table

Fig., 57. Chancha Barrel

Fig., 58. pH Controller & Dosing Pump

12. Conclusions

This paper presents a groundbreaking initiative, innovative technology, solution, and a comprehensive strategy poised to revolutionize the use of mercury and cyanide salts across artisanal and small-scale mining (ASM) and large-scale mining (LSM) operations worldwide.

The traditional use of mercury in gold recovery by artisanal miners is not only hazardous but also highly inefficient, capturing just 20-30% of the gold in the ore and leaving vast amounts of valuable gold trapped in tailings. The pervasive presence of mercury in our environment—whether in rain, snow, food, water, or even within our central nervous system—underscores its devastating impact on life on Earth.

Artisanal mercury pollution, particularly from ASGM, is a significant contributor to this global crisis, with severe consequences for both human health and the environment. Mercury's persistence in the atmosphere, where it can remain airborne for up to a year, enables it to travel globally, impacting ecosystems far from its source. As it precipitates back to Earth through rain, ice, and snow, it contaminates water bodies, poisons fish, and poses a serious threat to human health. The Lancet Commission on Pollution and Health has linked pollution to an estimated 9 million deaths annually and economic losses of USD $4.6 trillion, underscoring the urgent need for alternative solutions. Mercury is poisoning the planet.

This paper advocates for a transformative strategy to introduce, implement, and demonstrate the effectiveness of cutting-edge technology and the use of Manipueira—a natural lixiviant derived from the bitter cassava plant. This 4-stage process is designed to replace mercury use in chancha barrel processing, recognized as the planet's deadliest due to its severe environmental impact, as well as in Chilean mill ore processing and cyanide leaching of gold from ore and toxic mercury-contaminated tailings.

Preliminary research indicates that Manipueira not only mitigates the environmental and health dangers posed by mercury but also significantly improves gold recovery rates. Experiments have shown that Manipueira can leach up to 99.6% of the gold from ore concentrates and mercury-contaminated tailings—a dramatic improvement over the mere 20-30% recovery typically achieved with mercury, and in just 2 hours. Unlike current artisanal leaching protocols, all the hydrogen cyanide in the Manipueira extract solution is consumed during the process, preventing its release into the environment as long as the pH is properly maintained.

By adopting Manipueira, artisanal and small-scale miners can not only increase their gold yields but also significantly reduce their environmental footprint. This solution is poised to be a game-changer for the mining industry, with the potential to revolutionize gold recovery practices, ensuring a more sustainable and profitable future for miners while safeguarding the health of people and the planet.

The strategy emphasizes education, joint venture partnerships, stakeholder engagement, workshops, technical assistance, and financial support as incentives to adopt this climate action initiative. However, this initiative is not just about eliminating the use of mercury; it's about fostering coexistence between artisanal miners and ore processing center owners. This coexistence model allows artisanal miners to focus on mining activities while ore processing is managed by centers or companies, offering a solution for formalizing miners, increasing economic benefits, and reducing pollution.

The symbiosis of artisanal ore processors and flour makers is a win-win situation that reduces environmental pollution, mitigates human health threats, and addresses an unintended consequence of harvesting the bitter cassava plant, while providing flour makers with a second source of income.

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Conflict of Interest

The author(s) declare no conflict of interest.

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