Cost Benefit Analysis of Genomics for Mining

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Or...

An Evaluation of Potential Genomic Applications in the Mining Industry
Presentation Overview

1. Genomics as a tool
2. Evaluation Approach
3. Background on Scenarios and Outcomes
4. Concluding remarks
1. Genomics as a Tool

- Genomics definition: a science that aims to decipher and understand the entirety of the genetic information encoded in an organism’s DNA and corresponding complements such as RNA, proteins, and metabolites.
1. Genomics as a Tool

- Interpreted: a tool to help better understand how biology functions
  - Identification
  - Response to change
  - Optimization
  - Etc.

- Genomics definition: a science that aims to decipher and understand the entirety of the genetic information encoded in an organism’s DNA and corresponding complements such as RNA, proteins, and metabolites.
1. Genomics as a Tool

- Why do we need another biological tool?
  - Only 1% of microorganisms can be cultured, so we’re missing 99% of the picture
  - For macro-biology, dependent on samplers schedule and experience – so species not conveniently present or mis-identification
  - Unravelling what biology can do and what impacts it
1. Genomics as a Tool

- What do you need to know?

- Many of us use ICP – but how much do we know about plasma and electron orbitals?

- Partnerships are the way forward…but then that’s why many of us are here
2. Evaluation Approach

• SRK study evaluated the potential economic benefits of biological optimization using genomics for three scenarios:
  o Bio-oxidation (ore processing)
  o Passive Water Treatment
  o Closure and Reclamation
  o *None involve genetic modification* ….

• Not a priority ranking and a suite of other opportunities identified from exploration geochemistry to baseline studies – and not just microorganisms…
3. Scenarios – Background and Outcomes

- **Bio-oxidation or Bio-leaching**
  - A process that uses bacteria to oxidize refractory sulphide ore
  - Bacteria are **catalysts** – transfer electrons from sulphide to \( \text{CO}_2 \) to make organic carbon
  - Acidic, aerated, and moderate temperature (40°C)
  - Can be in stirred tanks or heap-leach
  - Gold is most common, although any deposit that requires oxidation has potential
  - ‘Competition’ is pressure oxidation – higher throughput, higher recovery, but more expensive
3. Scenario: Bio-Oxidation

- Timely…
  - CIM article October 2014 – “Keep the gold bugs happy”
3. Scenario: Bio-Oxidation
3. Scenario: Bio-Oxidation

- **Evaluation Inputs**
  - Re-processing of tailings deposit – full details in paper
  - Economic model used to evaluate – hypothetical but realistic
    - 80% recovery
    - 1.5 g/t @ US$ 1,170/oz
    - CostMine (2013) inputs
    - 10 year mine life…etc
3. Scenario: Bio-Oxidation

![Graph showing Project NPV Change vs. Gold Recovery]

- **POX: goal posts?**
3. Scenario: Bio-Oxidation

- **Heap leach**
  - Much lower recovery – higher potential for gain?
  - Copper – still major challenge to get much above 60%

- **So where does genomics fit in?**
  - Provides the means to optimize and improve rate limiting steps – to date mostly a action-reaction approach
  - For example, faster reaction rate, more complete oxidation, and faster adaption to changing ore feed
3. Scenario: Passive Water Treatment

- Bacteria as catalysts
  - ‘Reduction’ using organic carbon and respiring on oxidized constituents like nitrate, selenate, ferric iron, sulphate, etc.
  - Scenario looked at backfilled open pits that have some portion of the waste rock water saturated – aka saturated rock fill (SRF) – supports anaerobic bacteria
  - Specifically for removal of selenium from mine waste contact waters in British Columbia coal fields – selenium redox chemistry affects solubility
3. Scenario: Passive Water Treatment

C. CI migrations to Saturated Zone
- CI load continues to increase as infiltration migrates towards saturated zone
- Degree of saturation increases towards saturated zone
- Oxidation rates may decrease (and therefore CI release) towards saturated zone

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Figure 3-1

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Conceptual Model for Saturated Rock Fills (SRFs)

In carbon-containing saturated zones (including groundwater), many CIs (e.g. Se) can be attenuated by microbial activity.
- The region where this is possible likely extends beyond water table
- The form of sequestered selenium is unknown, but likely selenite or elemental selenium
- Microbial populations are established in dumps and will likely be effective as long as there is a source of DOC and trace nutrients

LEGEND
- GREEN: Supported by data or literature.
- BLUE: Not proven but likely from 1st principles.
- RED: Not proven and no data to evaluate

D. Groundwater Seepage
- A portion of ex-pit seepage will report to groundwater
- Seepage from saturated zone will report to groundwater
- Seepage to groundwater low in dissolved selenium
- Overall contributions to groundwater likely greatest from saturated zone, but not the only source.

E. Run-off
- A small portion of precipitation will run-off dump
- Run-off may partially infiltrate dump at gravity low, or continue on as surface water

A. Precipitation and Infiltration
- Precipitation infiltrates ex-pit rock above saturated zone
- Soluble constituents of interest (CIs) are transported

B. Weathering Processes
- Ex-pit rock continues to weather generating constant source of CIs
- Exception for CIs may be ANFO as likely flushed from system, and nitrogen loading likely low

E. Overflow and run-off
- Overflow from saturated zone will daylight and mix with run-off
- Saturated zone overflow may contain less selenium

Mined-Out Bedrock
3. Scenario: Passive Water Treatment

- SRF compared to Fluidized Bed Reactor (FBR)(which is also biological)
  - MEND 2014 report for FBR costs (costs quoted in Globe article double)
  - Conservative CAPEX costs for SRF – injection and monitoring wells + haulage
  - SRF technology still being developed, but based on experience with open pit configurations in coalfields
### 3. Scenario: Passive Water Treatment

<table>
<thead>
<tr>
<th>Treatment Method</th>
<th>CAPEX (M)</th>
<th>OPEX (M)</th>
<th>NPV (M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fluidized bed reactor</td>
<td>$46</td>
<td>$12</td>
<td>$198</td>
</tr>
<tr>
<td>Backfilled pit</td>
<td>$10</td>
<td>$8</td>
<td>$112</td>
</tr>
<tr>
<td>Savings*</td>
<td>$36</td>
<td>$4</td>
<td>$86</td>
</tr>
</tbody>
</table>

* Per facility….so if you need 6 FBR plants for your operations that’s $516M…
3. Scenario: Passive Water Treatment

- Where does genomics come in?
  - Full scale implementation not yet realized
  - Genomics needed to advance the research and develop process
    - Tolerance of microbial community to freshet and other chemistry changes
    - Rate limiting steps
    - Stakeholder and regulatory explanation – deciphering the black box
    - Eventually also as a monitoring tool to ensure the system operates as designed – no other tool to do this.
3. Scenario: Closure & Reclamation

- Covers often placed on mine waste at closure
- Depending on design and cost, they can meet a number of functions from dust suppression to inhibition of oxygen diffusion (sulphide oxidation)
3. Scenario: Closure & Reclamation

- Covers can change moisture content and gas diffusion profile
- Changing physical conditions could support different microbial communities
- In-situ treatment (like SRF) or gas inhibition all together
3. Scenario: Closure & Reclamation

- Scenario based on experience with northern mines and covers used to inhibit ARD
- Considerations – Tailings Cover
  - 150 ha plan area
  - 800 mm of precipitation – 50% to 1.5% infiltration
  - Rudimentary cover = $80,000/ha
  - Two-layer = $160,000/ha
  - Geosynthetic = $300,000/ha (typically needed to stop sulphide oxidation)
  - Water treatment base case of $2.50/m³ – but decreases with better cover performance
3. Scenario: Closure & Reclamation

The graph illustrates the total closure cost (NPV) for different water treatment unit costs and cover types. The costs are grouped by water treatment unit cost ($2.50/m³, $1.50/m³, $0.50/m³) and cover type (No Cover, Rudimentary Cover, Two-Layer Soil Cover, Geosynthetic & Soil Cover). The total closure cost decreases as the water treatment unit cost increases, indicating a direct relationship between the two variables. This trend is evident across all cover types, with the Geosynthetic & Soil Cover option showing the most significant decrease in cost compared to the No Cover option.
3. Scenario: Closure & Reclamation

<table>
<thead>
<tr>
<th>Cover Type</th>
<th>CAPEX (M)</th>
<th>OPEX (M)</th>
<th>Total (M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geosynthetic Cover</td>
<td>$30</td>
<td>$2</td>
<td>$32</td>
</tr>
<tr>
<td>Rudimentary Cover</td>
<td>$12</td>
<td>$0</td>
<td>$12</td>
</tr>
<tr>
<td>Savings*</td>
<td>$18</td>
<td>$2</td>
<td>$20</td>
</tr>
</tbody>
</table>

*per facility
3. Scenario: Closure & Reclamation

- **Genomics role:**
  - Provide understanding on how microbial communities in soil respond to covers – positive and negative effects
  - Opportunity is to get a rudimentary cover to perform like a geosynthetic one
  - ‘Layer cake’ of microbial communities
4. Concluding Remarks

- Role for genomics seems only limited by the number of mining-biology interactions that exist
- Project economics could be increased, or cost savings realized
- Economic benefits in addition to much more sustainable long term options
- Opening up ‘black box’ of biology to all interested parties should not be underestimated
5. Acknowledgements

• Genome BC and OGI – funding and connections
• Industry survey participants