Green Mines - Green Energy:
Generating Green Energy on Tailings

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Have you ever considered the possibility of remediating tailings impoundment areas with organic wastes to yield agricultural lands for energy crops and biofuel production? A pilot program for this exciting new research area is underway on Ontario mine sites, and further field trials are anticipated at other mine sites across Canada in the near future.

CANMET Mining and Mineral Sciences Laboratories (CANMET-MMSL) of Natural Resources Canada has established a consortium of parties interested in participating in the research. Members currently include Vale Inco, Xstrata Nickel, Goldcorp Canada Ltd. (Porcupine Gold Mines), Highland Valley Copper, BHP Billiton, Barrick Gold, Cape Breton Development Corporation, St. Marys Paper, Domtar, Abitibi Consolidated, Agriculture and Agri-Food Canada, Ontario Ministry of Agriculture, Food and Rural Affairs, Alberta Research Council, GSI Environment, Gro-Bark, Sylvis, Laurentian University (MIRARCO), the City of Greater Sudbury and Natural Resources Canada.

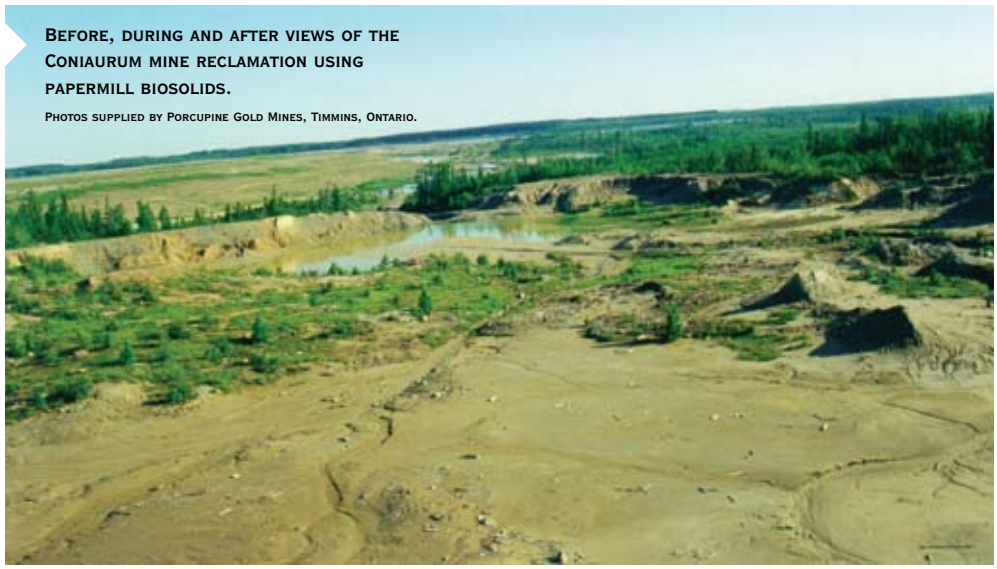
Currently, the major project thrust involves covering tailing impoundment areas with organic waste materials from industrial and other sources, then planting energy crops such as canola, soy and corn. These crops can then be harvested to provide feedstock for the production of biofuels such as biodiesel and ethanol, or for other forms of bioenergy. It is also anticipated that the program will eventually branch out in other directions, such as the incorporation of organic materials into tailings as amendments (rather than a cover), and the use of woody species such as poplar, willow or alder. The initiative may also attempt to further develop applications such as the establishment of wetland areas at aquatic interfaces, intermediate barriers for flooded tailings and passive treatment systems. The underlying goal is to demonstrate and document a range of ways in which these organic materials can be successfully utilized to establish more productive land on mine sites.

The anticipated benefits are numerous and, where applicable, could represent a major contribution from the mining industry toward local biofuel production, sustainable development and greenhouse gas reductions. Further, the organic materials are consolidated into one industrial "landfill" (the tailings), thereby removing the burden of on-site storage and management, or disposal in municipal landfills – by the waste generators. For mining companies, there is potential to eventually generate a modest cash flow from the reclaimed tailings and gain carbon credits. The initiative also provides great public relations — demonstrating a commitment to environmental sustainability and good corporate citizenship.

While initiated in Ontario, the principal goal of the consortium is to develop similar, cooperative research projects elsewhere in Canada, and to disseminate the findings wherever these technologies may be applicable. Discussions are underway for additional field trials in Sydney, Nova Scotia and in British Columbia.

Covering tailings with organic materials for the purposes of general reclamation and the limiting oxygen ingress to the tailings is certainly not a new concept. However, the intention of the current Green Mines – Green Energy (GMGE) research is to take these efforts two steps beyond these typical purposes – to the establishment of a commercial crop production operation on the tailings (productive land use) and a contribution towards the production of "green fuel".

While tailings impoundment areas



Before, during and after views of the Coniaurum mine reclamation using papermill biosolids.
Photos supplied by Porcupine Gold Mines, Timmins, Ontario.

have previously been considered as potential sites for growing crops for human or animal consumption, concern over metal or other contaminant uptake by the crops has generally prevented this from being developed. This concern largely becomes negligible when the crops are harvested for fuel production.

There is an increasing body of evidence that substantiates the technical and economic viability of using waste organic materials to reclaim mine tailings. For example, in northern Ontario, the successful rehabilitation of the Pronto Mine near Elliot Lake using papermill biosolids (Tisch & Beckett, 1999; Okonski, 2002) was a proving ground for government regulators in Ontario, and opened the door to additional applications in Sudbury (Vale Inco) and in Timmins (Porcupine Gold Mines). Biosolids have also been utilized at mine sites in other provinces, including Quebec, Alberta and extensively in British Columbia. However, the large-scale use of biosolids (papermill and other) has been primarily aimed at general reclamation - to control dust and erosion and to improve site aesthetics.

On the supply side, there is also growing pressure on municipalities and industry to divert clean organic materials from municipal landfills. For example, major centres such as Toronto are capable of producing significant quantities of compost derived from household wastes (e.g. table scraps). However, concern remains regarding the quality of the compost produced, as well as potential markets for long-term utilization of the compost. The rehabilitation of mine tailings offers significant opportunity for long-term management (and beneficial use) of papermill biosolids, composted municipal waste and possibly other wood wastes. In addition, provincial regulators are increasingly being asked to approve reclamation plans for mining and other brownfield projects involving the use of various wood wastes, with little scientific data available regarding potential impacts.

There is a knowledge gap, particularly in the long term, of the impact of thick cover layers of organic material – which are generally required to grow energy crops - on the chemistry, mineralogy, hydrology and overall stability of the tailings. The generation of anaerobic conditions combined with the release of a variety of organic acids may increase the dissolution of As, S, Fe and other metals associated with Fe oxides. For example, Pierce et al. (1995) found that municipal compost used as a cover over acid generating tailings produced an iron sulphide precipitate at the compost/tailings interface, but found that reductive dissolution of secondary tailings oxidation products was still occurring at the 290 day point (completion) of the study. The authors suggested that this was simply a transitory phase, but recommended that further testing be undertaken to determine if the anaerobic conditions eventually lead to the immobilization of iron, sulphur and trace metals. Thus, there is clearly a need for further detailed, long-term studies of cover/tailings interactions examining a variety of tailings types and disposal scenarios, in addition to examining the feasibility and economics of growing "energy crops" on mine tailings.

Through cash and/or in-kind funding from Vale Inco, Porcupine Gold Mines, Xstrata Nickel, City of Greater Sudbury, Green municipal Fund, MIRARCO and CANMET-MMSL, four half-hectare (50m x 100m x 1m deep) field plots are currently being constructed in Ontario. Construction during the winter months is optimal, as access to the tailings by heavy equipment is easier when they are frozen. The field plots will be located at Vale Inco's Copper Cliff tailings near Sudbury (2 plots), Porcupine Gold Mine's Delnite tailings in Timmins, and Xstrata Nickel's Strathcona tailings in Onaping. Municipal compost and three different sources of papermill biosolids will be utilized. Monitoring will include surface and groundwater quality, biomass production and metal content in both the cover material and the crop. Smaller plots on local agricultural land will also be established in order to compare crop yield on local agricultural land to that obtained on the tailings.

In addition, with financial contributions from Vale Inco and Porcupine Gold Mines, CANMET-MMSL has been conducting laboratory research to assess the effect of organic carbon from both papermill biosolids and municipal compost on tailings effluent quality (column leach study), treatability (via lime neutralization) and toxicity. To date, treatability and toxicity were only evaluated using organic carbon derived from papermill biosolids.

Column Leaching Study

In November 2006, CANMET-MMSL initiated a comparative laboratory column leaching study to compare leachate quality from uncovered tailings to tailings covered with either a 20 cm or 100 cm depth of papermill biosolids. For the Vale Inco (acidic copper/nickel) tailings, papermill biosolids from both St. Marys Paper (Sault Ste. Marie) and Domtar Ltd. (Espanola) were utilized, while for Porcupine Gold Mines (alkaline gold) tailings, papermill biosolids from Abitibi Consolidated Inc. (New Liskeard) were used. The experimental design, carried out in duplicate, is indicated below and is designed only to assess the net effect – from the bottom of the columns only – representing the tailings groundwater at a tailings depth of one metre.

- tailings control (75 cm oxidized and 25 cm unweathered tailings);
- tailings control plus 20 cm biosolids;
- tailings control plus 100 cm of biosolids;
- biosolids control (100 cm); and
- tailings control plus 20 cm of biosolids mixed with oxidized tailings (for Goldcorp only).

The columns were constructed from 25 cm (10") diameter clear lexan tubing. A simulated water table was established near the oxidized/unweathered tailings interface and for the first 12 months, the columns were sampled on a monthly basis. Sampling has recently been cut back to quarterly for the Vale Inco columns and bi-monthly for the Porcupine Gold Mines columns. Samples are analyzed for pH, Eh, conductivity, dissolved metals, sulphate, alkalinity, acidity, dissolved organic carbon (DOC), nitrate and ammonium. Only the results for the Vale Inco tailings are briefly highlighted in this article.

CANMET-MMSL added an additional ten columns as part of an internal project. Six of these columns utilize Vale Inco tailings covered with municipal compost - with the same configurations as the existing columns that utilize papermill biosolids. The remaining four columns repeat the one-metre covers of St. Marys and Domtar biosolids over Vale Inco tailings, but with the tailings limed prior to placement of the covers.

General observations to date include an extensive blackening of the biosolids/tailings interface with the application of 100 cm of papermill biosolids. This is indicative of sulphate reduction.

Similar results (blackening) were observed by Pierce et al. (1995), with the black precipitate identified as an iron sulphide. There are two main mechanisms occurring within the tailings as reducing conditions develop below the organic

Close-up of evidence of sulphate reduction in leaching columns at CANMET-MMSL. Inset: Overview of leaching columns at CANMET-MMSL.

covers. The first is reductive dissolution of secondary mineralization (oxidation products) contained largely within the oxidized tailings, and the second is sulphate reduction, which converts mobile iron and metals to stable sulphide forms. It is expected that over time, metal and sulphate levels from columns containing organic covers, especially one metre thick, will decline. To date, and despite the clear indication of sulphate reduction occurring, there has been little difference observed between the covered and control (tailings only) columns. Given the large volume and depth of tailings in the columns, it is expected that it will take considerable time for existing oxidation products to be flushed out of the oxidized and unweathered tailings, so that treatment effects can be observed.

It is expected that these columns will remain operational for a minimum of three years, in order to observe longer-term interaction with the tailings at depth. Most previous studies of similar intent have terminated the columns within a period of one year, and have focused only on a narrow depth of tailings immediately below the organic cover. Upon completion, the columns will be destructively sampled and will include detailed mineralogical analysis of the tailings profiles.

Effluent Treatability

Batch neutralization tests were utilized to simulate the conventional lime/air treatment system used by Vale Inco at Copper Cliff, Ontario. To simulate treatment of raw water containing various concentrations of papermill biosolids leachate, samples of St. Marys and Domtar papermill sludge were leached with distilled water to produce leachate of a known (measured) total organic carbon (TOC) concentration. The undiluted St. Marys and Domtar leachate contained 209.3 mg/L and 37.3 mg/L TOC, respectively. This full strength leachate was mixed with pH-adjusted Copper Cliff raw water to give various final TOC concentrations ranging from 0 – 42 ppm. The samples with varying concentrations of TOC were then subjected to lime treatment, in duplicate, simulating conditions at the Copper

Typical set-up for effluent treatability tests.

Solids (sludge) separated in treated water.

Corn and canola growing in papermill biosolids under laboratory conditions.

Cliff wastewater treatment plant.

All neutralization tests utilized hydrated lime to achieve a final pH of approximately 10.5. Once the target pH was obtained, the test was allowed to continue for 15 minutes. Aeration was applied in all tests. To evaluate the effect (if any) of flocculant addition in the presence of additional TOC from the papermill sludge, some tests used flocculant to aid settling. Most tests were conducted with one litre aliquots. However, some tests were conducted with eight litres of raw water so that the final effluent could be used for toxicity testing (described below).

Samples of the raw water, as well as filtered and unfiltered effluent samples, were submitted for a complete chemical analysis. In addition, pH, redox, conductivity, and temperature and lime consumption were monitored during treatment. The sludge generated was evaluated for settleability, solids content and production. Toxicity Characteristic Leaching Procedure (TCLP) testing was completed on the sludge to evaluate metal leachability.

Results have indicated that, at the levels tested, organic carbon had no significant impact on effluent treatability. While elevated concentrations of salt ions (Na, K, Mg, SO_4) in the final effluent were observed, in fact, many other treatment parameters showed improvement in the presence of the carbon-rich leachate.

Effluent Toxicity

The objective of the ecotoxicity component was to provide an assessment of the potential impacts of a papermill biosolids cover on final effluent toxicity, specifically on acute lethality requirements, effluent quality as monitored by sublethal toxicity and chronic toxicity of copper. Toxicity

threshold values were first derived for the aquatic species used under the Metal Mining Effluent Regulations (MMER). The effects of biosolid leachate at concentrations below the toxicity threshold on treated effluent toxicity to *C. dubia* and *L. minor* were then studied. Finally, the effect of biosolid-derived DOC on chronic toxicity of copper to *C. dubia* and copper speciation were determined.

Testing was carried out on samples derived directly from the papermill biosolids without mixing with mine water, and on samples generated from the effluent treatment tests described above.

No acute toxicity was observed in leachate derived directly from the biosolids. Biosolids-derived DOC in the mine effluent exhibited a similar copper complexation capacity to natural organic carbon. However, while relative differences were observed between the two papermill biosolids, overall, the toxicity data suggested that leachates generated by the papermill biosolids will have no significant negative or beneficial impacts on the final mine effluent quality at the DOC concentrations tested.

Growth Studies

A growth trial was completed in order to determine if there may be significant challenges to establishing corn and canola in the St.Marys and Domtar biosolids. The experiment was designed to test growth in pots with 100 cm of biosolids alone (control) and in pots with either 20 cm or 100 cm of biosolids overlying 20 cm of oxidized Vale Inco tailings. The corn seed was particularly interesting, in that it was an early-maturing semi-dwarf cultivar cereal corn provided by Agriculture Canada. It can be sown and harvested using small grain equipment and only requires approximately 2000-2200 crop heat units (CHU) to develop, which makes it suitable for more northern locations such as Sudbury. It flowers in approximately 60 days, and is significantly earlier in flowering and grain maturity than all hybrids being recommended for field corn. In addition, it possesses some cold and drought tolerance.

Overall, the above ground growth of corn and canola was quite good in the biosolids, and was generally found to be slightly better when grown in pots where tailings were present below the biosolids. Root growth was poorer than expected, and is likely a reflection of inadequate fertilization.

The steering committee for the GMGE initiative is currently developing a structured workplan to better develop project goals and priorities, and is seeking additional participants, field sites and funding opportunities for further research. If you are interested in receiving further information on the Green Mines - Green Energy project please contact Bryan Tisch, Project Manager, Natural Resources Canada, btisch@nrcan.gc.ca, 613-943-8746.

Literature Cited

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