Sustainable Reuse of Mining Lands: Strategies and Implementation

Recently completed reports highlight options for the cost effective remediation of former gold mining sites for mercury and other metals for the sustainable reuse of the sites, including for renewable energy generation. This work was sponsored by the UK Foreign and Commonwealth Office in partnership with the Ministries of Environment and Mining in Colombia. r3 Environmental Technology (UK and Colombia) and partners released the reports in March 2017. The project was titled: **Strategies for rehabilitating mercury- contaminated mining lands for renewable energy and other self-sustaining re-use strategies.** Reports are available in both English and Spanish.

Project Summary

Three aspects of site rehabilitation and reuse formed the focus of the reports: (1) application of gentle (low input) approaches to risk management, particularly the use of an innovative technical solution (i.e. specialised biochars) for the immobilisation of mercury at two sites, (2) strategies for re-use, including development of a guidance document to identify opportunities for sustainable re-use of brownfields for a wide range of non-built functions, and (3) a preliminary assessment of the (photovoltaic) energy potential at three brownfield areas. Key findings are as follows:

1. *Mercury remediation*

- Widespread international consensus exists on the hazardous exposure values (and appropriate safe levels) for mercury and other metals in soils and other media.

- Low cost, plant-based agronomic techniques already used in many other countries can be adapted to reduce risks from mercury and other metal contaminated sites in Colombia

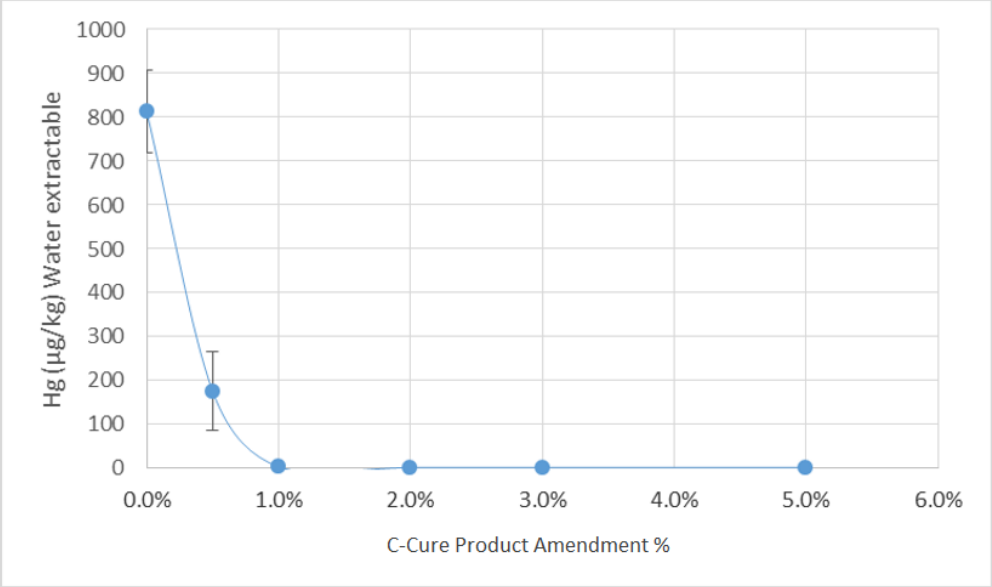
- Gentle Remediation Options, or GROs, are effective risk management methods involving either:
    - The use of plant, fungi, and/or bacteria-based methods,
    - Soil amendments which can change contaminant speciation, leachability or bioavailability
    - The combination of plant, fungi, and/or bacteria-based methods with soil amendments.
- GROs can have significantly lower deployment costs versus conventional remediation technologies, and can also contribute strongly to sustainable remediation strategies.

- In most contaminated soils and mine tailings, mercury does not accumulate in the above-ground biomass, but it may volatilise through the plants leading to mercury emissions to the atmosphere. Therefore, the most effective plant-based approach to mercury remediation or management is through stabilising mercury in the soil with soil

amendments and then establishing a vegetative cap of green cover or biomass, rather than attempting to phyto-extract the metal.

- For example, soil or spoil amendments with biochar may be used in this approach to immobilise heavy metals (including mercury) and simultaneously act as soil conditioners, to reduce soil toxicity and enhance plant establishment and growth.

- Lab scale testing of soil samples from Colombia containing mercury (and other metals) treated with proprietary biochar products has shown considerable promise in reducing risks and restoring soil quality. The project has proposed a series of field based trials to test proof of concept.



2. *Guidance and Strategies for Re-use of Land*

- An *Opportunity Guidance* based on the "Brownfield Opportunity Matrix" (BOM) developed under the sponsorship of the European Union was adapted for brownfields sites in Colombia (in English and Spanish). It "maps" possible interventions to possible services that might be delivered from the land along with illustrating potential linkages with case studies. It shows the wider synergies, benefits, services and sustainability/value gains that might accrue from a judicious selection of interventions (for example, by choices of approaches to remediation and renewables).

- *Technical parameters for gentle (low input) remediation and renewables production on brownfield sites*. Accepting the model of risk management (i.e. the process of assessing risks and deciding whether it needs to be mitigated), the crux of a combined remediation and renewables approach is that the project manages the risks causing concern, and also generates renewables, but in a way that does not create any additional risks.

- *Low input "gentle remediation" options* for mercury and other metals are introduced and described based on the results of international research and best practices. These strategies/ technologies result in a net gain (or at least no gross reduction) in soil function as well as achieving risk management.

- *Techniques that can generate renewable energy* on brownfields are outlined, including biomass production, photovoltaics, wind, and potentially geothermal / geological sources. Compared to conventional energy sectors, studies have revealed great potential for job creation in the green and renewable energy sector. Applied in the context of brownfield regeneration, renewable energy supply is a potential source of revenue for ongoing site management.

3. *Renewable Energy Generation*

- Using U.S. renewable energy decision tools, the potential of deploying solar energy at three pilot sites was assessed including such factors such as the solar resource, infrastructure, and owner interest and site readiness.

- Additional high level assessments by Kyocera Solar outlined the potential for deploying solar energy at the two most promising sites.

- Recommendations for bringing renewable energy projects to fruition include (1) engaging stakeholders early (i.e., World Café), (2) demonstrating social benefits to the community (i.e. using a Brownfields Opportunity Matrix), and (3) developing formal public/private partnerships for financing, construction and management.

- Development of a public/private partnership that includes a global renewable energy company, a Colombian university and SME enterprises based in Colombia holds considerable promise for bringing a renewables project to fruition in the near future.

A detailed fact sheet outlining the contents of three public reports from the project is attached.

Copies of the reports in English and Spanish are available on the r3 Environmental Colombia web site at: http://www.r3environmental.com.co/en/projects.html

Fact Sheet

Strategies for rehabilitating mercury- contaminated mining lands for renewable energy and other self-sustaining re-use strategies.

The following is a brief discussion of the three technical reports available on the project:

1. **An onsite field testing plan for techniques that promise to be replicable to other similarly contaminated sites, based on technology evaluations and bench scale test work. (Download at: http://www.r3environmental.com.co/en/projects/76-estrategias-parastrategies-for-rehabilitating-mercury-contaminated-mining-lands-in-colombia-for-renewable-energy-and-other-sustainable-re-use.html)**

Colombia is endowed with abundant minerals, metals and fossil fuels. Increasing extraction of natural resources such as gold is driving economic growth, while at the same time causing pollution of soil and water, degradation of sensitive ecosystems, and increased risks to human health. Since 2000, the area covered by mining titles rose from 1 million ha to 8.5 million ha (about 8% of the land area). Artisanal mining accounts for 70% of the gold mined in Colombia, and provides a livelihood for about 200 000 poor people. (OECD, 2014). A recent study conducted by the Ministry for Environment and Sustainable Development found nearly 1843 locations potentially considered brownfields or contaminated sites for all economic sectors.

This document focuses specifically on the approaches and feasibility to rehabilitate land affected by soil mercury pollution as well as a field implementation plan in order to bring this land back into productive use. This onsite field testing plan, which suggests techniques potentially

replicable at other similarly contaminated sites, is based on the outcomes of a desk study and bench scale testing of soil samples from the two sites selected in the project.

Initially, this document provides an overview of low input “gentle remediation" options for mercury and other metals based on the results of international research and best practices. Gentle Remediation Options, or GROs, are defined as risk management strategies/technologies that result in a net gain (or at least no gross reduction) in soil function as well as achieving risk management. GROs encompass many technologies, including the use of plant (phyto), fungi (myco-), and/or bacteria-based methods, with or without chemical additives or soil amendments. They can be applied to reduce contaminant transfer to local receptors by in-situ stabilization, or extraction, transformation, or degradation of contaminants.

As the treated soils remain unsealed, GROs are highly applicable to soft-end use for a site, e.g. for urban or community park-land, renewables deployment, biomass generation etc. Depending on the specific site situation GROs can have significantly lower deployment costs than conventional remediation technologies and contribute to sustainable remediation strategies.

A special focus of this project was evaluating biochars as a soil amendment—given their special potential for mercury treatment. Biochars and activated carbons show good potential for Hg adsorption and stabilization. Proprietary biochar products, licenced to project partner C-Cure Solutions, are designed to immobilise heavy metal pollutants by adsorbing them. Once adsorbed onto C-Cure products, pollutants are no longer leachable and don’t interfere with biological processes (detoxification). Depending on the soil conditions, adsorption of most heavy metals onto the C-Cure products is irreversible and stable. Furthermore, detoxification of soil leads to restoration of normal soil function and allows revegetation to take place.

On-site samples taken in Colombia were assessed for total metal concentrations and leachable metal concentrations using standard procedures. Subsequently, samples that contained the highest concentrations of mercury were extracted using a sequential extraction procedure to determine if the mercury was (a) water soluble, (b) stomach acid soluble (c) bound to organic matter, (d) in an elementary form or (e) present as mercury sulphide. Each of these extractions can be related to significant exposure routes of mercury.

One (of 8) soil sample having both the highest total Hg concentration and highest leachable Hg concentration was used to test treatment with the C-Cure-CCA treatment product. Using an amendment rate of 5% (wet weight) resulted in all of the water soluble and human stomach acid soluble mercury being stabilised in the soil. For eight additional metals, amendment rates of the C-Cure product ranging from 2.3% to 8.4% were successful in reducing concentrations to values classified as inert according to international criteria.

This report concludes with a proposed 18-month plan for onsite field testing of remediation of metal contaminated sites to validate the technologies, understand cost, and consider implementation, business development, and other scale up issues. Preliminary results suggest

that the C-Cure remediation technique is very effective at reducing leachable and bioavailable heavy metals and mercury in contaminated mine wastes. Further work would be required to test and demonstrate the technique at a commercially relevant scale.

Providing stable risk mitigation will facilitate re-use of the affected land, and renewable energy production could be a major re-use opportunity, for example, in conjunction with local supply and community enterprise projects. A series of initial renewable energy feasibility studies carried out have confirmed the potential for approaches such as solar (photovoltaic) energy (See below.)

2. **Guidance and Strategies for Re-use of Land by Transferring State of the Art Knowledge (Download at: http://www.r3environmental.com.co/en/projects/76-estrategias-parastrategies-for-rehabilitating-mercury-contaminated-mining-lands-in-colombia-for-renewable-energy-and-other-sustainable-re-use.html)**

This guidance document provides an overview of the information needed to: (1) assess opportunities for the joint deployment of gentler remediation and renewables production on sites in Colombia, (2) understand the technical parameters of the approaches available, and (3) perform assessments of overall sustainability and link this to cost benefit analysis (CBA).

Opportunities Guidance

This is a simple *MS Exce*l tool to help stakeholders identify wider potential sustainability/value gains from brownfields restoration. The Opportunity Guidance is based on the "Brownfield Opportunity Matrix" (BOM) developed under the sponsorship of the European Union. It works by mapping possible interventions to possible services that might be delivered along with illustrating potential linkages with case studies. It shows the wider synergies, benefits, services and sustainability/value gains that might accrue from a judicious selection of interventions (for example, by choices of approaches to remediation and renewables). The spreadsheet is

supported by a package of stakeholder engagement guidance. All of these materials, customised for use in Colombia, can be downloaded (at no cost) from: <http://www.r3environmental.com.co/en/projects/76-estrategias-parastrategies-for-rehabilitating-mercury-contaminated-mining-lands-in-colombia-for-renewable-energy-and-other-sustainable-re-use.html>.

Technical parameters for gentle (low input) remediation and renewables production on brownfield sites

The accepted international norm for determining how to remediate a site is risk based decision making. Risk management is the process of assessing risks and deciding what needs to be done about them; that is, whether the risk is significant and, if so, whether it needs to be mitigated by some form of remedial intervention. The crux of a combined remediation and renewables approach is that the project manages the risks causing concern, and also generates renewables, but in a way that does not create any additional risks. Indeed, in some cases the remediation process may also be the renewables production process (which is the case for biomass based approaches). More generally, a risk management approach may integrate interventions at different levels. For example, partial contaminant source removal (for pathway management to deal with residual contamination) may be combined with additional protection via a planning control (e.g. restrictions on use of water from particular boreholes).

Recently, building on earlier ideas about low input approaches, the concept of Gentle Remediation Options (GRO) has emerged. *GRO are risk management strategies/technologies that result in a net gain (or at least no gross reduction) in soil function as well as risk management.* This emphasis on maintenance and improvement of soil function means that they have particular usefulness for maintaining biologically productive soils; this is especially important where a "soft" end use for a site (such as urban parkland, biomass/biofuels production etc.) is being considered.

A range of techniques that allow generating renewable energy can potentially be deployed on brownfields, including biomass production, photovoltaics, wind, and potentially geothermal / geological sources. Compared to conventional energy sectors, studies have revealed great potential for job creation in the green and renewable energy sector. Applied in the context of brownfield regeneration, renewable energy supply is a potential source of revenue for ongoing site management. It also avoids the use of greenfield (or agriculturally productive) sites for renewables production, thus reducing potential land-use conflicts.

Sustainability Assessment and Valuation

Internationally interest has been growing in integrating sustainability as a decision-making criterion for remediation projects i.e. to select an approach that achieves a balanced net benefit when considering wider environmental, economic and social impacts. Sustainable remediation has become an area of intense development across the world, with public and private sector

organisations involved in a number of projects and networks intended to improve remediation practice and make it more sustainable, including in the UK and Colombia. Using a site conceptual model of sustainability as a common thread through the different tiers of sustainability assessment leading towards a quantitative valuation in financial terms can be very helpful. The use of cost benefit analysis (CBA) can be highly controversial for a number of reasons. However, CBA underpins both policy decision making in many cases and, of course, investment decisions, for public as well as private funds. Subsequent valuation (CBA) based upon the same shared sustainability model and showing how specific valuation techniques have "best fit" to different aspects of this shared model (in a transparent way) enables CBA that is robust and consistent with sustainability assessment.

3. A high-level review of three sites in Colombia for potential re-use for renewable energy: a report abstract (Download at: http://www.r3environmental.com.co/en/projects/76-estrategias-parastrategies-for-rehabilitating-mercury-contaminated-mining-lands-in-colombia-for-renewable-energy-and-other-sustainable-re-use.html)

The purpose of this document is to showcase the kind of analysis that can be conducted to determine the preliminary feasibility of siting renewable energy production on contaminated mining sites as well as on other brownfields with high solar energy input. Thus, this document provides decision makers in countries facing the reality of remediating and seeking to sustainably reuse brownfields (including mining sites) more insight into how such sites may be evaluated for their potential for renewable energy production. It is a portion of a longer report made available only to the client.

This project adapted UK, EU and US EPA thinking and tools on brownfields rehabilitation for renewable energy and other soft re-uses for gold mining areas impacted by mercury contamination. In particular, this report abstract demonstrates a tool developed by US EPA , *"RE-Powering's Electronic Decision Tree",* to help determine the feasibility of a site to develop a renewable energy project, taking into account its use in contaminated or degraded sites.

Linking the safe re-use of mining brownfields (following application of low input "gentle" remediation techniques) with the generation of renewables presents a "virtuous" opportunity for land (re)use for several reasons.

- A variety of local energy market arrangements are possible: The approach is scalable--workable from community based projects to large projects with major mining companies.
- The income from renewables can help offset the cost of making the land safe, for example, from mobile mercury species.
- The use of this degraded land is a more sustainable approach to providing renewables than converting habitat or agricultural land over to renewables production.

- Colombia gets a lot of energy for free from the sun compared with many other countries in the developed world (e.g. the UK).

On the other hand, some limitations and barriers were identified which need to be taken into account when starting a project under the proposed strategy. Some of them are: limited renewable energy incentives with continuing subsidies, market barriers, rules designed for conventional sources, lack of human capital with knowledge of relevant technologies, and regulatory and institutional factors conceived for conventional energy production.

This report provides the results of testing the decision tree at two mining sites in Colombia, Segovia and Tadó, so as to show the feasibility of using the sites for the installation of photovoltaic cells. For purposes of comparison and illustration, an additional site contaminated by pesticides, which has a higher level of solar radiation, was selected on the northern coast of Colombia. This site is in Cartagena City. The three sites provide several different levels of possible energy production ranging from on-site use of power by the site owner to the sale of power to off-site buyers or a utility.