



UNEP

A PRACTICAL GUIDE

REDUCING MERCURY USE IN
ARTISANAL AND SMALL-SCALE
GOLD MINING



Reducing Mercury Use in Artisanal and Small-scale Gold Mining



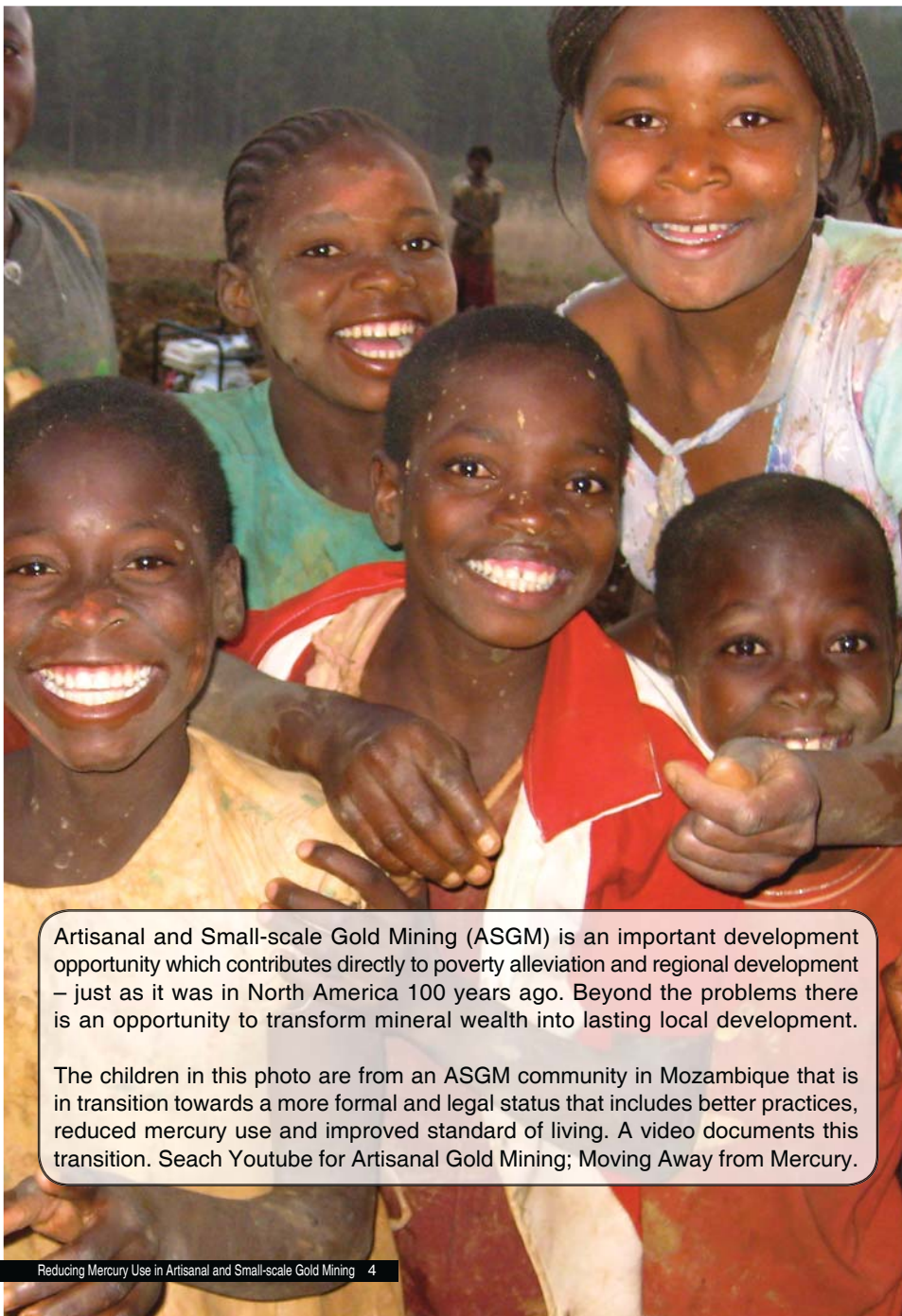
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A Practical Guide



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Artisanal and Small-scale Gold Mining (ASGM) is an important development opportunity which contributes directly to poverty alleviation and regional development – just as it was in North America 100 years ago. Beyond the problems there is an opportunity to transform mineral wealth into lasting local development.

The children in this photo are from an ASGM community in Mozambique that is in transition towards a more formal and legal status that includes better practices, reduced mercury use and improved standard of living. A video documents this transition. Search Youtube for Artisanal Gold Mining; Moving Away from Mercury.

Who Can Use this Document?

This document has been produced to educate policy makers, miners and civil society about available technologies and approaches for reducing, and ultimately eliminating mercury use in artisanal and small-scale gold mining (ASGM).

. . . for government

- A simple educational and planning tool for the technical aspects of intervention programs and policy considerations
- A decision tool to understand best practices options
- An explanation of the technical fundamentals that underpin and encourage formalization and other improvement initiatives

. . . for miners

- A graphical introduction for best practices
- A guide explaining how local conditions are important for improving gold mining practices
- An explanation of barriers that need to be overcome in order to improve practices and reduce mercury use

. . . for civil society

- An educational tool to more adequately understand ASGM
- An explanation of barriers that mining communities face when trying to improve mining practices and reduce mercury use

Why worry about mercury?

Mercury is a powerful neurotoxin that is harmful to children and adults, but especially to developing fetuses, and young children. Mercury can travel through the atmosphere, far from its original source of emission. Because of its long range transport, it causes global contamination of fish, birds, mammals, and the human food chain. Worldwide, consumption of mercury contaminated seafood puts billions of people at risk of mercury poisoning, which affects brain and nerve development and function.

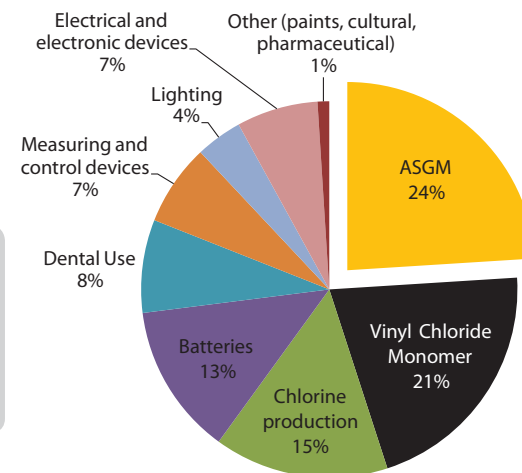


Industrial Mercury Use and Emissions¹

World Mercury Demand (Annual Consumption)

Total = 4,167 tonnes

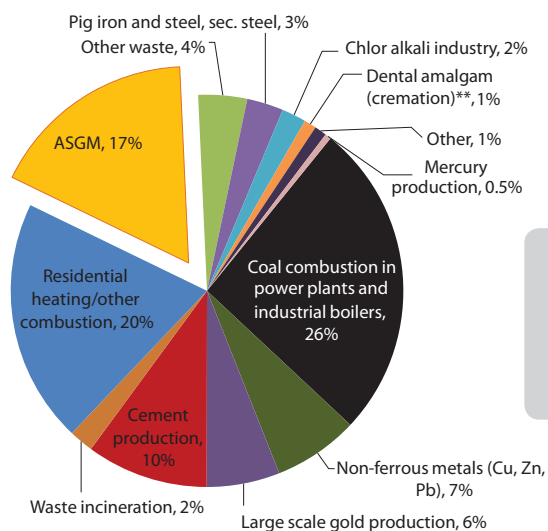
ASGM is the single largest demand for mercury in the world. An estimated 1400 tonnes of mercury were used by ASGM miners globally in 2011 (www.mercurywatch.org).



Mercury Emissions to Global Atmosphere

Total = 1,921 tonnes

ASGM is the largest source of mercury pollution to air and water combined. It is second only to coal combustion as a source of mercury air pollution.



[1] United Nations Environment Programme, Chemicals Branch, DTIE, Summary of Supply, Trade and demand information on mercury, requested by UNEP. Governing Council decision 23-9 IV, November 2006, Table 2.

How is mercury used to capture gold?

When mercury is brought into contact with gold particles in sediments or crushed ore, it forms “amalgam” - a soft mixture of roughly 50% mercury and 50% gold. To recover gold from the amalgam, it is heated to evaporate the mercury, leaving the gold behind. Mercury is released into the environment in several of the steps.

Note: Unlike many pollutants, mercury is an element- it cannot be broken down. The element symbol for mercury is Hg. The diamond symbol at right, is used here to designate mercury vapor emission and human exposure.



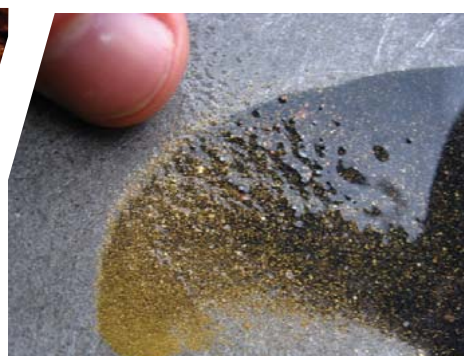
1. Rocks containing gold (“ore”) are mined using various methods.



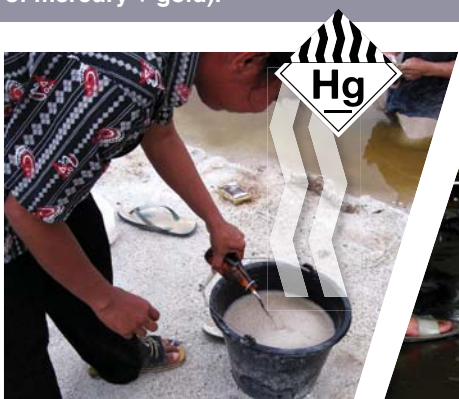
2. If necessary, the ore is crushed to liberate gold particles.



3. In most conditions, the gold bearing material is concentrated to reduce mass.



4. Mercury is added to extract the gold by forming an amalgam (mixture of mercury + gold).



5. Amalgam is collected and heated, evaporating the mercury, and leaving a porous “sponge gold” product.



6. “Sponge gold” is melted to produce solid gold doré.



7. The doré is refined in gold shops to 24K and traded internationally.



Why is mercury used in ASGM?

- It is quick and easy
- Very independent- one person can do it alone
- Gets gold in most field conditions
- Cheap and accessible
- Facilitates precise transactions and divides profits – between labourers and owners for example; or between concentrates and tailings
- Produces quick capital (money each day or week versus, for example, each season)
- Miners are not aware of the risks, and those that are aware often do not have access to the capacity or capital required for alternatives
- No choice (boss's instructions)
- Permits custom processing of small individual ore batches

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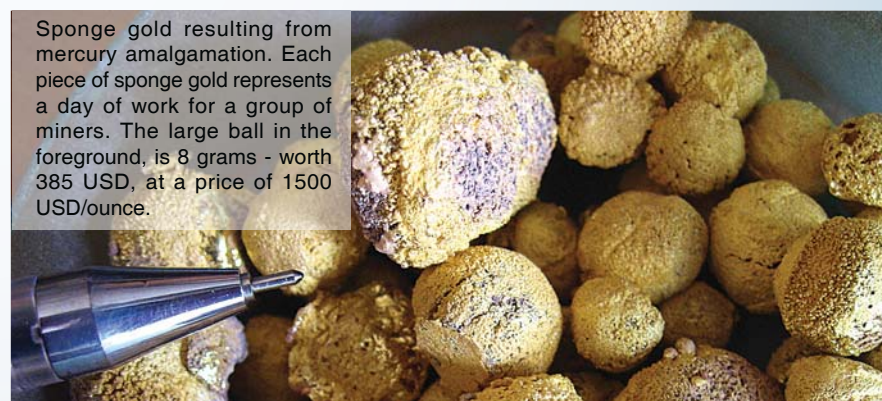
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Chapter 1 - Mercury Use in Detail

There are two main categories of mercury use in ASGM:

1. Whole Ore Amalgamation (WOA)
2. Concentrate Amalgamation

Each of these can be done in a variety of ways. This is explained further using examples from ASGM sites in numerous countries.



1.1 Whole ore amalgamation (WOA)

In WOA, mercury is brought into contact with 100% of the ore ("whole ore") several methods can be used (see examples presented in photos).

WOA is worst practice because:

- Mercury use ranges from high (4 parts mercury for each part gold recovered) to very high (20 parts mercury for every part gold). In extreme cases, for example where ore is rich in silver, the ratio can be 50:1.
- WOA is inefficient - it rarely captures more than 30% of the gold and results in major losses of mercury to tailings (waste material).
- Large amounts of mercury are lost to the tailings because the mechanical process produces tiny mercury droplets ("floured mercury") that are too dispersed to capture. The result is mercury contaminated sites that are very difficult to clean up.

example

Whole ore amalgamation in trammels. Mercury is poured into steel drums with ore and grinding media inside. Mercury amalgamates gold as the ore is crushed (Indonesia).



example

"Quimbelete" WOA: mercury is mixed with ore in rock basins, and amalgamated by crushing with round boulders (Peru).

- Reprocessing existing WOA tailings can be economic due to recovery of gold that remains in the material.
- Whole Ore Amalgamation can be eliminated in most cases by moving to a system that first produces a concentrate, that can recover equal amounts of gold or more using far less mercury.



example

Copper plates: Mercury is coated onto copper plates and crushed ore is washed over the plates in a slurry. Gold particles stick to the mercury and are scrapped up as amalgam (Colombia).

1.2 Concentrate Amalgamation

In concentrate amalgamation, gold is first concentrated into a smaller mass before amalgamation- typically using gravity. Mercury is used only on the concentrate which contains only the heaviest minerals and gold. Despite using less mercury, concentrate amalgamation results in the same exposure hazards - the most dangerous of which is inhalation of mercury vapor. In concentrate amalgamation, the ratio of mercury used to gold produced is much lower than WOA (generally 1:1 to 1.3:1), and little or no mercury goes into the tailings.

example This example from Indonesia begins with sluicing, but numerous different methods can be used for the concentration stage.

① Processing to create a concentrate: in this case a sluice box is used. Heavy gold particles are trapped in sluice carpets as the slurry (ore and water) passes over the inclined surface.



② The concentrate is collected by washing the carpets into a basin. Detergent soap is often used.



③ Mercury is added to the concentrate.



⑥ The mercury gold mixture is filtered through a cloth to separate residual liquid mercury (for re-use), and a soft silver colored "amalgam" which is typically around 50% gold and 50% mercury.



⑦ The ball of amalgam is heated to evaporate the mercury, leaving "sponge gold" behind. This name refers to its porous texture.

④ Mercury is mixed into the concentrate (in this case by hand), adheres to gold particles, and draws them into a heavy liquid pool at the bottom of the basin.

⑤ The mercury now contains gold and is carefully separated from the concentrate by panning.



1.3 The Health Risk to Miners and Families



Millions of infants, children, women of child bearing age (potentially pregnant), and breast-feeding women, work or live in ASGM communities and are at risk of mercury exposure. Pictured above is a man burning amalgam in front of children and in a residential area. Many are unaware of the dangers. Simple cost effective protocols such as those of UNIDO (see annex 3) can greatly lower risk.

Mercury vapours in the air around amalgam burning sites can be alarmingly high and almost always exceed the WHO limit for public exposure of 1,000 nanogram/cubic meter¹. This risks the health of workers but also those in the communities surrounding the processing centers. Exposure to levels of mercury vapors above 1,200,000 nanogram/cubic meter can be fatal.

[1] Information on the Human Health effects of Mercury:
<http://www.who.int/ipcs/features/mercury.pdf>
http://www.who.int/ipcs/assessment/public_health/mercury/en/index.html

Gold shops or processing centres where amalgam burning occurs are the sites of some of the highest levels and most continuous exposures. Like a hotel room used by smokers, mercury vapours absorb and condense on surfaces and are continuously emitted later causing exposure even months after amalgam burning has ceased. Ultimately these vapours enter the global mercury cycle contaminating the food chain.



Chapter 2 - Solutions

This chapter presents technical solutions for reducing mercury use in ASGM. Each step of the mining process offers opportunities to improve practices and reduce mercury use and exposure, often by reducing costs through improved technology and increased efficiency.

- 2.1 Identifying appropriate solutions - which ones will work?
- 2.2 How to improve mercury use through improving concentration
- 2.3 How to reduce mercury use through other better practices
- 2.4 How to eliminate mercury use with mercury free technologies



2.1 Choosing Which Solutions Will Work

Reductions in mercury use will most likely be broadly accepted and become permanent if they maintain or increase profits. This can be done in numerous ways:

1. Conserving or eliminating reagents, including mercury
2. Saving time by more efficient processing or increasing throughput
3. Recovering more gold by improving extraction techniques, which might include using better technology
4. Get a better price for gold by following standards that get a better market price. An example of this is the Fairtrade-Fairmined Standard developed by the Alliance for Responsible Mining (ARM) and the Fair Trade Labelling Organisation (FLO). This approach gets miners a premium through a fair-trade mechanism.
5. Good practices preserve livelihoods by preventing penalties such as paying fines, being shut down, or otherwise obstructed for non-compliance.

Two Step Approach

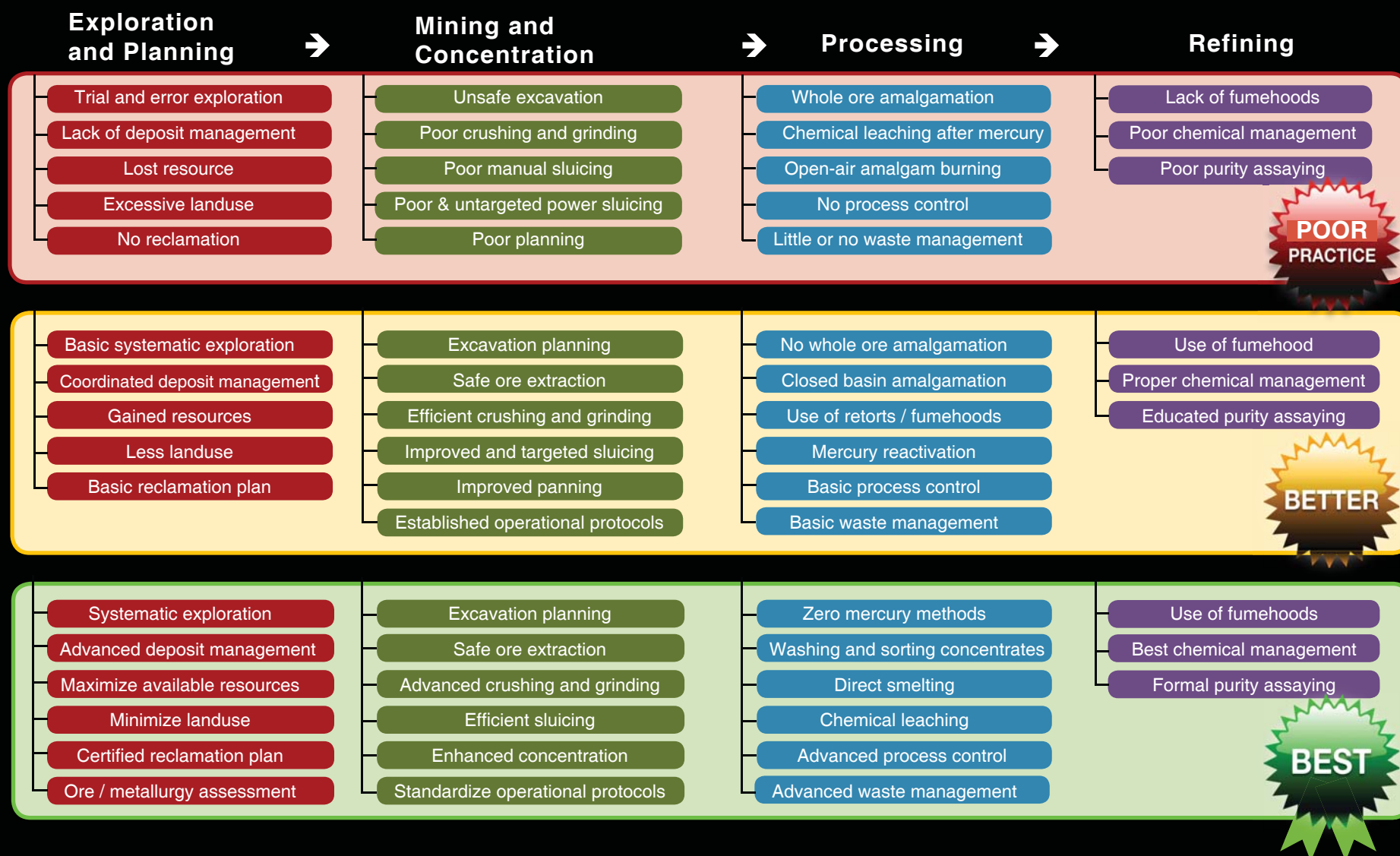
Technical Interventions for mercury reduction have been most successful when a two step approach is employed:

Step 1: Reduce mercury use and emissions through improving practices, which use less mercury. This is profitable for miners, improves health through lower exposures and risk awareness, and can build positive relationships (2.1, 2.2, 2.3).

Step 2: Eliminate mercury use by using alternative technologies that are more profitable for miners, and better for health and environment (2.4).

Solutions Chart

Use this diagram to assess the status of an ASGM operation and evaluate what solutions to apply



2.2 Improving Concentration to Increase Gold Recovery and Avoid Whole Ore Amalgamation

Producing a concentrate is key in reducing or eliminating the use of mercury.

- required to eliminate Whole Ore Amalgamation - a worst practice.
- required for zero mercury methods like direct smelting

The following pages elaborate concentrating methods that can be employed in the efforts to reduce and eliminate mercury use



Concentration can be done in several ways, nearly all of which use gravity to separate heavy particles including gold, from lighter particles. Concentration greatly reduces the mass of material that must be processed to separate the gold. Concentrating eliminates the need for whole-ore amalgamation, and reduces the amount of mercury required for amalgamation to roughly 1 part mercury per part of gold recovered. If the mercury is recycled, losses can easily be reduced to 0.05 parts mercury per 1 part of gold recovered (a 95% decrease). If concentration is done with sufficient sophistication, it can eliminate the need for mercury altogether.

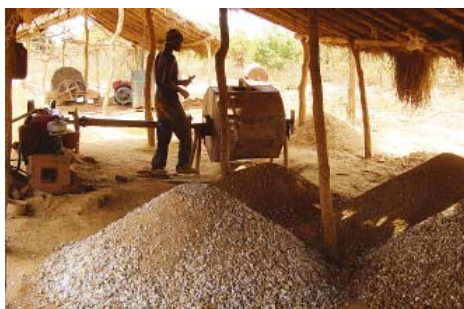
Choice of technology to produce a concentrate depends on the type of ore, grain size and mineralogy of the gold, and access to capital and know-how with which to acquire and operate processing equipment. Access to capital and expertise is often affected by legal status— with illegal or informal status being a significant barrier for miners to acquire and operate better equipment in many areas.

ASGM miners commonly lose 25-75% of gold during concentration. Because concentrating gold is challenging, many miners extract easy-to-recover gold using mercury (generally less than 50% of the gold) and then another person – a processor or boss, keeps the tailings for future extraction with cyanide or other methods.

Gold Liberation (Crushing and Milling)

In order for gold to be concentrated it must be “liberated”. Many alluvial gold deposits do not require liberation, because gold already occurs as free gold particles. In most other deposit types, however, gold occurs inside other minerals and must be separated from these before it can be concentrated. This is accomplished by crushing and milling rocks into a powder. The technical term for this is “comminution”.

Crushing and milling is a multi-step process. Primary crushing can be done manually using hammers, or with machines such as stamp or hammer mills or jaw crushers. This produces a gravel that can be milled into a powder. Good milling produces an even grain size that is fine enough to liberate the gold for the chosen extraction process. There are many types of mills used in ASGM, some which require water (wet milling) and some which do not (dry milling).



Rocks are crushed manually using hammers, and then milled using ball mills (Tanzania, 2010).



Converted flour mills traditionally used for corn and millet, are used to mill rock (Nigeria, 2011). These re-tasked mills are not designed for use on rocks, produce enormous amounts of dust, and miners must process the material several times before it is adequately fine even for low efficiency extraction.

The dust can be very dangerous. In the Nigerian State of Zamfara (pictured at right), this practice has tragically caused the world's worst lead poisoning epidemic due to children accidentally ingesting soils contaminated by powdered ore that is naturally elevated in bio-available lead minerals.



More Info: Search the US Center for Disease Control (CDC) or WHO for “lead poisoning Zamfara, Nigeria”



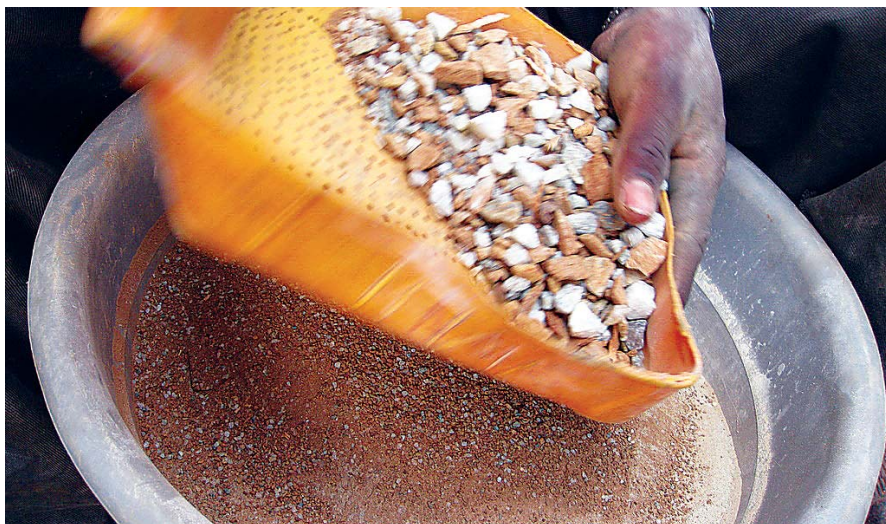
Hammer mills have become widespread in ASGM in many countries. These are typically powered by a 20-30 horsepower motor. Rock is manually delivered by the operator and the mills can be run wet or dry; hammers batter the material and it passes through a screen. Often when wet, it passes directly onto a sluice box inclined next to the hammer mill, as in the photo above (Mali, 2011). But this approach, although simple, is lacking proper milling and therefore has lower gold recovery.



Stamp mill for reducing rocks to pea-sized particles (Sulawesi, Indonesia, 2007).

The Importance of Grain Size

Creating a concentrate typically works best if the particles being concentrated are of similar size. Screens should be used for sieving (sorting) material for this reason. The use of screens is simple and cheap, and can improve gold recovery in many ASGM contexts.



Above and left- miners crush rocks manually with a steel mortar (not shown), and then screen the crushed material to produce batches of fine material which is then passed along to the concentration stage (Mali, 2011).

This photo shows the screen on the underside of a hammer mill. The hole size is around 2mm, meaning that the material passing through the screen will have a maximum size of 2mm (Burkina Faso, 2011). Typically, this is too coarse and will not liberate all the gold.



Grain size of the gold particles must be investigated and understood so that adequate and efficient liberation of the gold particles is accomplished during milling. It is generally effective to mill rock to “smaller than 0.5mm”, but in many ASGM operations rock is only milled to 2mm, resulting in poor gold liberation. There are exceptions, however, and it is also possible to mill too much. Running batch tests on gold liberation and recovery is important, and can improve gold recovery substantially.

In many hard-rock ore deposits, gold is not present as “visible gold”, and the rocks must be crushed extremely finely in order to effectively liberate gold particles (Product of ball mill, Mozambique, 2009).



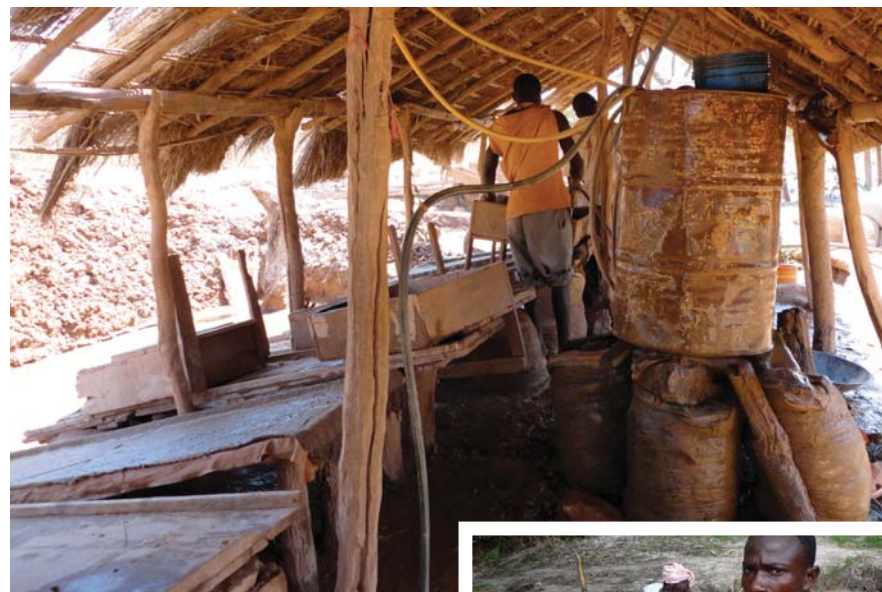
Sluices

Sluices work on the principle that heavy particles sink to the bottom of a stream of flowing water while lighter particles tend to be carried downstream and are discharged off the end of the sluice. Carpets trap the gold and other heavy particles. Flow and momentum accelerates with distance, making the trapping mechanism less effective further down the sluice, particularly for capturing small gold particles. For this reason most gold is caught in the first meter of simple sluices.

For efficient sluice operation, consistent water supply is important. When buckets are used to deliver sediment and water onto sluices, surges in flow can remobilize gold particles from the carpets, reducing gold recovery. Regular flow can be obtained by loading a small reservoir (20-100L) with water that delivers consistent flow to the sluice (see opposite photo). On large sluices typically for alluvial deposits, motorized pumps are often used to deliver material to the sluice box (see photo below).



Large sluice boxes are constructed with wooden timbers and lined with plastic and carpets (Indonesia, 2008).



Water availability and delivery are important for efficient sluicing. Above- a fuel drum filled with water and hoses are used to deliver water to sluices (Tanzania, 2010). At right- water is delivered to sluice through a plastic pipe with holes drilled in it (Liberia).



Zigzag sluice configurations- in which a top sluice drops material onto a second sluice below, can be used to break flow velocity, and therefore increase gold recovery. Sluices are usually inclined at 5 to 15 degree angles.

A combination of two sluice surfaces is often an optimal set-up. These are called primary and scavenger sluices.



Right- a zigzag sluice is cleaned out at the end of the day (Suriname).

Gold Trapping Surface

Sluice linings can be made from a range of products, but rubber mats and carpets are most common. Small ridges called riffles can also be used. They cross the path of the sluice surface, and aid the entrapment of gold particles by causing variation in flow. To maximize gold recovery, carpets must be checked and cleaned to recover concentrate at appropriate intervals - if carpets are becoming clogged with minerals, the surface will be less effective for trapping gold particles. It is wise to check if gold is being lost by panning sediment from sluice tailings or overflow.



Above- square hole rubber mat used as a primary sluice lining (Mongolia, 2011) - easy to clean but less effective than carpets or miners moss. Right- a miner cleans his sluice carpet to recover concentrate (Indonesia, 2008).



Above and below left, different types of “miners moss”, a rubbery fabric designed specifically for capturing gold, are used to produce heavy mineral concentrate containing gold (Mongolia, 2011). Below right- ribbed carpet is also be used and is widely available (Mali, 2011).



Centrifuges

A centrifuge consists of a rotating bowl that has a series of ridges that trap gold as the bowl spins. Force applied to the feed material (milled ore, heavy mineral concentrate, alluvial sands, etc.) can be 50 to 200 times the force of gravity, providing more effective separation of gold from lighter minerals than systems dependant on gravity only like sluices. Ore is usually fed into the concentrating bowl in a slurry of 60-75% water (25-40% solids). Inside the bowl material moves upwards as the bowl spins, and heavy minerals including gold are trapped between the ridges while light minerals overflow up and out. The bed of concentrate that remains below in the ridges must be fluidized to allow gold to replace lighter minerals. In sophisticated models, this is accomplished by back-pressure provided by small water jets. Alternatively, turbulence bars can be used - as shown in the photo below right, of a system built in Zimbabwe. This design is less effective than systems with back pressure jets but is simple to build and operate. It mimics the original Knudsen concentrators from California.



Small-scale centrifuges are operated in batches as opposed to continuous process. An operating (spinning) cycle typically lasts 0.5 to 2 hours, after which the concentrate must be cleaned out of the ribs (see photo on opposite page). Centrifuges come in a variety of sizes and can process small or large amounts of material - the small Icon™ machine shown at left, can process 2 tonnes of milled rock per hour.



Centrifuges come in a variety of designs and cost ranges, with more expensive designs having better engineering and therefore higher efficiencies and throughput capacities.

Generally, centrifugal concentrating requires:

- slurry feed with relatively uniform grain size (screening material is important)
- access to process water
- access to a power supply
- capital investment (small-scale centrifuges typically begin at several thousand dollars)

Centrifuges must be tuned to the ore being processed, and they must be operated with diligence. This is accomplished by adjusting grain size (milling time), rate of feed, rotation velocity, and cycle duration. One of the main challenges is to keep the concentrate bed active (fluidized) to avoid compaction and ensure heavy minerals can replace lighter ones leading to richer concentrates.

Spiral Concentrators

Spiral concentrators are most useful for secondary or tertiary concentration. They are specialized pans with spiral grooves on their surface, mounted on a tilted axis so that one side of the pan is lower than the other. They can be useful to work primary concentrates from many kilograms down to a few hundred grams. The concentrate produced by a spiral concentrator may be suitable for zero-mercury treatments such as direct smelting.

A small electric motor which is run by a portable battery turns the pan, and water showers the spirals. Concentrates are added to the bottom of the inclined pan using a small scoop. Heavy minerals are carried upwards in the spirals as water washes lighter minerals back down. The heaviest particles including gold remain in the spirals and drop through a hole in the center of the pan to a cup which is accessed from the back.

A miner using a large spiral concentrator as a final concentration step (North America, 2010).



Vortex

Vortexes are also most appropriately used as a secondary or tertiary concentration device. This design is commonly called a blue bowl. During the final step of producing a small high grade concentrate, it is particularly good at capturing fine gold.

A 30-50cm diameter bowl is setup so that water enters the bowl from a hose. Concentrate is placed inside the bowl and the flow of water is controlled to create a whirl-pool which drains out through an elevated hole in the center.



The spinning water suspends light particles, while heavier (gold) is left behind. The suspended particles flow through the drain into a bucket below. For best results the vortex requires clean water under a small amount of pressure, which can be supplied by a small pump or a raised water vessel. Vortexes are very cheap and simple to operate.



Shaking Tables

Shaking tables are slightly inclined with a trough along the lower edge, and slightly raised ridges along their length. Feed material and water are added along the high edge of the table, and a motor is used to shake the table. Inclination, water flow and shake result in particle movement along the table towards the lowest corner. Heavy particles do not move as far as lighter particles, and this creates an effective separating (concentrating) method.

Shaker tables can provide excellent separation of liberated gold from other minerals and produce high grade concentrates greater than 50%. The gold of course must still be extracted from the concentrate using another process (gravity, chemical, or direct smelting for example). They can be expensive, however, and require careful attention and training to operate effectively.

A large shaking table in operation (Mongolia, 2010).



This laboratory photograph clearly shows the separation mechanism of a table, as yellow gold is separated from less heavy black sands. The particles are directed by grooves in the table's surface.



Flotation

Flotation separates different materials by using differences in their surface properties. It is applied to a wide variety of materials and utilizes surfactants like xanthates, as well as other compounds, as agents to float and collect minerals. Flotation is one of the main processes used by large scale mines to concentrate sulfides and gold but can easily be done at the small scale too.

The principle behind flotation is the ability to attach bubbles or other buoyant materials to a mineral's surface - a function of the minerals "wettability". A hydrophilic mineral is one that is easily wetted, while a hydrophobic mineral is one that is water repellent. Many minerals such as silicates, sulfides, oxides, and carbonates can be separated by flotation- even minerals that have similar density and are difficult to separate by gravity. For this reason, flotation can enable the processing of complex ore types, including ores that are difficult to process using gravity methods.

3 Main Steps for Flotation:

1. Add reagent to slurry to make minerals hydrophobic
2. Froth (bubble) the slurry to transport desired minerals upwards and create a surface froth
3. Skim (separate) the mineral laden froth from the bath (flotation cell) to produce a concentrate

This flotation system begins with a crusher then mill, proceeds to a sluice to capture coarse gold, and then proceeds to this flotation cell. A sulfide concentrate rich in gold is skimmed from the system using paddleboat skimmers. The gold in the concentrate is extracted with cyanide (Ecuador, 2011).

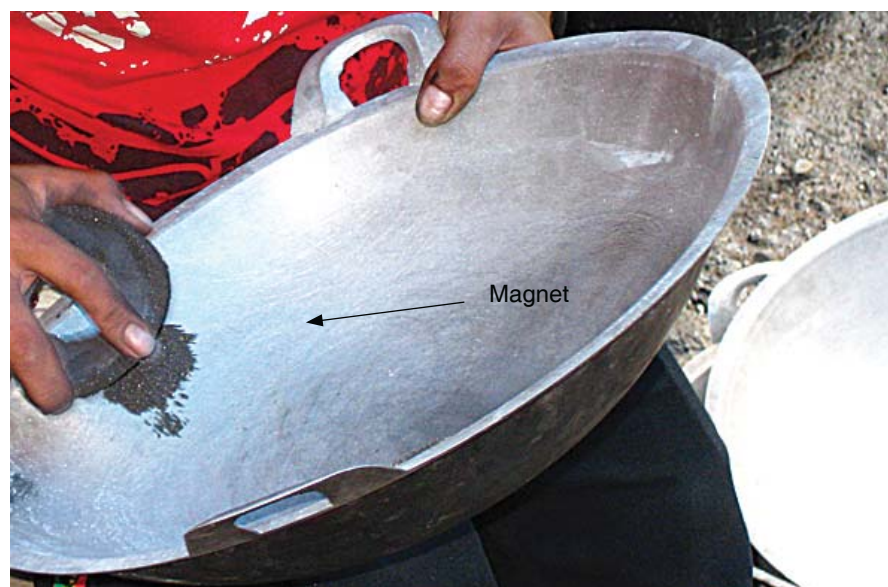


Magnets

Magnets are often used as a tool in the final stages of concentration to remove magnetic minerals - mostly magnetite. Magnetic minerals are typically dark in colour but some such as pyrrhotite (a sulfide) can be bronze colored and have a metallic lustre.



A hand held magnet is used to remove unwanted minerals, with care to avoid losing gold. To do this, the magnet is used below the pan to separate magnetic from non-magnetic minerals. Frequently wet mineral concentrate is heated to dry the minerals before using magnets for this purpose. This also increases the strength of magnetism in some minerals. A piece of paper or plastic is often used to cover the magnet so that the minerals can be easily removed from it.



Magnets have also been used to form sluice beds by making a “carpet of magnetite”. In certain cases, these magnetic sluices can improve the efficiency of recovering fine gold from concentrates. A thin magnetic sheet is placed on a small sluice. Magnetic mineral particles collect on the surface, forming a bed into which fine gold particles can settle. The sluice liner is comprised of polarized magnetic strips along its length. The gold must still be separated from the magnetite rich concentrate produced.



2.3 - Reducing Mercury Pollution Through Better Practices

Avoiding Mercury Use before Cyanidation

Cyanidation operations processing feed material that is contaminated with mercury is a Worst Practice. Tailings from whole ore amalgamation, often contain significant amounts of mercury and gold. For this reason, miners (often a different group than the mercury users) buy and re-process these tailings using cyanide. This greatly exacerbates mercury pollution by delivering mercury to the environment as dissolved mercury-cyanide compounds. These toxic compounds are more easily dispersed in waters, make mercury more bio-available.

The tailings and waste from this process create heavily contaminated sites that are very difficult to clean up. Mercury evaporates from waste material, leading to prolonged mercury emissions to the atmosphere.

Small-scale pit leach, heap leach, tank leach, and agitated tank carbon-in-leach (CIL) cyanidation operations are often used to reprocess mercury contaminated tailings (a worst practice) but increasingly to process whole ores directly - similar to the large-scale gold mining industry.



Tiny mercury droplets can be seen in the feed material at operations that practice whole ore amalgamation before cyanidation.

Solutions to this problem

1. Whole Ore Amalgamation should always be avoided. A first step to avoiding WOA is to concentrate ores prior to mercury amalgamation. This greatly reduces mercury consumption and pollution and is a good step towards elimination of mercury.
2. Remove mercury from feed before applying cyanide - this applies to tailings already contaminated with mercury, however no standard methods exist and those being attempted require further development and research.
3. Do not use mercury in the first place – use only gravity or cyanide or other chemical leaching methods to recover the gold.

Avoiding Open Air Burning of Amalgam

Once an amalgam has been formed it is heated to evaporate the mercury from the gold. This is done by heating the amalgam in the open, releasing mercury vapor into open air (“open air burning”), or alternatively by heating the amalgam inside of a mercury capturing device such as a retort or fumehood (“closed-circuit burning”).

Open air burning of amalgam is another Worst Practice.

When amalgam is burned the mercury evaporates as highly toxic vapor, which is invisible and odorless. This mercury vapour poisons miners, gold shop operators, and members of their families and communities, who are exposed to high concentrations. The problem is worsened when gold shops are located in urban areas. In addition to the acute inhalation concern, this mercury is emitted to the atmosphere and circulates around the world worsening global mercury pollution.



Ball of amalgam is heated by placing it on a hot wooden ember, and blowing on the ember to increase the temperature (Mozambique 2010). Mercury vapor inhalation and exposure is acute.



Gold shops often have air-mercury concentrations thousands of times natural levels— even when they are not burning amalgam (Kering Pangi, Indonesia, 2009).

Chimneys are used when heating large amounts of amalgam produced by whole ore amalgamation, as at this location in Indonesia.

Solutions to this problem are explained on the following pages.



Retorts

Rather than open burning, amalgam can and should be heated using a closed circuit device such as a retort or fumehood, so that the mercury can be re-captured. Simple and affordable versions of these technologies can reduce mercury emissions by 75 to 95% and can be profitable for miners and gold shops because mercury consumption is reduced. Retorts heat amalgam in one part and cool and condense the mercury vapour back into a liquid in the other part of the device. The mercury can then be re-used.



(1) Amalgam is placed in a stainless steel retort; (2) The retort is clamped tight, and placed on a gas burner; (3) Mercury vapor leaves the amalgam, condenses in the steel tube, and drips into the vessel containing cool water. Once the retort has fully cooled after use, it is opened to reveal a large flat piece of sponge gold (Indonesia, 2009).



Important Precautions

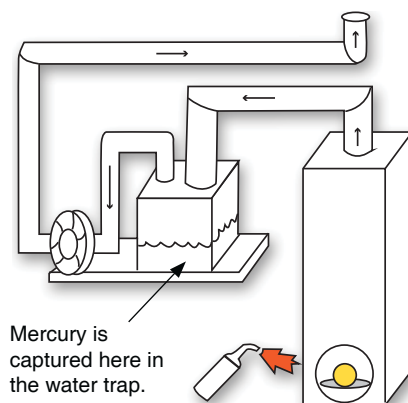
- Once a retort or fumehood is used, it becomes contaminated with mercury and must be treated with care- they should be kept in a secure space and precautions must be taken if they are transported inside cars or in backpacks to prevent exposure.
- Retorts should never be operated by children or by women of child bearing age.
- Retorts should only be used in very well-ventilated areas, preferably outdoors or inside of a fumehood.
- Retorts should not be opened until cool, or else mercury gas can escape and cause exposure.

Numerous types of retorts are used in ASGM. Choosing the most appropriate type must be done by the end users who understand their specific needs. Above- this glass retort is more expensive and fragile but has the benefit of seeing what is inside. They are carefully used in Ghana (2010); below left- very large retorts fabricated for use with large amounts of amalgam (Indonesia, 2011); below right- the "kitchen bowl" retort using a wet sand seal around the edges is a very low cost and simple retort design.



Fume Hoods

Like retorts, fumehoods designed with mercury capture systems can reduce mercury emissions, and occupational exposure to mercury fumes. A well designed but affordable system can capture 80% of emissions. Highly sophisticated systems can capture more but are much more expensive. Two different fumehood designs are presented here.



example The waterbox mercury condenser is a cheap and easy to manufacture add-on to basic small fumehoods (chimneys) used in gold shops in many countries. Mercury vapor is pushed through the system by a fan. The vapor is bubbled through water in the plastic vessel, and cools. This causes the mercury to condense as liquid mercury and collect below the water where it is isolated from the atmosphere. This mercury can be collected for re-use.

Above right- basic schematic of water trap setup; right- a fumehood installation in a gold shop in Indonesia; below- water trap setup on a shelf, showing 100watt blower fan, and plumbing fixtures.



example This fumehood design by the USEPA uses common fuel drums, impaction plates and a fan to trap mercury aerosols. The drum is attached to a fumehood exhaust system. Mercury collects inside the drum.

Recycling mercury captured by retorts or fume hoods prevents the need for fresh mercury imports and can reduce emissions by up to 95%. Capturing mercury at gold shops or in the field by miners can be the first step in moving towards mercury free processing.

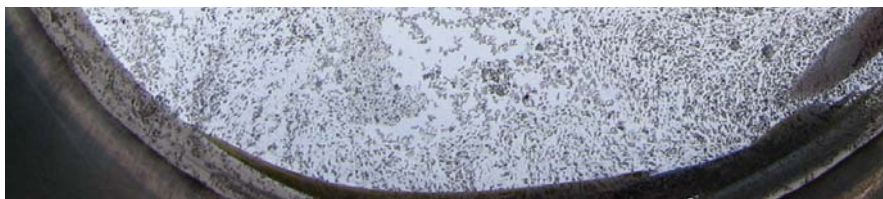
Recycled mercury must be treated with care to prevent intoxication and contamination. Once mercury has been captured by a retort or fume hood it should be stored safely. A good way to store mercury is sealed in a plastic or steel vessel, under a layer of water which prevents the mercury from evaporating.



Mercury Activation

Use less mercury, make less waste, and get more gold

Mercury becomes less effective for amalgamation once it has been used and gets contaminated with other substances or has become oxidized. An effective method for cleaning and activating mercury was developed by Dr. Freddy Pantoja. The method uses a solution of table salt and a simple battery to “activate” the mercury. The result is mercury with a mirror clean surface, and coalescence of “floured mercury” (tiny mercury droplets), if present. The steps to activate mercury are:



1. Pour the used mercury into a plastic, glass, or ceramic cup. Do not use a metallic cup because the metal will conduct electrical current. A dirty/oxidized mercury surface is shown in the photo above.

2. Mix a large spoon of table salt into a glass of water and when the salt is dissolved, pour the solution over the mercury. Sodium hydroxide (commonly called lye or caustic soda) also works very well, will produce less toxic by-products (like chlorides) and corrode the copper wires less.

3. Connect with a copper cable- the negative pole of a 9V or 12V battery to the mercury and the positive pole to the solution - a motorbike or car battery is good. The surface of mercury becomes clean of the dark colored oxidation product in 5 to 10 minutes. Mercury Activation should be done immediately before amalgamation to ensure minimum mercury use and maximum gold recovery.

Copper wires are used to connect the battery to the mercury and the salt-water solution.



Left- 9 Volt battery being used for mercury activation. A series of smaller batteries connected in series also work well.

Right- after activation the mercury surface is a clean reflective mirror; water is kept over the mercury so that mercury vapor does not escape.



4. For best results, the activated mercury should be filtered through a pinhole filter. To do this, make a tiny hole (<1mm) in the center of a piece of paper and carefully pour the mercury through the hole - dirt and oxides will be trapped on the paper. Filtering is helpful to clean mercury even when it has not been activated.

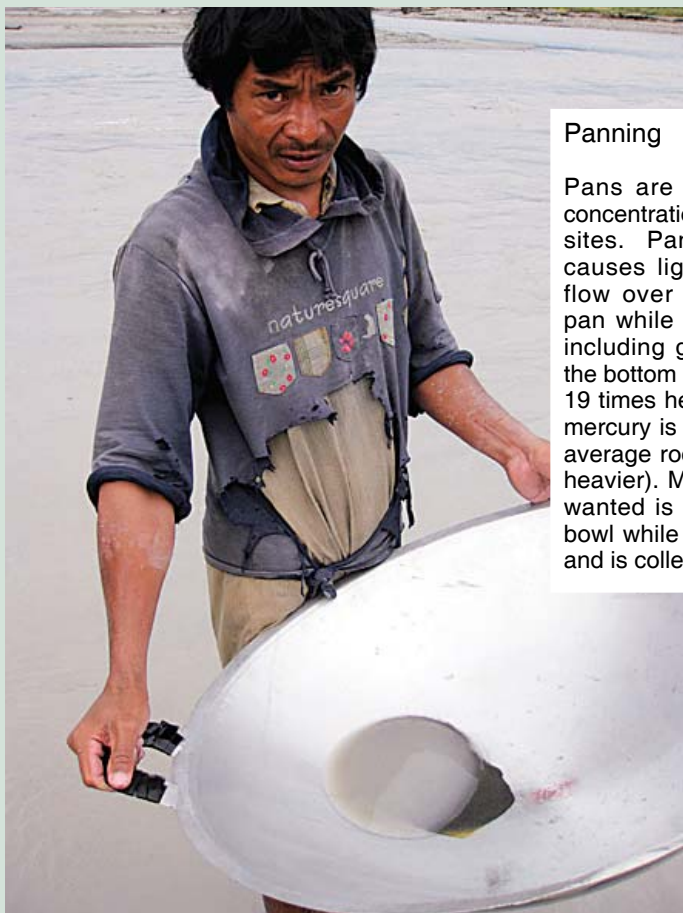
Activated mercury stored securely in a durable glass bottle with water on top, tape around the tightened cap, and properly labelled as mercury and as toxic.



2.4 - Eliminating Mercury Use; Zero Mercury Processes

Gravity Only

Gravity methods are the most widely used method of concentrating gold in ASGM. Using gravity is effective because gold is heavy: approximately 7 times heavier than an average rock of the same size. There are a wide variety of approaches to gravity concentration from very basic (panning and sluicing) to more complex (centrifuges and shaker tables), which require special equipment.



Panning

Pans are widely used for concentration in many ASGM sites. Panning with water causes lighter particles to flow over the edge of the pan while heavier particles including gold remain near the bottom of the pan (gold is 19 times heavier than water; mercury is 13 times heavier; average rock is only 3 times heavier). Material that is not wanted is panned from the bowl while the gold remains and is collected.



The sequence of images above shows miners panning up a sluice box concentrate (1,2), and then drying and heating it (3) to allow magnetic minerals to be removed (4) to produce a near pure gold product (5).

Direct Smelting of Concentrates

... a zero mercury process sometimes called the “Borax Method”

As an alternative to extracting gold using mercury, the entire concentrate is melted. The gold sinks to the bottom of the melt and after cooling, gold can be separated by breaking off the glass-like slag. This method is sometimes referred to as the “borax method”, because sodium tetraborate (borax) is used as an important “flux” in the process, facilitating the melting process. This method is already employed by almost all gold shops simply to produce a gold dore.

Advantages

- Does not use mercury; reduces health, environmental problems.
- If concentrates contain unliberated gold, direct smelting can capture it whereas mercury will not. i.e. under some circumstances it gets more gold - however only a very limited mass can be smelted (see obstacles)

Requirements

- An ore type and processing method which permits miners to create a concentrate containing at least 5-25% gold
- Borax and other fluxes
- Additional tools including torch, tongs, ceramic crucibles, etc.

Obstacles

- Capital investment in equipment and materials
- A heat supply capable of melting silicate minerals - around 1500°C

Obstacles Continued...

- Heating requires power which is energy over time (watts) and in any system there are energy losses. This means that melting double the mass of concentrate will require more than double the time if the same energy is applied. For this reason direct smelting is difficult to scale up to larger masses- it cannot directly replace the action of mercury on even on a relatively small mass of concentrate. Masses of concentrate greater than 100-500g simply cannot be melted easily. The Ghanain method is currently designed for batches of 50g.
- A major limitation of the method for ASGM, is that only a small mass can be processed: approximately 50-100g per half hour smelt. 50 grams of a 5% gold concentrate will produce a 2.5 gram bead of gold. If smaller than this, the gold bead becomes difficult to collect and losses to the slag will be greater. For example at 2% gold content, 50 grams of concentrate would only contain 1 gram of gold which is complicated to extract, so in reality this method requires small masses and relatively rich concentrates.
- For these reasons, direct smelting works best and will be most appealing for situations where small masses of high grade concentrates can be produced without substantial losses of gold during the concentration stage. This is difficult to do for some ore types. It works best in deposits in which gold particles are coarse.
- In cases where gold in the concentrate is not well liberated, direct smelting will obtain more gold than the use of mercury (if losses while producing the concentrate are not substantial). It will not, however, be able to replace mercury everywhere. Two examples of direct smelting are provided.

Example #1: The Borax method, as used in the Philippines

- ① Concentrate is carefully reduced by panning until it is more than 25% gold. Care is taken so that gold is not lost in the process; this is done using multiple pans (below).



- ② The concentrate is carefully collected, and mixed with equal parts borax. Roughly 50 grams of the mixture is poured into a small plastic bag.

- ③ A clay crucible is pre-heated using the blow torch and melting a small amount (5mL) of borax in it.



- ④ The plastic bag is placed in the crucible and burned, using charcoal and/or a fan to increase the heat, for 5-15 minutes. The result is a solid piece of gold dore.



Direct Smelting of Concentrates

Example #2: Direct Smelting method developed in Ghana¹

The Ghanaian direct smelting kit is designed to smelt around 50g of concentrate in 20 minutes. It is a well engineered system that produces consistent and high quality results. Heating a larger mass requires more time and more fuel, different equipment, or multiple kits.

- ① Produce 25-100 grams of concentrate containing at least 5% gold.



- ② Place the concentrate in a high temperature clay crucible. If the concentrate contains sulfide minerals it may help to first oxidize it by hand with a torch.

- ③ Mix in appropriate fluxes and reagents to lower the melting temperature and viscosity of the non-gold minerals. The most effective recipe will depend on the ore and must be learned experimentally. Two common recipes are provided below:

#1

- 1 part concentrate
- 1/2 parts borax
- 1/2 part lime (CaO)

#2

- 1 part concentrate
- 1/2 part borax
- 1/2 part potassium nitrate
- 1/2 part silica

- ④ Place crucible in furnace and heat until the melt is above the melting point of gold (1064°C) for at least 5 minutes. This will produce two separate liquids or “melts” – a silicate melt that is typically thick but light (low density), and a metallic melt of the gold and other metals such as silver lead and copper that is viscous (thin) and heavy and sinks.



- ⑤ Remove the molten concentrate (the melt) from the furnace and pour into a cuppel - a triangular shaped vessel. The gold will sink into the bottom tip of the cuppel.

- ⑥ Cool and remove the cone shaped solid from the cuppel and break the gold off the bottom with a hammer. The gold bead is often cleaned with a wire brush.



[1] system designed by Prof. Sulemana Al-Hassan at University of Mining and Technology (UMAT), Tarkwa, Ghana.

Chemical Leaching as an Alternative to Mercury Use

Although this is a somewhat controversial issue, it would be remiss to not discuss it in this document. Chemical leaching of gold ores, including the use of cyanide is a mercury-free process and when managed properly can be less polluting. For example, cyanide is a degradable compound that can be destroyed, is not persistent, and is not a global pollutant, whereas mercury cannot be destroyed, is persistent, and is a global pollutant.

The industrial gold industry which once used mercury, has moved away from it by adopting chemical leaching methods. The dominant method used for extracting gold from ores in large scale mines is now chemical leaching using cyanide¹. One of the reasons is because it can obtain very high recovery rates— often 90% of the gold in the ore and cyanide is cheap. In the large scale industry, innovations in cyanide leaching also allowed large deposits of low gold grade to be processed and this allowed formerly uneconomical ore deposits to be exploited¹.

For the same reasons, the use of cyanide has become increasingly adopted by small-scale miners. Reprocessing tailings that were initially processed inefficiently is increasingly common in ASGM. A worst practice occurs when mine tailings from operations that used mercury are reprocessed using cyanide.



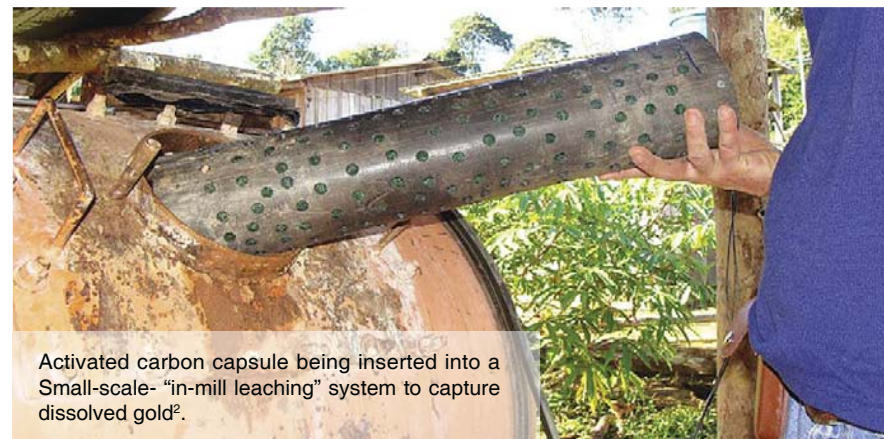
At this small-scale cyanide processing plant, cement lined vats are used for tank leaching; below left- cyanide solution is drained from tanks; center- activated carbon is used to absorb gold-cyanide complexes from solution; right- chemistry lab and critical safety equipment is present on site and miners are trained to use it (Tanzania, 2010).



The adoption of cyanide by the informal sector has generally happened without the safety and environmental standards applied by the formal industry. Misuse and poor management of cyanide in informal small-scale mining is common and has led to disastrous local pollution. Nonetheless, chemical leaching in small-scale mining can be a viable alternative to using mercury if properly done and well managed. This requires capital, training, monitoring, and also innovation.

One of the biggest problems with cyanide use in small-scale gold mining is commonly a lack of waste management. Waste management is almost always a cost to mine operators, and as a result is often substandard or non-existent in ASGM. There are many examples of small-scale cyanidation plants that simply discharge their waste directly into rivers or forest. This is completely unacceptable. There are also examples where tailings impoundments have been built and waste management efforts have been made, but there remains need for improvement.

A recent innovation that reduces complications with waste management is “pre-concentration and in mill leaching”². Pre-concentration produces a concentrate that minimizes the amount of cyanide (or other leachate) required by as much as 200 times. Concentration is followed by “in-mill leaching”, during which the gold is simultaneously liberated and leached, reducing the time required for processing. Benefits of this process include (i) reduced and less toxic waste stream that is simpler and cheaper to manage; (ii) processing times that can compete with mercury (1 day) – hence reduced or zero mercury use; (iii) higher gold recoveries.



Activated carbon capsule being inserted into a Small-scale- “in-mill leaching” system to capture dissolved gold².

[1] Müller J., and Frimmel H.E. (2010), Numerical Analysis of Historic Gold Production Cycles and Implications for Future Sub-Cycles, The Open Geology Journal, 4, 29-34.

[2] Sousa R.N., Veiga M.M, Klein B., Telmer K., Gunson A.J., Bernaudat L. (2010), Strategies for reducing the environmental impact of reprocessing mercury-contaminated tailings in the artisanal and small-scale gold mining sector: insights from Tapajos River Basin, Brazil . Journal of Cleaner Production, vol. 18, 1757-1766

Model of a mercury-free processing plant

- 4 pages

Under the right conditions and with the right equipment, a large percentage of gold in a deposit can be effectively extracted with only gravity methods. This rarely exceeds 70% of the total gold but that is a relatively high percentage in ASGM. These photographs were taken in Mongolia, 2011 and document some of the work of the SAM project¹.



① Gold bearing rocks are extracted from a properly timbered mine shaft



② Rocks are crushed down to 1-2cm size using a jaw crusher

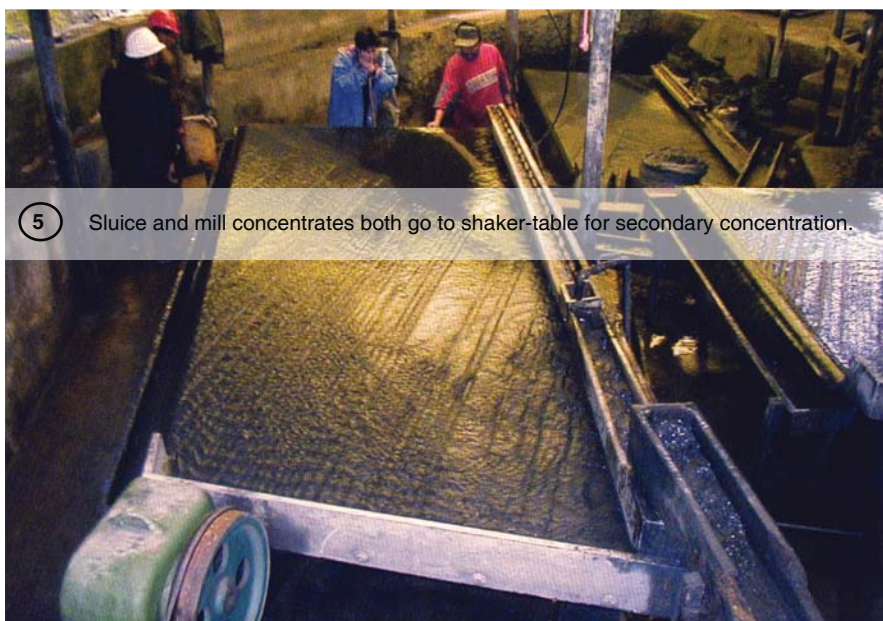
[1] The project and plant design was developed by the Sustainable Artisanal Mining Project, (SAM), a collaboration between the Mongolian Government and the Swiss Development Cooperation (SDC), Mongolia.

③ Chilean mills are used to mill the rock- a large portion of the gold stays in the mill; rock powder flows with water from the mill onto a primary sluice, and then a secondary scavenger sluice which captures fine gold.





④ Extraction of gold from sluice carpets.



⑤ Sluice and mill concentrates both go to shaker-table for secondary concentration.



Gold concentrate from shaking table.

⑥ The gold concentrate is smelted (with borax) and poured into case iron mould. The resulting unrefined gold ingots (gold dore) are 94% pure in this example but purity varies with ore type.



⑦ Tailings from this process contain 30% of the gold and so are still valuable. They are currently accumulated on site for future collection for subsequent processing, likely by a leaching technology in a more centralized facility.

2.5 - Mercury Reduction: Related Technical Topics

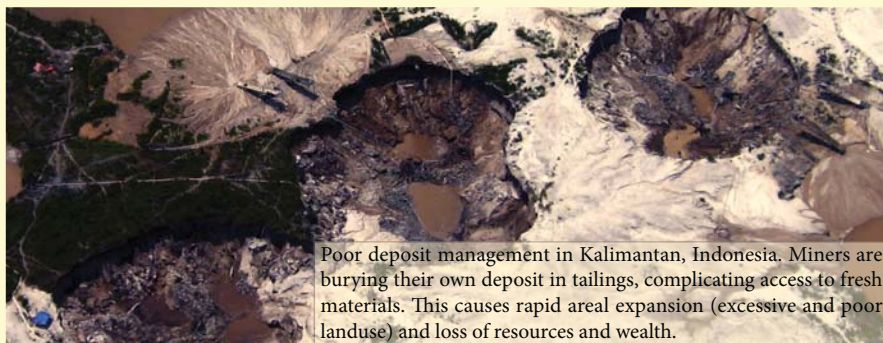
Gold Deposit Type, Exploration and Planning

Gold is a very rare element but also very precious. Its average concentration in the earth's rocks is 3-4 ng/g (parts per billion). In some cases at current prices, if naturally concentrated by as little as 25 times (~0.1 grams per tonne) some types of deposits are mined by ASGM, such as coarse free gold in shallow alluvial sediments (see photograph below). On the other end of the scale, mineralized veins (primary ores) can be 20 to 200 grams per tonne. For these deposits much less material is processed.

General types of gold deposits exploited by ASGM are: [A] alluvial deposits (particles of gold in river sediment); [B] weathered soil hosted gold (saprolites); and [C] hard-rock hosted gold (primary or lode gold). The type of ore dictates the type of extraction possible, which in turn dictates how mercury is used and potentially eliminated. Best practices in one situation cannot necessarily be applied elsewhere. Mercury reduction approaches must fit the ore type and current practices.

Exploration is one of the most difficult aspects of mining. ASGM mainly rely on prospecting using trial and error—walking the ground and testing for gold content. Because there is no direct financial return during exploration and because ASGM cannot access capital to fund exploration, ore deposits are often discovered and exploited in haphazard and inefficient ways.

There is an important opportunity for engaging with small-scale miners at the exploration stage that can support lowering and eliminating mercury use. Planning how the deposit will be extracted based on simple exploration mapping methods can maximize resource exploitation, minimize land use, and improve gold recovery and waste management, which in turn makes reducing mercury use more affordable and sustainable.



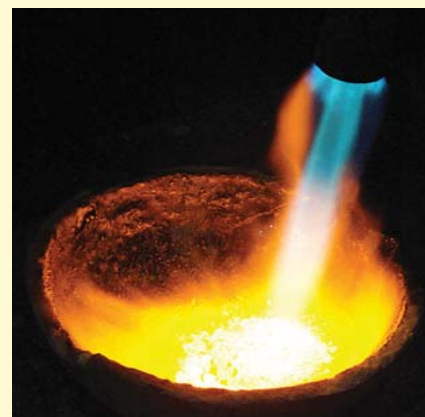
Poor deposit management in Kalimantan, Indonesia. Miners are burying their own deposit in tailings, complicating access to fresh materials. This causes rapid areal expansion (excessive and poor landuse) and loss of resources and wealth.

Purifying Gold – the Quartering Method

Gold can be easily purified to 99.5% in a relatively simple process called the quartering method. This can help improve confidence in gold sale and trade relationships, and helps gold shops to receive higher margins. It increases local know-how, and can provide an unbroken supply chain of local gold for use in local gold craft. It connects sellers more closely to the markets and earns them more money and so can bring influence and finances towards moving to less or zero mercury use. It is particularly common in Asia.

The quartering method involves melting 2.5 parts silver together with 1 part gold dore. The silver-gold melt is cooled and digested in nitric acid leaving behind a pure gold residue because gold is not soluble in nitric acid whereas silver and other metals are. The pure gold residue is remelted to produce a gold bar that is 99.5% pure. A flux such as borax is used in this process to assist melting and removing mineral impurities, similar to direct smelting. It is therefore easy to follow direct smelting with purification, which adds value. The Quartering Method is presented and explained on this and the next two pages.

- ① Weigh the gold dore and then weigh out 2.5 times that amount of silver and place with the gold in a crucible, to be melted.



- ② Melt the silver and gold in a crucible with a torch, adding a teaspoon of borax to assist in melting and removing mineral impurities.



- ③ Pour the molten silver-gold alloy from a height of 1 meter into a bucket of water with a steel bowl placed in the bottom. When the molten metal stream is quenched in the water it forms high surface area pellets - a silver-gold gravel (shown in the photo below).



- ⑤ The gold remaining in the flask looks like a brown mud. Wash it into a steel pan, and rinse with clean water. Drain the water, and dry the gold over low heat.



- ④ Acid Digestion: Place the silver-gold gravel into a glass beaker (Erlenmeyer flask). Add 20mL of pure nitric acid per gram of gold and boil for 10 minutes. NOTE: Used acid must be collected to recapture dissolved silver, and then be properly disposed of.



NOTE: Nitric acid fumes are poisonous and must not be inhaled. Use simple plumbed water traps, chimneys and proper ventilation (fans) to eliminate human and environmental exposure.

- ⑥ Finally, place the dried gold into a high temperature crucible. Melt it with a torch, and pour the molten gold into a button or bar.



NOTE: To recover the silver, place a copper bar into the used acid in a plastic pail. Silver beads will precipitate from solution onto the bottom of the vessel. The silver can also be precipitated as silver-chloride by adding table salt to the used acid - this produces a white precipitate (silver chloride) that will darken over time. Decant the water, and heat gently to dry. After it is dried, the silver chloride precipitate can be melted to recover the silver metal. This method produces noxious fumes and should only be done inside a fumehood.

Waste Management and Contaminated Sites

Two of the biggest differences between the large scale formal gold mining sector and the artisanal and small scale mining sector are (a) the use of mercury; and (b) that ASGM either do not practice waste management or do so using substandard practices. This creates contaminated sites.

Both Ecuador and Mongolia have begun to address this issue. They are currently implementing projects that will centralize waste management but retain the existing individualistic and small scale socio-economic conditions vital to the ASGM community.

The projects are based on building waste management systems that meet international standards (tailings disposal systems) that are accessible and affordable for ASGM communities.

The projects, by integrating environmental and social needs, bring with them the added benefit of further facilitating formalisation, legalisation, and better mining and processing practices - more wealth.

Design: (a) Centralized waste management; (b) Retention of custom milling - non-centralized processing; (c) Develop community governance structure; (d) Elimination of mercury from the waste stream; (e) Long term elimination of mercury use; (f) Improved mining and processing practices; (g) Clean up of contaminated sites

General Elaboration:

- In collaboration with governments and the mining community, development of a centralized tailings impoundment that meets international standards. The facilities should not accept mercury contaminated tailings as they are extremely complicated to manage – this provides mercury usage disincentives.
- Connect the waste stream of the processing centres to the tailings impoundment – via truck or relocation or other means. An pilot may need to be facilitated and financed to provide an example for others. This should accommodate the existing small scale mining community's existing individualistic and small scale socio-economic conditions and also serve to unite operators to practice acceptable environmental protocols.
- Construction of a pilot processing plant and training centre. This serves to demonstrate (i) mercury free processing; (ii) better gold recovery or less costs per unit gold recovered; (iii) appropriate waste treatment; (iv) other. It also can act as a centre for innovation, training and communications.
- Development of a plan to reprocess and dispose of existing tailings and contaminated sites. Tailings from existing and past ASGM operations can cause significant environmental pollution. These can be re-processed and then disposed of properly if they are still gold-rich or otherwise disposed of in accordance with appropriate environmental practices if financing is available.
- Health and safety and environmental educational programs. This will serve to increase miners' health and safety awareness and serve as further disincentives of mercury use.

Continued...

- Establishment of an environmental monitoring system. Environmental assessments will be conducted to be able to measure improvements.
- Promotion of leadership in the ASGM sector with regional outreach and collaboration. Build relationships and share information with other miners and communities to provide an example for the ASGM sector to follow.



Poorly managed waste, contaminated sites, and a solution for artisanal and small scale gold mining in Portovelo, Ecuador: (a) substandard tailings ponds; (b) direct discharge to rivers; (c) site contaminated with tailings; (d) **solution:** an adjacent valley (burned pasture) that is a suitable for a tailings impoundment that meets international standards and that can serve the needs of the ASGM community.

ANNEX 1 - The Big Picture

ASGM is a sector that, compared to other industries, is poorly understood. This Annex is included to provide context and perspectives on ASGM for those interested in understanding the issue more broadly.

Societal Interaction with ASGM is broad: ASGM touches many parts of society in many countries - including those in which it is not practiced. Emissions of mercury from ASGM impact communities worldwide but there are many other ways that ASGM interacts with society. Those involved include ASGM communities and their local governments; regional and national government stakeholders such as the ministries of mining, environment, health, trade, education; national treasuries (federal gold reserves); and the private gold sector from bottom to top - mining companies; stock exchanges; mine services, financial services, gold traders, buyers, refiners, jewellers, luxury goods makers - anybody that owns or deals with gold. ASGM is also very relevant to nations heavily involved in gold mining overseas such as Canada, China, the US, Australia, the UK, etc. as the interaction between the formal and informal sector is growing. This interaction can occur at the exploration stage when junior exploration companies utilize the presence of ASGM for exploration, or at the exploitation stage (e.g. photograph at right).

The Modern Artisanal and Small Scale Mining Sector

Despite being frequently referred to as a “gold rush”, the modern ASGM sector has been going strong for at least 40 years. The modern ASGM sector began shortly after gold was

de-linked from the american dollar by President Nixon in 1972 but it really got going in January 1980 when the price of gold briefly spiked at over \$800/oz (around \$2300/oz in 2012 dollars normalized for inflation). At that price, it was attractive for many poor agrarian workers to move into gold mining as a way to escape poverty. This price spike was short lived but afterwards the gold price remained relatively high compared to the 1950s, 60s and 70s when it was below \$100/oz. Since the peak, its lowest price was \$252/oz, reached in July 1999. This allowed ASGM to continue vigorously. Since 2000, however, the price of gold has more than quadrupled (it reached \$1900 in September 2011). This has led to increased numbers of miners and an improved standard of living in the ASGM sector.



Serra Pelada, Brazil, 1979.



Convergence of formal and informal: Small-scale gold miners on the steps of a large scale gold mine, Kalimantan Indonesia, 2008.

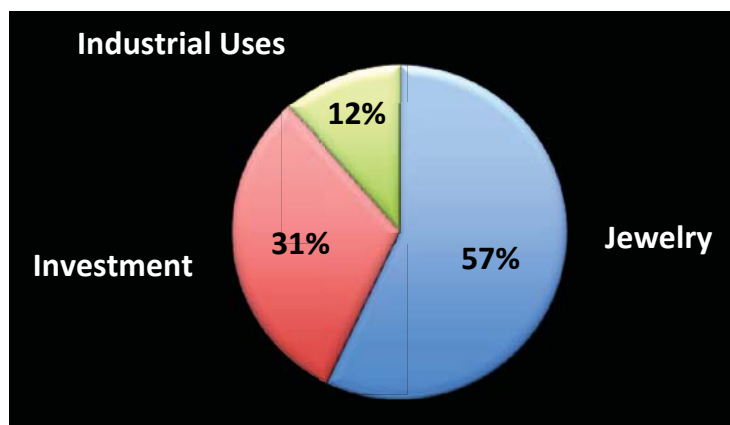
ASGM in Development

ASGM is an important development opportunity which contributes directly to poverty alleviation and regional development – just as it did in North America 100 years ago. This is increasingly recognized by world bodies such as the UN and World Bank. Some relevant points about this opportunity:

- Gold represents an excellent method of transferring wealth from rich to poor countries
- Small producers often get 70% or more of international price in remote areas - very different than coffee, bananas or most other agricultural products
- ASGM needs to be brought into the formal economy to maximize benefits
- In order to comply with modern environmental standards, reducing mercury use is a key step in realizing ASGM opportunities

Gold Consumption

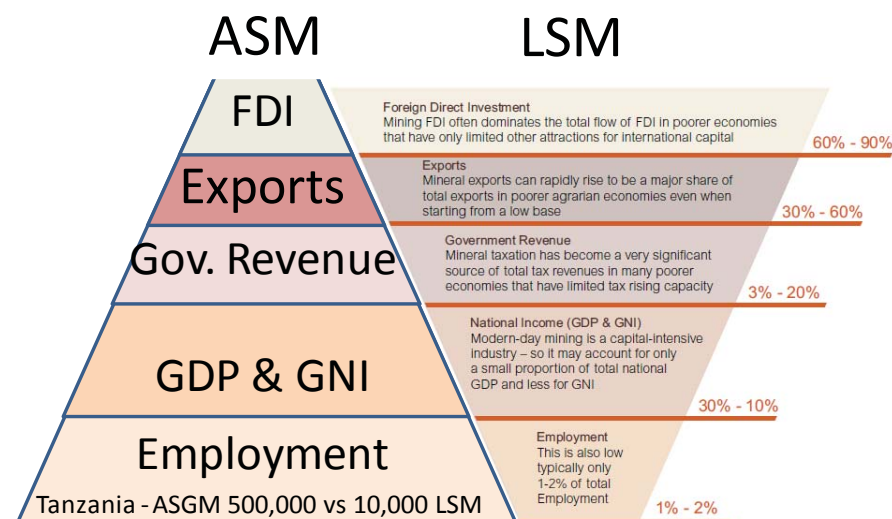
The last decade has seen shifts in gold consumption habits globally. In 2010, India, China, and countries of the Middle East consumed 70% of the gold on the global market. India consumes roughly 950 tonnes/year and consumption there has been increasing over the last years - many prefer to save by buying jewelry rather than putting money in banks. Gold demand in 2010 was 3971 tonnes, and 32-37% of this demand was met with the increasing use of recycled gold. Consumption for investment purposes has also been growing.



Comparison between ASGM and the Large Scale sector (LSM)

A basic comparison of the large scale formal sector and the small scale informal sector reveals that both have benefits with respect to the environment, governance, and society.

- Socio-economics of ASGM vs LSGM is inverted - see triangles below
- ASGM is more energy efficient (joules per unit gold)
- ASGM release less greenhouse gasses (CO2 emitted per unit gold)
- ASGM produce less waste rock and tailings per unit gold (however generally do not practice waste management, whereas LSGM does)
- LSGM release 5 times less mercury
- LSGM release 40 times less mercury per unit of gold
- LSGM use half as much cyanide per unit of gold



ASM triangle from Telmer, 2010, *Setting the Scene: Meeting of first working group on gold*, OECD, Paris;
LSM triangle from *The Golden Building Block*, World Gold Council, 2009

ANNEX 2 - Summary of the ASGM Sector in 2011

- ASGM is a major gold producer and the world's largest employer in gold mining, representing around 15% of gold supply (around 400 tonnes) and 90% of the gold mining workforce worldwide
- The number of miners is estimated to be around 10-15 million in 70 countries, including approximately 3 million women and children
- At \$1500/oz ASGM gold production has a gross value of around 19 billion dollars; this equates to about \$1900/miner per year - but it is not evenly distributed
- The secondary economy of ASGM, using a multiplier of 5, is around 100 billion USD and involves 50 to 100 million people. At a normalized wealth level (purchasing power parity: PPP) this is roughly 40 times poorer than the average American
- There is significant and growing interaction between the formal mining industry and ASGM. Both conflict and cooperation with formal mining operations has been growing in many countries
- The use of mercury is widespread in ASGM. Mercury use in ASGM is estimated to be 1400 to 1500 tonnes per year in 2011 (www.mercurywatch.org)
- Irresponsible mercury use in ASGM causes health and environmental problems both locally and globally
- Mercury related pollution problems are exacerbated by socio-economic barriers to the adoption of better practices

ANNEX 3 - Relative cost of technical interventions for a single mine operator, in order of increasing cost¹.

Technical Intervention	Cost (USD)	Barriers
Screens for sieving material	5 - 50	requires additional time and knowledge
Retort	5 - 50	requires additional time and knowledge
Reactivation (salt water and 12-volt battery)	5 - 20	requires additional time and knowledge
Improved Sluice	10 - 100	requires water, access to supplies
Mercury vapor capture system	50 - 500	requires additional time and knowledge
Direct smelting kit	depends on system used 100 - 2,000	initial cost; effective only on small batches of high grade concentrate; requires efficient heat source, technical know-how
New ball or hammer mill	2,000 - 5,000	high initial cost; requires energy, may require water, technical knowledge
Shaking table	1,000 - 10,000	high initial cost; requires energy, water, technical knowledge

[1] Developed at the Global Forum on Artisanal and Small-scale Gold Mining, 7–9 December, 2010, Manila - hosted by UNEP and its partners in the Global Mercury Partnership. Search UNEP Global Mercury Partnership.

ANNEX 4 - UNIDO Technical Guidelines on Mercury Management in Artisanal and Small-Scale Gold Mining

I. PURPOSE

In the absence of an international management code for mercury management in artisanal and small scale gold mining (ASGM), many governments have been unsure how to address policy in ASGM.

The UNIDO International Guidelines on Mercury Management in Artisanal and Small-Scale Gold Mining are proposed for the purpose of assisting governments in the development of policy, legislation and regulation that will lead to improved practices of artisanal and small-scale gold mining (ASGM).

These guidelines apply to all legal mining areas, gold shops, and mineral processing operations where mercury is used for gold amalgamation. The guidelines provide minimum standards which can lead to the future elimination of mercury use in ASGM operations. In all cases possible, miners should be encouraged to adopt appropriate mercury-free mineral processing methods.

The central aim of these guidelines is to assist governments in the development of legislation and/or regulation to accomplish the following goals:

- (1) reduce ASGM-related mercury emissions into the environment;
- (2) reduce occupational and second-hand exposure to mercury;
- (3) eliminate the major inefficient and unsafe practices of mercury use; and
- (4) reduce unsafe storage and disposal of mercury.

II. BACKGROUND

These measures are formulated based on health, environmental, technical, socioeconomic and legal assessments that were undertaken by the Global Mercury Project. This project was initiated with the support of the Governments of Zimbabwe, Tanzania, Sudan, Indonesia, Brazil and Laos, with the United Nations Industrial Development Organization (UNIDO), the Global Environmental Facility (GEF) and the United Nations Development Program (UNDP).

In more than 50 developing countries across Asia, Africa and South America, an estimated 15 million people are involved in artisanal and small scale gold mining (ASGM). This activity usually involves the use of substantial amounts of mercury in mineral processing, often in highly unsafe and environmentally hazardous conditions. As many as 100 million people may be affected, directly and indirectly, by mercury emitted from ASGM. Mercury is a neurotoxin that bioaccumulates through the food chain, and mercury misuse in ASGM is responsible for an estimated 1,000 tonnes of mercury discharged annually into the environment, with negative impacts in diverse ecosystems including international waters. Globally, many of the hazards are similar – extensive emissions in tailings, contamination of water bodies, vapor inhalation, etc. However, environmental regulations are minimally developed for ASGM in most countries or not yet developed, and consequently, mercury is generally unaddressed.

III. IMPLEMENTATION

Governments should identify the appropriate authority responsible for implementation of these guidelines, and make any appropriate modifications to the technical measures to include in developing new mercury laws, policies or regulations. It is recommended that such policies be adopted under the clear jurisdiction of authorities that are responsible for small-scale mining issues, in consultation with other relevant authorities, recognizing that such authorities may be best suited to conduct monitoring.

Strong emphasis should be placed on encouraging local-level governance and community based monitoring systems. Community stakeholder participation in the processes of policy development and field implementation are critically important.

Governments should provide ways to legalize the artisanal and small-scale miners as well as to educate them on environmental management. Technological assistance and capacity/education services should be provided in all areas where there is a high concentration of small-scale miners.

These guidelines apply to all legal operations where mercury is used to amalgamate gold, amalgam is being burned or retorted, and gold is being melted. These guidelines provide minimum threshold standards that significantly reduce mercury emission and exposure where properly implemented. However, in all cases possible, miners should be encouraged to adopt appropriate mercury-free mineral processing methods.

IV. PRINCIPAL TECHNICAL MEASURES

1. RESPONSIBILITY OF EMPLOYERS OF MINING/PROCESSING PLANTS / GOLDSHOPS OPERATION

In all cases, the primary mining/ore processing license holder and gold shop owners should be held legally responsible for safe practices, including those involving mercury. The mining license holder or gold shop owner should institute reasonable safety measures to prevent the exposure of employees or other persons to mercury fumes.

2. LICENSE TO WORK WITH MERCURY

All licensed operations where mercury is used or handled should obtain a special license specifically for mercury at its facility. When miners apply for mining licenses and before beginning operations, miners should demonstrate awareness of how to comply with these guidelines.

3. NO WHOLE ORE MERCURY AMALGAMATION

No person should amalgamate the entire ore, through the use of a mercury-copper plate or using mercury directly into any gravity concentrator, centrifuge, or ball mill, Chilean mill of stamp mill. This causes mercury flouing which reduces recovery and induce that a large portion of mercury is lost to the environment with tailings. Amalgamation must be used ONLY for gravity concentrates.

4. MERCURY AMALGAM BURNING

No person should heat/burn mercury amalgam to recover the gold without using a retort. Retorts contain and condense the mercury vapour releases and should be used to recycle mercury (in the form of a bowl retort, pipe retort, hood, etc). Amalgamation burning must not take place in domestic residences. This must be done distant (say MORE THAN 500m) from any house. No

children and pregnant women must be present during the retorting activities.

5. NO MERCURY-CYANIDE INTERACTION

No person should use mercury in conjunction with cyanide, or conduct cyanidation of mercury rich tailings as this practice increases mercury methylation.

6. AMALGAM BARREL

Amalgamation of concentrates must NOT be conducted manually. This must be conducted in small plastic or steel rotating barrels with rubber balls or a chain inside to increase the homogenization of the mixture of concentrate and mercury. Amalgamation time should be kept as short as possible. Amalgamation should be controlled and stopped, if no visible free gold can be seen. The amount of mercury added into the barrels must be gradual, until all free gold is caught. No cyanide or potassium permanganate or any other oxidizing agent must be allowed to be added to the barrel; only a dash of detergent is enough to clean gold particle surfaces. An amalgam separator such as an elutriator must be promoted to separate amalgam from heavy minerals after amalgamation. A carpet sluice placed after the elutriator will ensure that the fine mercury is captured.

7. CENTRALIZED AMALGAMATION SITES

Amalgamation and retorting should only be conducted in designated sites (amalgamation pools and isolated retorting places) distant at least 500 m from any inhabited place. For any mining location where amalgamation occurs, the primary license holder or mine manager shall designate a portion of the mining location as the prescribed structure, facility or locale where amalgamation may take place. Amalgamation may only take place in such structure, facility or locale. The holder of an ASGM license shall ensure that washing or settling ponds are constructed in his or her license area to provide for washing and sluicing, and no such washing and sluicing shall be done along or close to rivers, streams or any other water sources.

8. PROTECTION OF WATER BODIES

No person should conduct amalgamation or separation of amalgam from concentrates or burning amalgam or retorting in any natural water body or within a distance of 100 metres from any natural water body, including rivers, streams, lakes, and other water bodies.

Amalgamation tailings must not be discharged into a water body or in places susceptible to flooding.

9. PROTECTION OF RESIDENTIAL AREAS

No person should use mercury for amalgamation or any other purposes in residential areas or within a distance of 100 metres from any residential areas, including villages, towns, cities, or settlement areas.

10. DISPOSAL OF MERCURY OR MERCURY-CONTAMINATED TAILINGS

Any disposal of mercury-contaminated tailings should be done in a safe and proper way. No person should discharge mercury-contaminated tailings into a water body or in places susceptible to flooding. Disposal of mercury-contaminated tailings must be done by placing it on a clay or

laterite soil-lined pit of several metres depth, located 100 metres away from any water body. When the hole is filled with mercury-contaminated tailings, this must be covered with 1 meter of clay or laterite, then compacted, covered with soil, and re-vegetated.

11. EXTRACTING RESIDUAL GOLD FROM MERCURY-CONTAMINATED TAILINGS

Mercury-contaminated tailings must not be recycled to the concentration circuit once this contaminates the primary tailings. If any process is to be applied to recover residual gold from mercury-contaminated tailings such as leaching with cyanide, thiourea, etc., the residual mercury must be removed (e.g. by gravity concentration) prior to leaching. The effluents and tailings from gold extraction must still be treated as mercury-contaminated tailings and must be buried.

12. CONDENSERS FOR GOLD SHOPS

Any shop buying retorted gold, or any shop that is retorting gold, must have a proper fume hood installed to capture, condense and recycle mercury. The design of the fume hood should be such that over 90% of the mercury is captured.

13. STORAGE OF MERCURY

Metallic mercury should be stored safely at all times when not used; in (a) a secure location that is inaccessible to children; and (b) unbreakable air-tight containers that are covered with a thin layer of water (e.g. 1 centimetre) to prevent mercury evaporation. Mercury should NOT be stored in a domestic residence.

14. PROTECTION OF PREGNANT WOMEN AND CHILDREN

People who perform amalgamation, retorting, melting gold or handling mercury must ensure that no pregnant women, or children under the age of sixteen, enter the structure, facility or locale in which mercury is being used.

15. MERCURY-FREE METHODS

The above guidelines demonstrate minimum threshold requirements. These measures significantly reduce mercury emission and exposure where properly implemented. However, in all cases possible, miners should be encouraged to adopt appropriate mercury-free mineral processing methods. For small amounts of concentrate, the blowing-tapping method should be promoted.

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More...



Helping Artisanal and Small-Scale Gold Miners to derive the greatest benefit from this development opportunity, while minimizing the environmental and social consequences is needed and possible, but requires understanding, innovation and will.

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