Can fibre-rich plants serve the joint role of remediation of degraded mine land and fuelling of a multi-product value chain?

Towards Resilient Futures Community of Practice Project
Meet the team

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The New Paradigm of Responsible Mining

**Exploration**
- Investors
- Government
- Regional economic players
- Water management
- Community

**Construct & commission**
- Labour
- Procurement
- Entrepreneurs
- Water management
- Adequate planning for burgeoning community

**Mine Operation**
- Investors get significant return on investment
- Region benefits from investment of part profits
- Diverse economic activities, incl. renewable resource-based
- Mine waste re-purposing
- Government engages in long-term planning

**Mine Closure**
- Thriving economy based on renewables
- Re-purpose infrastructure to a diverse and complex economy
- Ongoing mineral related activities, incl. continuing re-purposing of mine waste

**Post Mine Succession**
- Labour force transition into new opportunities
- Thriving complex economy
- Infrastructure support taken over by ongoing economic sector

THE HIGH ROAD:
A 'resource development' model for providing minerals and metals for a sustainable world

THE LOW ROAD:
A 'mineral extraction' model for mining providing maximum shareholder returns

Competitive economies
Resilient communities
Flourishing ecosystems

Mine closure
Vulnerable communities
Degraded environment

Seeking a vibrant post-mining economy
Background to study

- Inefficacy of post-mining practices
- Over 300,000 job losses since 1987
- Significant loss of biodiversity

- Unsuccessful mitigation of mine closure liabilities
- Insufficient provision for post-mining economic activities
- Environmental burden
- Nearly 6000 abandoned mines

- Socio-economic issues
- Lost livelihoods
- Lack of economic activities to support community infrastructure

- Metal contamination
- Acid mine drainage
- Impacted soil and soil microbiome
- Dust
- Air pollution
Challenges of post-mining practices

No universal scheme for sustainable post-mining land use since each mine has its own potential and limitations.

Where human settlements are close to mining activities, post-mining land use must have a strong anthropogenic focus.

Examples of post – mining land use:
- Agriculture
- Forestry
- Recreation
- Construction
- Conservation
- Artificial lakes
- Mining heritage

Identifying the correct post-mining land use is crucial to guide future economic activities.
Transforming degraded mine

<table>
<thead>
<tr>
<th>Remediaion</th>
<th>Focused on “cleaning up” contaminated soil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Restoration</td>
<td>Seeks to salvage and re-establish pre-mining ecosystems</td>
</tr>
<tr>
<td>Reclamation</td>
<td>Seeks an alternate ecosystem more suited to current activities of the region</td>
</tr>
<tr>
<td>Rehabilitation</td>
<td>Centres on sustainable management of the land</td>
</tr>
</tbody>
</table>

Potential to create a post-mining economy by using degraded mine land as a substantial resource to be transformed into a reusable form of land with potential to sustain production of a renewable feedstock or raw material for valorisation into the follow-on economic mix.
The case of fibrous plants
Exploring the potential of fibrous plants

- Land remediation potential
- Metal recovery potential
- Fibre-derived products
Phytoremediation & Phytomining

**Phytoremediation**: use of plants to extract, sequester and detoxify environmental contaminants, when the metals accumulate in harvestable parts of the plants, the technique is termed **phytoextraction**

The recovery of metals which have monetary value via phytoextraction is typically termed **phytomining**
Plants suitable for phytoremediation & phytomining

- **Natural hyperaccumulators**
  - High metal uptake
  - High metal selectivity
  - Higher toxicity tolerance
  - Typically slow growth
  - Biomass has little value
  - E.g. *Berkheya coddii* (Ni), *Arabidopsis helleri* (Cd)

- **High biomass non-hyperaccumulators**
  - Low metal uptake
  - Low metal selectivity
  - High biomass producing
  - Low growth requirements
  - Biomass has high value
  - E.g. Energy crops, fibre crops, fragrance crops

- Mostly suited for bioremediation & phytomining purposes
- For combined land remediation and valorisation
Multi-product potential of fibrous plants

- Fibre
  - Long Fibre
  - Short Fibre
  - Woody tissue

- By-products
  - Chemicals
  - Energy

- Other products
  - Fabric
  - Cordage
  - Piping
  - Oils
  - Bio-char
  - Thermoplastic
  - Bio-composites
  - Shives
  - Pharmaceuticals

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The case of fibrous plants

A selection of plants for a fibrous post-mining economy in South Africa
Common fibrous plants grown in SA

Fibre plants

Bast
- Flax
- Hemp
- Jute
- Kenaf

Leaf
- Sisal
- Palm

Seed
- Cotton
- Kapok

Fruit
- Coconut

Wood
- Pinewood
- Baobab

Grass
- Bamboo
<table>
<thead>
<tr>
<th>Name</th>
<th>Preferred soil type</th>
<th>Preferred annual rainfall (mm/yr)</th>
<th>Temp. tolerance (°C)</th>
<th>pH tolerance</th>
<th>Annual/perennial</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bambusa balcooa</td>
<td>Clay, loamy</td>
<td>700 - 4500</td>
<td>9 – 35</td>
<td>4.5 – 7.5</td>
<td>Perennial</td>
</tr>
<tr>
<td>Dendrocalamus asper</td>
<td>Rich</td>
<td>1200 - 1500</td>
<td>15 – 34</td>
<td>4.5 - 7</td>
<td>Perennial</td>
</tr>
<tr>
<td>Baobab</td>
<td>Clay, sandy</td>
<td>240 - 2500</td>
<td>14 – 42</td>
<td>4.3 – 7.5</td>
<td>Perennial</td>
</tr>
<tr>
<td>Coconut</td>
<td>Coarse sand, clay</td>
<td>1500 - 2500</td>
<td>13 – 35</td>
<td>5.5 - 7</td>
<td>Perennial</td>
</tr>
<tr>
<td>Cotton</td>
<td>Sandy loam</td>
<td>450 - 1500</td>
<td>15 – 42</td>
<td>5.5 – 7.5</td>
<td>Annual</td>
</tr>
<tr>
<td>Flax</td>
<td>Loamy</td>
<td>450 - 750</td>
<td>5 – 30</td>
<td>5 – 7</td>
<td>Annual</td>
</tr>
<tr>
<td>Hemp</td>
<td>Clay, silt loam</td>
<td>500 - 700</td>
<td>6 – 32</td>
<td>6 – 6.5</td>
<td>Annual</td>
</tr>
<tr>
<td>Jute</td>
<td>Silt, sandy loamy, clay</td>
<td>1000 - 2500</td>
<td>13 – 45</td>
<td>4.8 – 5.8</td>
<td>Annual</td>
</tr>
<tr>
<td>Kapok</td>
<td>Loamy soil</td>
<td>750 - 3000</td>
<td>12 – 40</td>
<td>5 – 6.5</td>
<td>Perennial</td>
</tr>
<tr>
<td>Kenaf</td>
<td>All soil types</td>
<td>240 - 490</td>
<td>10 – 35</td>
<td>4.3 – 8.2</td>
<td>Annual</td>
</tr>
<tr>
<td>Palm</td>
<td>Sandy soil</td>
<td>100 - 400</td>
<td>15 – 52</td>
<td>6 – 8.5</td>
<td>Perennial</td>
</tr>
<tr>
<td>Pinewood</td>
<td>Sandy soil</td>
<td>850 – 950</td>
<td>&gt; 13</td>
<td>5 – 6</td>
<td>Perennial</td>
</tr>
<tr>
<td>Sisal</td>
<td>All except clay</td>
<td>500 - 1500</td>
<td>10 – 32</td>
<td>4 – 6</td>
<td>Perennial</td>
</tr>
</tbody>
</table>
Regions of interest for investigation

- High number of abandoned mines, and associated degraded mine land
- Surrounding areas are densely populated
- Water pollution and scarcity
- Potential arable land in terms of pH, rainfall and climatic conditions

Average rainfall: 300–800 mm per annum
Average temperature: 7 – 30 °C
Soil pH: 5.5 - 7
### Regions of interest - Characteristics

<table>
<thead>
<tr>
<th>Potential Sites</th>
<th>Target metal or product</th>
<th>Associated metal or product</th>
<th>Soil Texture</th>
<th>Soil pH</th>
<th>Rain (mm p.a.)</th>
<th>Temp (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carletonville, Gauteng</td>
<td>Gold</td>
<td>Pb, As, Ni, Cd, Cu, Zn, Hg, Co &amp; U</td>
<td>Shallow - rocky</td>
<td>5.6 – 6.4</td>
<td>500 - 650</td>
<td>5 - 30</td>
</tr>
<tr>
<td>Witbank, Mpumalanga</td>
<td>Coal</td>
<td>Al, Ba, Ca, Cl, Cu, Fe, K, Mg, Si, S, N</td>
<td>Sandy-clay loams</td>
<td>5.5 – 7.2</td>
<td>600 - 800</td>
<td>7 - 28</td>
</tr>
<tr>
<td>Polokwane, Mpumalanga</td>
<td>Platinum</td>
<td>Pd, Rh, Ni, Au, Ir, Cu</td>
<td>Loamy topsoil on rocks</td>
<td>5.5 – 6.4</td>
<td>300 - 500</td>
<td>10 - 30</td>
</tr>
<tr>
<td>Plant</td>
<td>Temperature (°C)</td>
<td>Precipitation (mm)</td>
<td>Height (mm)</td>
<td>Growth Cycle (days/years)</td>
<td>Metals Present</td>
<td></td>
</tr>
<tr>
<td>---------------</td>
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<td></td>
</tr>
<tr>
<td>Bambusa balcooa</td>
<td>400 – 5400</td>
<td>450 – 750</td>
<td>240 – 490</td>
<td>5 – 6 years</td>
<td>Pb, Zn, Cr, Fe</td>
<td></td>
</tr>
<tr>
<td>Flax</td>
<td>9 – 35</td>
<td>5 – 30</td>
<td>90 – 170</td>
<td>80 – 100</td>
<td>Pb, Zn, Cd</td>
<td></td>
</tr>
<tr>
<td>Hemp</td>
<td>6 – 32</td>
<td>500 – 700</td>
<td>240 – 490</td>
<td>90 – 170</td>
<td>Cd, Zn, Fe, Cu, Ni, Pb</td>
<td></td>
</tr>
<tr>
<td>Kenaf</td>
<td>10 – 35</td>
<td>500 – 1500</td>
<td>1 – 4 tons/ha</td>
<td>100 – 240</td>
<td>Cd, Zn, As, Fe, Pb, Cr</td>
<td></td>
</tr>
<tr>
<td>Sisal</td>
<td>10 – 32</td>
<td>500 – 1500</td>
<td>1 – 4 tons/ha</td>
<td>2 – 4 years</td>
<td>Zn, Cd, Cu</td>
<td></td>
</tr>
</tbody>
</table>
# Phytoremediation and fibre production potential of selected plants

<table>
<thead>
<tr>
<th>Name</th>
<th>Fibre yield (tons/ha)</th>
<th>Metal bioaccumulation site</th>
<th>Metal selectivity</th>
<th>Metal uptake/absorption/centration</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Bambusa balcoola</em></td>
<td>12 - 18</td>
<td>Roots, shoots</td>
<td>Pb, Zn, Cr, Fe</td>
<td>Pb: 36 mg/kg of biomass</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Zn: 43 mg/kg of biomass</td>
</tr>
<tr>
<td>Flax</td>
<td>1 - 2</td>
<td>Roots, capsule</td>
<td>Pb, Cd, Zn</td>
<td>Pb: 311 mg/kg soil</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Cd: 13.1 mg/kg soil</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Zn: 490 mg/kg soil</td>
</tr>
<tr>
<td>Hemp</td>
<td>2 - 8</td>
<td>Roots, shoots, leaves, stems</td>
<td>Ni, Pb, Cd</td>
<td>Ni: 123 mg/kg leaves</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Zn, Cu</td>
<td>Cd: 151 mg/kg leaves</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Zn: 490 mg/kg leaves</td>
</tr>
<tr>
<td>Kenaf</td>
<td>5 - 10</td>
<td>Roots, shoots, leaves, seed capsule</td>
<td>Pb, Cd, Zn</td>
<td>Pb: 42.2 mg/kg soil</td>
</tr>
<tr>
<td>Sisal</td>
<td>1 - 4</td>
<td>Leaves</td>
<td>Cd, Zn, Cu</td>
<td>Cd: 1850 mg/kg sisal fibre</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Cu: 1340 mg/kg sisal fibre</td>
</tr>
</tbody>
</table>
Findings

- Flax, hemp and kenaf demonstrate high potential for metal removal and accumulation
- Phytoremediation data for _Bambusa balcooa_ and sisal were scarce
- Bast fibre crops (flax, hemp, kenaf) usually yield high fibre quality
- _Bambusa balcooa_ demonstrated a much higher biomass production potential and thus a higher fibre yield per hectare
- Where perennial plants are used, fibre harvesting can only start after a few years, but repeat planting is not required

Fibre crops have the ability to grow over a diverse range of climatic conditions and land qualities.
Findings

- Lack of top soil, organic matter and good microbial community dynamics within the soil microbiome of degraded land will inhibit plant growth.

- The productivity of some fibre crops is negatively affected by high levels of pollutants, including metals.

- Phytoextraction of metals by the fibre crops is expected to be slower than by hyperaccumulators owing to their lower accumulation of metals in comparison to hyperaccumulators, thus requiring more crop harvests.

- Metals can accumulate in harvestable parts of plants, making product safety an issue and the zone of metal accumulation an important consideration in selection.

The extent of pollution of the sites considered for combined remediation and multi-product development is a key factor in expected performance.
Recommendations

- For highly contaminated mine land, the soil quality may first need to be improved to support the growth of fibre crops. This can be done by physico-chemical and/or biological means.

- For biological means, hyperaccumulators are recommended to ensure the maximum rate and extent of metal extraction and associated valorisation by phytomining.

- Fibre crops can then be grown on the less contaminated land for better plant growth and fibre quality.
Ongoing & future work
Proof of concept with experimental work

- Collect metal contaminated soil from potential sites using randomised sampling
- Analyse soils using Inductively Coupled Plasma (ICP) to determine their metal concentrations
- Study germination of seeds in these degraded or contaminated soils in pots (Phase 1)
- Monitor plant growth compared to a control soil
- Analyse concentrations of metals in soils and plants after harvest to determine remediation potential and potential for harvesting
**Desktop case study – Combined hyperaccumulator & fibrous plant system (preliminary results)**

- Using *Berkheya coddii* and hemp on 10 ha of land of contaminated land to extract nickel and produce fibres and/or hemp seeds

1) Value of Ni extracted from *Berkheya coddii* vs Hemp

| Dry biomass of *Berkheya coddii* for 10 ha (tonnes) | 220 |
| Amount of Ni extracted for 10 ha (1% w: w) (kg) | 2200 |
| Price of Ni (R/kg) | 184 |
| Potential revenue from Ni (R) | 404 800 |

| Amount of Ni extracted from Hemp (kg/ha) | 0.285 - 2.03* |
| Amount of Ni extracted for 10 ha (kg) | 2.85 - 20 |
| Price of Ni (R/kg) | 184 |
| Potential revenue from Ni (R) | 524 - 3680 |

* Considering the shoot harvest only or the entire plant harvest respectively
2) Value from Hemp fibre price ($ 260/ton) and Seed price ($ 1.38/kg)

<table>
<thead>
<tr>
<th>Production system</th>
<th>Low productivity</th>
<th>Medium low productivity</th>
<th>Medium high productivity</th>
<th>High productivity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fibre yield (ton/ha)</td>
<td>Seed yield (kg/ha)</td>
<td>Fibre yield (ton/ha)</td>
<td>Seed yield (kg/ha)</td>
</tr>
<tr>
<td>Fibre only</td>
<td>4.6</td>
<td></td>
<td>5.8</td>
<td></td>
</tr>
<tr>
<td>Dual system</td>
<td>2.2</td>
<td>236</td>
<td>2.8</td>
<td>295</td>
</tr>
<tr>
<td>Seed only</td>
<td></td>
<td>272</td>
<td>2.8</td>
<td>340</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>6.9</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3.3</td>
<td></td>
</tr>
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<td></td>
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<td></td>
<td>4.6</td>
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<td>3.9</td>
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<td></td>
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<td>4.1</td>
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</tbody>
</table>
## Desktop case study – Combined hyperaccumulator & fibrous plant system (preliminary results) (cont.)

<table>
<thead>
<tr>
<th>Production system</th>
<th>Low productivity</th>
<th>Medium low productivity</th>
<th>Medium high productivity</th>
<th>High productivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fibre only</td>
<td>R 171 028</td>
<td>R 215 644</td>
<td>R 256 542</td>
<td>R 301 158</td>
</tr>
<tr>
<td>Dual system</td>
<td>R 128 368</td>
<td>R 162 319</td>
<td>R 192 355</td>
<td>R 226 503</td>
</tr>
<tr>
<td>Seed only</td>
<td>R 53 676</td>
<td>R 67 095</td>
<td>R 80 515</td>
<td>R 93 933</td>
</tr>
</tbody>
</table>
Process integration – the Biorefinery concept

- Cultivation
  - Harvested
  - Plants
  - Plants processing
  - Fibres
  - Fibre processing
  - By-products e.g. residual biomass, wastewater
  - Metals
  - Bioproducts
  - Energy products
  - Fit-for-purpose water

- Fuelling a multi-product value chain by maximising resource efficiency

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