



Mercury-free, small-scale artisanal gold mining in Mozambique: utilization of magnets to isolate gold at clean tech mine

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ABSTRACT

Artisanal and small-scale gold mining accounts for a significant portion of the current global gold market. Many artisanal gold miners use mercury to amalgamate gold and separate it from undesired gangue minerals, because it is relatively inexpensive and readily available. Unfortunately, the inappropriate handling and use of mercury has created environmental and health concerns in artisanal mining camps throughout the world. While the vast majority of artisanal and small-scale gold mines in Mozambique use mercury amalgamation in the gold mining process, the privately owned Clean Tech Mine in the Manica Province has eliminated the use of mercury at their mine. Instead, gold is isolated by centrifugation and magnetic removal of gangue materials. Furthermore, the operation of this mine stands in contrast to other mines in the area due to the responsible business practices initiated by its owner to ensure worker safety. This report details the mining practices employed by Clean Tech Mine to eliminate mercury use throughout the mining process, increase worker safety, and provide the surrounding communities with an opportunity for sustainable employment.

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1. Introduction

In 2002, artisanal and small-scale mining accounted for approximately 25% of the estimated 3000 tons of annual global gold production (Spiegel and Veiga, 2010; MMSD, 2002). Due to the current global economic crisis and rising price of gold (December 2011 average of 1653 USD/troy ounce, www.lbma.org.uk), artisanal and small-scale mining activities have dramatically increased in the recent years (Shandro et al., 2009). As gold deposits are often located in the developing nations, gold mining serves as a major source of income for over 15 million people in impoverished regions throughout the world (Veiga et al., 2004). Political instability, lack of governmental oversight, and the geographic isolation of many mines contribute to dangerous working conditions and detrimental health and environmental impacts for miners. These conditions ultimately affect all members of the mining community, including those not directly involved in the extraction and

processing of ore. While estimates suggest that approximately 4.5 million women and 600,000 children are active artisanal gold miners (Veiga et al., 2004; United Nations Industrial Development Organization (UNIDO), 2005), many additional women and children participate in non-mining related activities in close proximity to mining operations that utilize toxic substances such as mercury and cyanide.

The overwhelming majority of artisanal and small-scale gold miners utilize mercury to separate gold from the unwanted gangue materials (Telmer and Veiga, 2009). Miners use rudimentary tools to mine and process ore, adding elemental mercury to amalgamate fine gold particles after grinding the ore in a ball mill and concentrating by panning. Miners separate the gold from the amalgam by “burning” the amalgam, volatilizing the elemental mercury and dispersing it throughout mining camps. The adverse environmental and health effects of inorganic and organic species are well established (Risher et al., 2002). Exposure to mercury via inhalation during the burning process can result in memory loss, impaired coordination and motor function, and ultimately death (Swain et al., 2007; Levin et al., 1988; Asano et al., 2000). The fate of mercury in the environment is similarly well studied. Elemental

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mercury can be converted into inorganic mercury salts and then to highly toxic organomercury complexes, which bioaccumulate in the environment (Morel et al., 1998). The disastrous effects of organomercury poisoning in humans have been documented in several outbreaks, notably in Minamata Bay, Japan, where consumption of fish contaminated with high levels of methylmercury led to severe disease in the local population (Harada, 1995).

1.1. Reducing or eliminating mercury use in artisanal and small-scale gold mines

Several international initiatives to educate artisanal and small-scale gold miners about the dangers of mercury as well as promote effective strategies to eliminate or reduce mercury contamination have resulted in limited success. Perhaps the most viable alternative to mercury amalgamation is cyanidation. Recently, this substitute was effectively introduced to an artisanal gold mining operation in Portovelo, Ecuador (Veiga et al., 2009). However, economic and technical constraints limit the feasibility of this technology in the majority of artisanal and small-scale gold mining camps. Mercury retorts, designed to collect mercury emissions during gold processing, have the potential to reduce mercury contamination as well as mercury use (Hilson and van der Vorst, 2002). Unfortunately, retort use has only been marginally effective in most cases (Jonsson et al., 2009; Hilson et al., 2007), but some sustained success has been reported in mining camps (Shandro et al., 2009; Jonsson et al., 2009).

Additional alternatives to replace the amalgamation process, including the use of borax, gravity concentration, sluice boxes, and centrifugation have also been introduced to various artisanal and small-scale gold mines (Hilson and van der Vorst, 2002; Hilson et al., 2007; Vieira, 2006; Appel and Jonsson, 2010; Hylander et al., 2007). Educational and policy initiatives have also been introduced to address the negative consequences of artisanal and small-scale gold mining (Hilson et al., 2007; Hilson, 2006; Banchirigah, 2006, 2008; Spiegel, 2009). Some policies are more successful than others. Addressing the unique needs and characteristics of a specific mining community appears to be key for any technological alternative, educational program, or policy to be effective at limiting mercury use (Hilson et al., 2007; Veiga et al., 2006). In addition, any suggested alternatives must be more cost effective and/or more efficient at obtaining gold (Hinton et al., 2003). Global policies and strategies that do not take into account the intricacies of each community will likely not be accepted, and any initiative is unlikely to sustain success.

1.2. Artisanal and small-scale gold mining in the Manica Province of Mozambique

Mozambique is a mineral-rich country located in Southeastern Africa, that is in the process of rebuilding after many years of war decimated the country's infrastructure and economy (Finnegan, 1992; United Nations Development Programme, 2006). Mozambique has an estimated 60,000 artisanal and small-scale gold miners (MMSD, 2002; Shandro et al., 2009), with the majority of gold mining located in the Manica and Sofala provinces. The Manica Province is located in Western Mozambique, and contains the mineral-rich Chimanimani and Cordilheiras mountain ranges. Manica is bordered by the provinces of Sofala to the East, Tete to the North, Gaza to the South and the nation of Zimbabwe to the West (Fig. 1). The inhabitants of Manica are culturally and traditionally related to the people of Eastern Zimbabwe, therefore little distinction is made between Manicans and Zimbabweans in this area. For this reason, the region is generally referred to as Manica land. Agriculture and gold mining are the two major sources of employment in the Manica Province.

Due to the remoteness and inaccessibility of gold deposits in the Manica province, and the difficulty for the Mozambican government to oversee all active mines, gold mining is a largely unregulated industry in Mozambique. It has been conservatively estimated that there are well over 13,000 workers mining for gold in the Manica Province (Shandro et al., 2009), but only 3000 artisanal and small-scale gold miners are registered with the mining association. However, an accurate number of miners in the area is difficult to obtain because miners in the Manica Province tend to be transient and foreign miners including illegal Zimbabwean immigrants avoid identification (DeLorenzo, 2011). Gold mining is also largely seasonal due to the rainy season.

Both placer mining and hard rock mining are practiced in Manica using rudimentary techniques, and amalgamation is the most widely used method to separate gold from gangue concentrated by panning. There are six main mining camps in the Manica Province: Munhena, Tsetsera, Mimosa, Bandire (alluvial), Mpatangwenha, and Clean Tech (DeLorenzo, 2011). The Mozambican government recognizes these camps and permits have been issued allowing for the removal of gold. There are many more "illegal" mines that operate on private property, rivers, or remote, uninhabited land.

The extraction of gold from ore differs very little from one artisanal and small-scale mining site to another in the Manica province. Ore is crushed using a mortar and pestle, and the resulting rock is placed in a ball mill constructed from a discarded metal gas tank containing stainless steel ball bearings of various sizes. Elemental mercury is then added to the ball mill, and a miner manually grinds the rock into a fine powder over the course of an hour. The resulting material is transferred to a pan and loose debris and gangue minerals are separated by panning in open pits or rivers from heavier gold amalgam. In our observations, additional mercury is added at the individual miner's discretion throughout the entire process. After panning is complete, the amalgam is isolated on a fine mesh cloth and excess mercury rung out by hand is collected and reused. Often, the amalgam is then placed on a smoldering log to be "burned". The miner blows on the glowing embers of the log, "burning" the amalgam, evaporating mercury and liberating the gold. While the use of mercury in mining is an illegal activity in Mozambique, its use is ubiquitous (Denniase, 2011).

The burning process represents the largest source of environmental and human exposure to elemental mercury in the mining community. Most miners in Mozambique do not burn in a centralized location downwind of the community, and often burn in their living quarters, in the presence of women and children, and near waterways. Projects initiated in 2005 at the Munhena Mine led to the successful implementation of retorts to recapture volatilized mercury during the burning process (United Nations Industrial Development Organization (UNIDO), 2005), but so far there is no evidence to suggest that other mines in the Manica Province use retort technology effectively to curb mercury contamination. Local mining authorities contribute this to the lack of communication between individual miners; the remoteness and isolation of individual mining camps; the lack of a powerful central mining authority; and a large influx of illegal, first-time miners from Zimbabwe.

Recently, Clean Tech Mine in the Penhalonga district of the Manica Province eliminated the use of mercury in all gold mining processes. Clean Tech Mine owner Chrispen Elias Chibaia invested his own capital to introduce innovative technologies to design and implement safer, more responsible mining practices. This paper describes the implementation of these technologies and the unique business model of Clean Tech Mine, as well as the limitations of these practices for other artisanal and small-scale mines moving towards the reduction or elimination of mercury in the gold mining process. While the Clean Tech model cannot be universally applied to all artisanal and small-scale gold mining operations (specifically those with variable gangue composition or large concentrations of



Fig. 1. Location of Manica province and Clean Tech Mine. Source: adapted from <https://www.cia.gov/library/publications/the-world-factbook/geos/mz.html>.

non-magnetic impurities) it is a valuable example of how local practices can have a major impact on the surrounding communities striving to succeed in the gold mining industry. This investigation also demonstrates a connection and transfer of techniques from industrial gold mining to small-scale artisanal gold mining. Clean Tech Mine offers a safer, more efficient, and environmentally responsible alternative to typical small-scale artisanal gold mining practices.

2. Materials and methods

2.1. Site assessment and personal interviews

Four artisanal and small-scale gold mines in the Manica Province of Mozambique, representing traditional and developing techniques, were surveyed during May and June of 2010 and 2011. Sites were initially chosen to follow up on previous research initiatives in Munhena (United Nations Industrial Development

Organization (UNIDO), 2005). Personal interviews with local mining authorities, Jimmy DeLorenço, President of the Mining Associations of Manica and Sofala Provinces and Olavo Denniase, Director of Mines for the Manica Province suggested other possible sites to investigate (DeLorenco, 2011; Denniase, 2011). Site assessments at the mines at Upper Munhena, Lower Munhena, and Tsetera verified previously reported information regarding traditional artisanal and small-scale gold mining operations in the Manica Province. Data collected about Clean Tech Mine originated from four days of touring the mine and personal interviews with J. DeLorenço, O. Denniase, and Clean Tech Mine owner, Crispin Elias Chibaia (DeLorenco, 2011; Denniase, 2011; Chibaia, 2011).

2.2. Concentration of mercury in air

The concentration of gaseous mercury in air was determined using a Lumex RA-915+ portable mercury vapor analyzer (detection limit: 2 ng m^{-3} , calibrated with an internal Hg vapor source).

The instrument analyzes samples in real time, with a time resolution of 1 s. Air samples were monitored and recorded over 1 min (60 samples), and the sample values averaged to produce an average ambient mercury concentration.

2.3. Concentration of mercury in soil

Surface soil was collected from two different sites where isolation of gold occurs at the mine, and placed in clean brown glass vials. Approximately 0.1 g samples of soil were leached with 5 mL each of high purity HNO₃ and HCl acids (Seastar Chemicals Inc., Sidney, BC, Canada) using a microwave digestion system (Ethos; Milestone Inc., Shelton CT, USA) equipped with a multi-prep rotor (41 pfa vessels). The digestion program consisted of a 30 min ramp to 120 °C, 20 min at 120 °C, followed by a 60 min ramp to 180 °C where the temperature was held for 20 more minutes. The resulting digest was transferred to centrifuge tube and diluted to 50-mL with deionized water (≥ 18.2 M Ω). The digests were allowed to sit overnight to let any particles settle before transferring 10-mL to another 50-mL tube. Then 500 μ L of 0.2 N BrCl was added into each tube and the sample was further diluted to 50-mL with DI water as before. The resulting solutions contained 2% HNO₃, 2% HCl and 0.002 N BrCl. Mercury was determined using a quadrupole-ICPMS (X-Series 2; Thermo Fisher Scientific, Waltham, MA, USA).

3. Non-traditional mining at Clean Tech mine

3.1. Innovative practices and Organizational Structure of Clean Tech mine

Clean Tech Mine operates on an 80-ha, government approved location a few kilometers east of the Zimbabwean border in the Penhalonga district. As of July 2011, there are two timber-reinforced mines in operation, as well as a third mine under construction. The

mine employs approximately 100 miners from the local community, the majority of which are responsible for extracting ore. Although most of the mining techniques used are similar to traditional small-scale methods, Clean Tech has eliminated the use of mercury in all aspects of the mining process in favor of using magnets to manually separate the magnetic gangue materials from the gold.

Approximately 1–2 tonnes of ore is collected daily, in 2–5 kg batches, using an electric hammer in a timber-reinforced, multi-shafted mine. Small samples of ore are first sent to a miner who grinds the ore by hand using a mortar and pestle (Fig. 2A). The powder obtained is panned with water to qualitatively determine gold concentration. This analysis is based on the miner's experience, and information gleaned from this process provides feedback to miners extracting the ore. After testing, areas demonstrating qualitatively low gold yield upon inspection may be abandoned, while high-yield areas provide the miners with a direction from which to obtain additional ore. The ore is transported by wheelbarrow to a jaw crusher located approximately 500 m from the mine (Fig. 2B). The resulting material is transferred continuously to a small ball mill where it is ground with steel ball bearings (Fig. 2C). Although ore is only collected from the mines between the hours of 0600 and 1500 local time, grinding and ball mill operations run continuously. It was determined that stopping the ball mill overnight caused settling of the material in the mill, immobilizing the ball bearings dramatically decreasing the efficiency of the mill. Workers must then manually release the bearings from the settled material, which is dangerous, time intensive and leads to loss of gold. Keeping the ball mill operating continuously improves efficiency and limits expense.

Under standard operating conditions, the ground pulp from the ball mill is processed in a centrifuge manufactured in Zimbabwe, which is a rudimentary copy of the Knudsen Concentrator developed decades ago in California. There is no fluidization in the riffled



Fig. 2. Clean Tech Mining Practices. (A) Manual crushing of ore with mortar and pestle. (B) Grinding rough ore into small fragments. (C) Crushing ore with an industrial ball mill. (D) Centrifuge basin for collecting gold particles.

ribs and there is no exchange process in the concentrate bed. A steel arm scratches the surface of the bed and gold is lost when the riffles are full (Fig. 2D). Approximately 30–33 kg of gravity concentrate is produced from a batch of 15–20 tonnes of processed ore. Mr. Chibaia initially noticed that less gold was recovered from the ball mill than when it was milled manually (Chibaia, 2011). The pulp was too dilute and it was carrying gold and heavier materials (that were supposed to be trapped on the centrifuge) out with the tailings. Angling the pipe slows the flow of water and acts as a secondary trap for gold and heavier materials. Mr. Chibaia estimates that 50% of the gold recovered comes from the connecting pipe (Chibaia, 2011). The gold from the centrifuge concentrate is recovered without mercury. Most likely the gold recovery efficiency is low due to the fact that the centrifuge is rudimentary and the grinding process is in open circuit. Therefore, Mr. Chibaia retains the tailings for future reprocessing using more efficient techniques such as cyanidation.

3.2. Gold separation using magnets

The isolation of the gold occurs once daily. Basins are used to collect the heavy minerals from the ball mill pipes, centrifuge, and centrifuge drain. This material is panned using water pumped from a nearby water source, leaving a mixture of gold, iron minerals and iron shavings (Fig. 3A–B). At this point, artisanal and small-scale gold miners will traditionally add mercury to amalgamate the gold in the pan, squeeze the amalgam, and vaporize the mercury. At Clean Tech magnets are used to remove magnetite and iron shavings. A speaker magnet re-purposed from a discarded radio is passed over the basin, removing iron and other magnetic species (Fig. 3C). This process is repeated several times, and once all visible magnetic material is separated from the gold, 89–93% pure gold remains (Fig. 3D) (Chibaia, 2011). The gold is sold “as is” to government buyers in the city of Manica. Clean Tech’s mining

techniques, including utilizing magnets and summarized in Fig. 4, eliminate the need for elemental mercury in the gold mining process, providing a safer work environment for miners and members of surrounding communities. This is a situation unique to Clean Tech, as the heavy minerals concentrated by gravity separation processes are predominately magnetite and thus magnetically separated easily.

3.3. Sustainability and worker benefits

Clean Tech Mine strives for safer mining practices, and continues to reinvest profits in order to develop a sustainable business. Most of the ground tailings are saved and converted into brick for construction and sale (Fig. 5B). The iron-rich tailings removed during the gold purification process are stored on site for further refinement intended for future use or potential sale. In addition, unlike most of the artisanal and small-scale gold mines in Mozambique all of the shafts in the Clean Tech mine are timber-reinforced. Mr. Chibaia uses local timber (referred to as “gum trees”) for this purpose and has started a tree nursery to replace the lumber used in mine construction (Fig. 5A). The timber farm provides additional income when mining is not as lucrative, and has allowed Mr. Chibaia to hire a small team of local “foresters” to grow and replant trees throughout Clean Tech’s property.

By diversifying operations, Clean Tech ensures its opportunity to make a profit (and remain stable), even when gold production is lower than anticipated. An important aspect of Clean Tech’s business model is that 100% of the profit (after salaries and operation expenses) earned from operations is continually reinvested for technological advancement to seek further efficiency in the mining and purification process (Chibaia, 2011).

The work environment at Clean Tech is one of the most unique aspects of the mine. Every work-day (Monday–Saturday), breakfast and lunch is provided to all miners. Safety is always a priority, and



Fig. 3. Gold separation using magnets. (A) Ore from the connecting pipe and centrifuge is collected and panned. (B) Sediment containing gold and iron. (C) A speaker magnet is used to remove iron and magnetic species. (D) After separation, mostly gold remains.

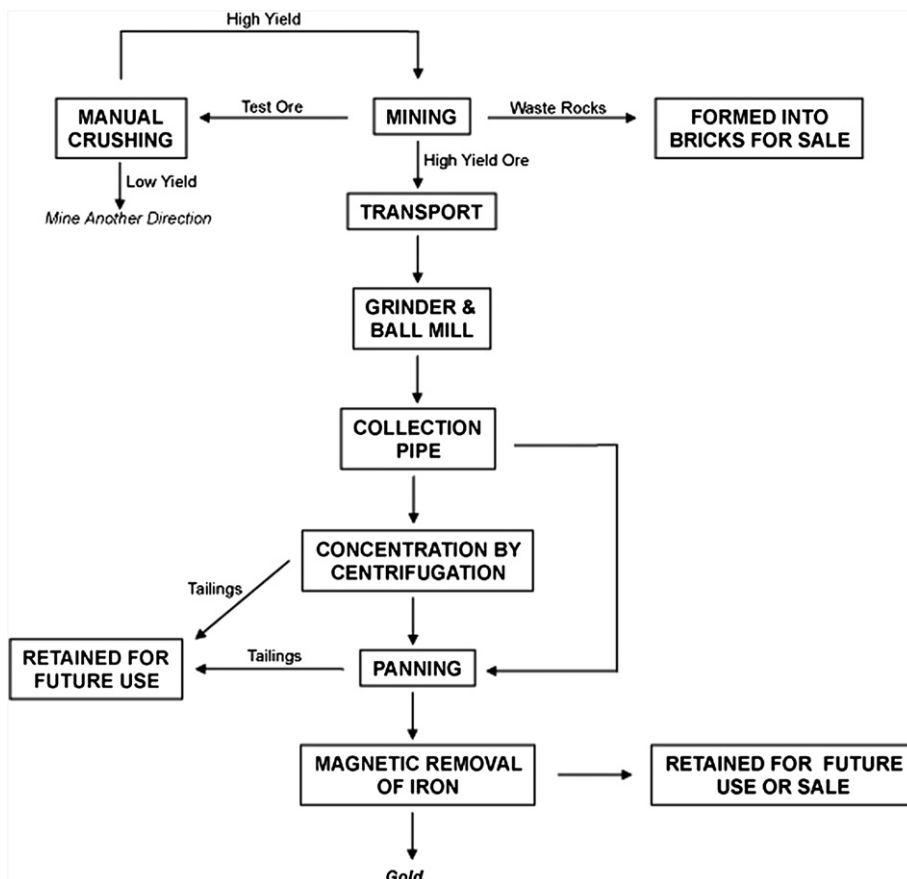


Fig. 4. Flowchart of the mining operations at Clean Tech Mine.

to ensure worker safety Clean Tech provides hard hats, gloves, rubber boots, and coveralls to all employees. The mines from which the ore is extracted are well constructed, likely reducing the chance of workplace accidents and incidents. Timber reinforcements placed every three feet in the mineshafts add the important element of structural integrity that is often missing in other small-scale mines in the surrounding areas.

Workers earn a salary that is not dependent on weekly gold production. The starting salary earned is the government-specified miner's wage. This starts at approximately 2500–3000 Meticais (90–110 USD) per month (Denniase, 2011; Chibaia, 2011). In contrast, many unorganized artisanal and small-scale gold miners in Manica work independently and earn money from the gold they

personally isolate. Clean Tech is one of the few artisanal and small-scale gold mines in Mozambique where miners work on salary, and the consistent income provides a much more stable working environment.

Clean Tech provides many additional worker benefits that are unexpected in artisanal and small-scale mines around the world. The owner ensures that proper education is available to all of his employee's children by providing transportation and some monetary assistance. The company provides health and survivor benefits, should an accident occur at the mine. In addition to providing uniforms (coveralls) and hard hats for all employees, to encourage employee solidarity and promote safe practices, employees are also provided with jerseys, as the company supports employee football



Fig. 5. Sustainable practices. (A) Clean Tech tree nursery. (B) Waste rocks are crushed and converted into bricks.

teams as a safe form of recreation and relieve stress in the workplace. These and other benefits increase worker satisfaction and encourage employee loyalty, and are not found in other artisanal and small-scale mining operations in the Manica Province.

3.4. Reduced mercury concentrations in ambient air and soil

Mercury concentration in air is a major source of mercury pollution in artisanal and small-scale mining camps. In 2005, Veiga and coworkers utilized a Lumex RA-915+ atomic absorption spectrometer to measure mercury concentrations at Munhena mine in the Manica Province of Mozambique (Shandro et al., 2009; United Nations Industrial Development Organization (UNIDO), 2005; Spiegel et al., 2006). Munhena is located approximately 6 km east of Clean Tech, and in 2005 Munhena miners used amalgamation to isolate gold and openly burned their amalgam in the mining camp without the use of retorts. Veiga reported that the average ambient concentration of elemental mercury in the camp was 400 ng Hg/m³ of air (United Nations Industrial Development Organization (UNIDO), 2005). Miners at Munhena who chose to sell gold to the Mozambican government would bring their gold to the Provincial Directorate of Mineral Resources in Manica City, where levels of mercury in the offices would reach 35,000 ng m⁻³, 35 times higher than the World Health Organization's (WHO) guideline for public exposure to mercury (Spiegel and Veiga, 2010). In 1998, Malm reported that mercury concentrations in the air during the burning of amalgam could exceed 60,000,000 ng Hg/m³ of air (Malm, 1998). At Clean Tech, we utilized a Lumex RA-915+ to determine the ambient mercury concentration and found that the average concentration of mercury throughout the property was ~25 ng m⁻³. This level of ambient mercury concentration is well within the safety guidelines recommended by the WHO (Risher, 2003).

Long-term accumulation of mercury in the soil of artisanal and small-scale mining sites is problematic. In 2000, van Straaten measured the concentration of mercury in soil at artisanal and small-scale gold processing sites in Tanzania and Zimbabwe, and reported mercury/soil concentrations of 2.50 mg Hg/kg soil (van Straaten, 2000). In 2006, Feng and coworkers reported Hg concentrations in soils near gold processing areas in the Shaanxi province ranging from 0.9 to 76 mg Hg/kg of soil (Feng et al., 2006). At Clean Tech, two soil samples were taken from separate gold processing areas with mercury concentrations of only 0.02 and 0.49 mg Hg/kg soil, 150 fold less than was reported in the Shaanxi Province and five fold less than reported in Tanzania (van Straaten, 2000; Feng et al., 2006). Preliminary soil and air samples indicate that mercury levels at Clean Tech are much lower than sites that actively use mercury. The difference between mercury concentration in soil and air, human exposure to mercury, and the effects of mercury on human health due to artisanal and small-scale gold mining activities indicates that miners at Clean Tech Mine operate in a much safer environment than those at more traditional artisanal and small-scale mining camps.

3.5. Eliminating mercury at Clean Tech mine

The benefits of eliminating mercury from the artisanal and small-scale gold mining process are clearly evident, and the complete absence of mercury use in the gold mining practices sets Clean Tech apart from other mines in the area. Mr. Chibaia, commented that not only is mercury harmful to his employees and the surrounding environment, but it is also relatively expensive and would cut down on profits reinvested in his mine (Chibaia, 2011). This technology is known to be an effective and efficient method for processing gold, when the ore is of appropriate composition

(Hylander et al., 2007). Clean Tech has adopted and innovated this method to fit the specific resources of their community, which is an important strategy for any mining community looking to adapt new technologies to their specific circumstances.

Several factors unique to this mine led to the success of eliminating mercury. First, the ore mined in this area contains high concentrations of gangue material that can be removed with magnets. This process results in an efficient and cost effective way to obtain gold that may not be applicable to other areas. Second, this mine is a highly organized privately owned mine. Most mines in the area are very loosely organized making the successful implementation of new and safer technologies more difficult due to a lack of resources. Lastly, this mine is owned and operated by a local, former artisanal gold miner. He has a unique understanding and commitment to the surrounding community that allows for integration and sustainability of these technologies that would be less successful from an outside initiative.

4. Conclusions

Artisanal and small-scale gold mining is a growing industry in the developing world. It provides an opportunity for individuals in impoverished areas with high unemployment to earn a living without the need of advanced education or upfront capital. However, the vast majority of artisanal and small-scale miners work in unsafe conditions. Currently, the easiest and most cost effective way of isolating gold from ore is through amalgamation, leading to long-term detrimental environmental and health impacts. However, the global supply of mercury will become more expensive and difficult to acquire now that the European trade ban on mercury is in effect and the United States Mercury Export Ban Act of 2008 goes into effect in 2013 (United States Congress, 2008). While the impact of these regulations on artisanal and small-scale gold miners is not fully realized, Clean Tech is at a strategic advantage to continue gold mining with little effect from these policies. Gold miners that rely on the use of mercury for processing must gain additional resources or technologies to continue mining.

Clean Tech Mine has initiated a safe alternative to traditional artisanal and small-scale gold mining techniques. At the heart of the company's success is its innovative mining practices that use magnets to isolate gold while eliminating the use of elemental mercury, and developing a sustainable and safe working environment for its employees. Clean Tech is owned and operated by a native Mozambican, who after working as an artisanal gold miner in the Manica Province for several decades has a unique understanding of the impact that the gold mining industry plays in the local community (Chibaia, 2011). This will lead to profound positive impacts on the health of employees, as well as the surrounding environment.

Clean Tech Mine demonstrates that innovative and inexpensive techniques for gold mining without mercury and provides a viable source for economic growth without compromising worker safety. Most importantly, the technology utilized at Clean Tech is readily available in areas around the world where artisanal and small-scale gold mining with mercury is an important source of employment and the geology of the ore supports magnetic isolation of gold. In the appropriate situations, this technology could allow for an economically viable reduction in mercury use for artisanal and small-scale gold miners.

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