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ENGINEERING RESEARCH

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

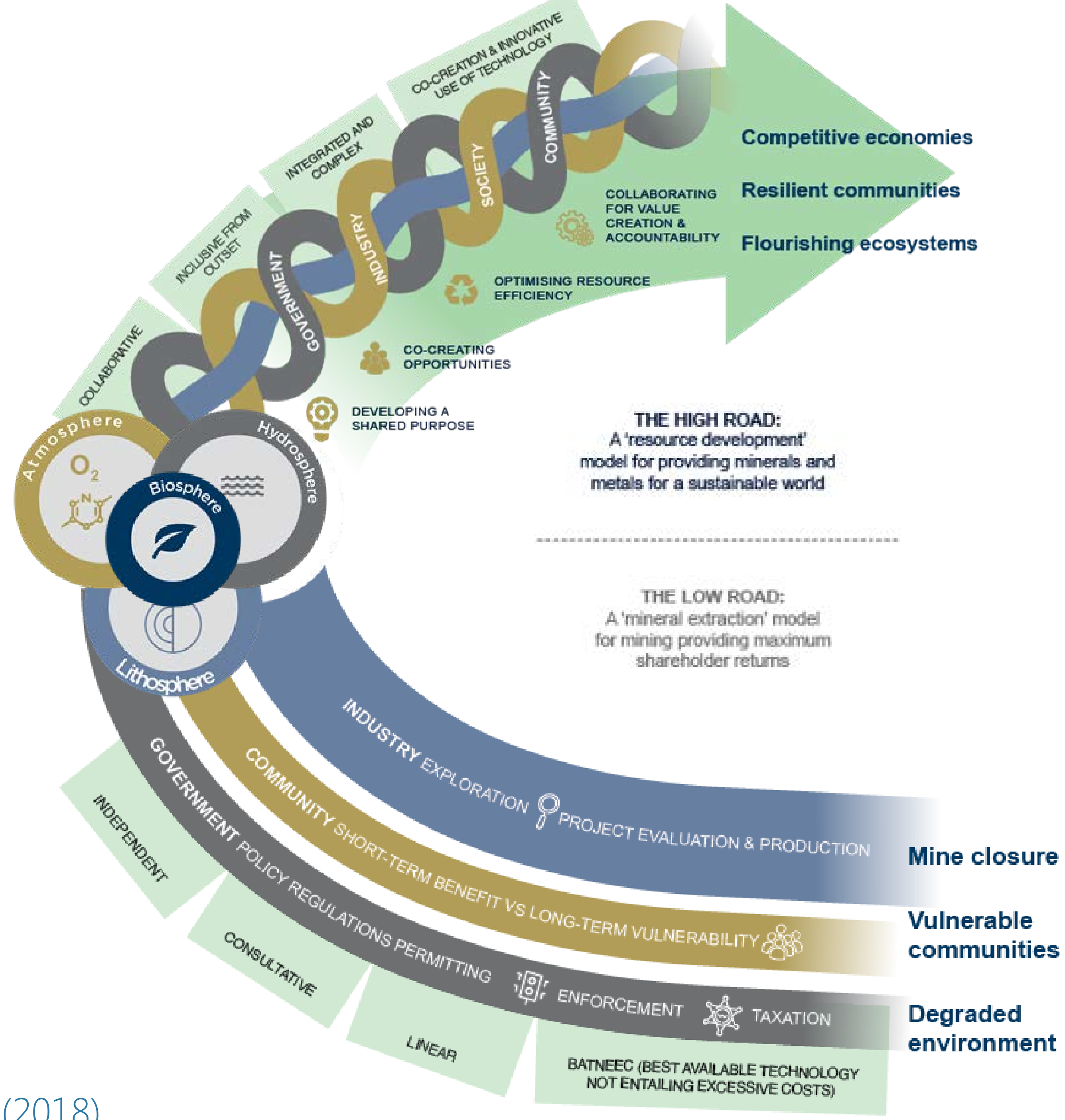
Construct & commission
- Labour
- Procurement
- Entrepreneurs
- Water management
- Adequate planning for burgeoning community

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

Digby et al. Green Mining (2018).



Digby et al. Green Mining (2018).

Seeking a vibrant post-mining economy

Background to study

Ineffiacy 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

Remediation	Focused on "cleaning up" contaminated soil
Restoration	Seeks to salvage and re-establish pre-mining ecosystems
Reclamation	Seeks an alternate ecosystem more suited to current activities of the region
Rehabilitation	Centres on sustainable management of the land

Potential to create a **post-mining economy** by using degraded mine land as a substantial resource to be transformed into a re-usable 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




Addressing land remediation & metal recovery

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 | VS | High biomass non-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)*

Mostly suited for bioremediation & phytomining purposes

- Low metal uptake
- Low metal selectively
- High biomass producing
- Low growth requirements
- Biomass has high value

E.g. *Energy crops, **fibre crops**, fragrance crops*

For combined land remediation and valorisation

Multi-product potential of fibrous plants




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

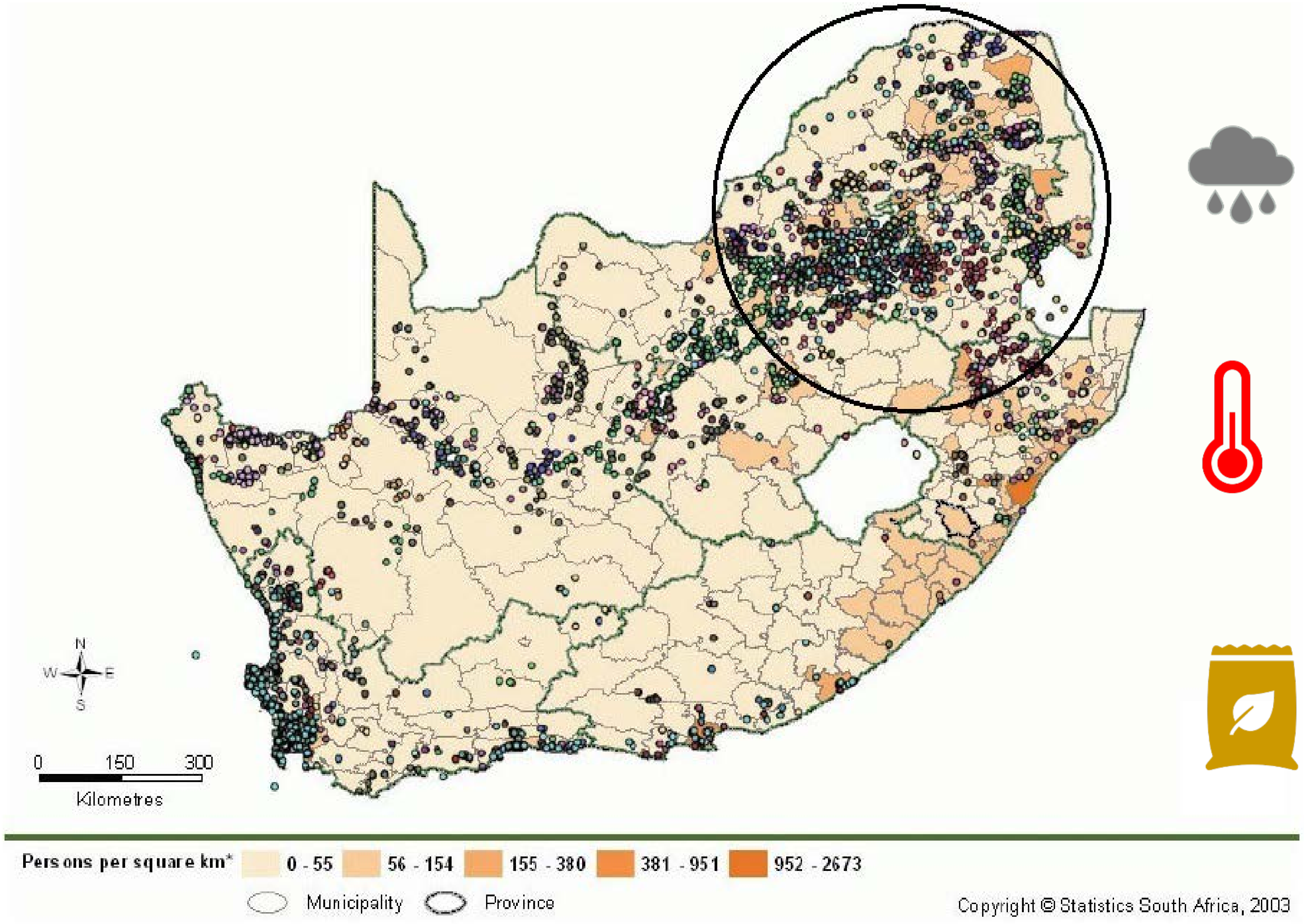
- **Bast**
  - Flax
  - Hemp
  - Jute
  - Kenaf
- **Leaf**
  - Sisal
  - Palm
- **Seed**
  - Cotton
  - Kapok
- **Fruit**
  - Coconut
- **Wood**
  - Pinewood
  - Baobab
- **Grass**
  - Bamboo




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

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

Potential Sites	Target metal or product	Associated metal or product	Soil Texture	Soil pH	Rain (mm p.a.)	Temp (℃)
Carletonville, Gauteng	Gold	Pb, As, Ni, Cd, Cu, Zn, Hg, Co & U	Shallow - rocky	5.6 – 6.4	500 - 650	5 - 30
Witbank, Mpumalanga	Coal	Al, Ba, Ca, Cl, Cu, Fe, K, Mg, Si, S, N	Sandy-clay loams	5.5 – 7.2	600 - 800	7 - 28
Polokwane, Mpumalanga	Platinum	Pd, Rh, Ni, Au, Ir, Cu	Loamy topsoil on rocks	5.5 – 6.4	300 - 500	10 - 30





	Bambusa balcooa	Flax	Hemp	Kenaf	Sisal
°C)	400 – 5400 mm	450 – 750 mm	500 – 700 mm	240 – 490 mm	500 – 1500 mm
	9 – 35 ° C	5 - 30 ° C	6 - 32 ° C	10 - 35° C	10 – 32 ° C
	12 – 18 tons/ha	1 - 2 tons/ha	2 – 8 tons/ha	5 – 10 tons/ha	1 – 4 tons/ha
	5 – 6 years	80 - 100 days	90 -170 days	100 – 240 days	2 – 4 years
M	Pb, Zn, Cr, Fe	Pb, Zn, Cd	Cd, Zn, Fe, Cu, Ni, Pb	Cd, Zn, As, Fe, Pb, Cr	Zn, Cd, Cu

Phytoremediation and fibre production potential of selected plants

Name	Fibre yield (tons/ha)	Metal bioaccumulation site	Metal selectivity	Metal uptake/absorption/concentration
Bambusa balcoola	12 -18	Roots, shoots	Pb, Zn, Cr, Fe	Pb: 36 mg/kg of biomass Zn: 43 mg/kg of biomass
Flax	1 - 2	Roots, capsule	Pb, Cd, Zn	Pb: 311 mg/kg soil Cd: 13.1 mg/kg soil Zn: 490 mg/kg soil
Hemp	2 - 8	Roots, shoots, leaves, stems	Ni, Pb, Cd Zn, Cu	Ni: 123 mg/kg leaves Cd: 151 mg/kg leaves Cu: 1530 mg/kg leaves
Kenaf	5 - 10	Roots, shoots, leaves, seed capsule	Pb, Cd, Zn	Pb: 42.2 mg/kg soil
Sisal	1 - 4	Leaves	Cd, Zn, Cu	Cd: 1850 mg/kg sisal fibre Cu: 1340 mg/kg sisal fibre

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

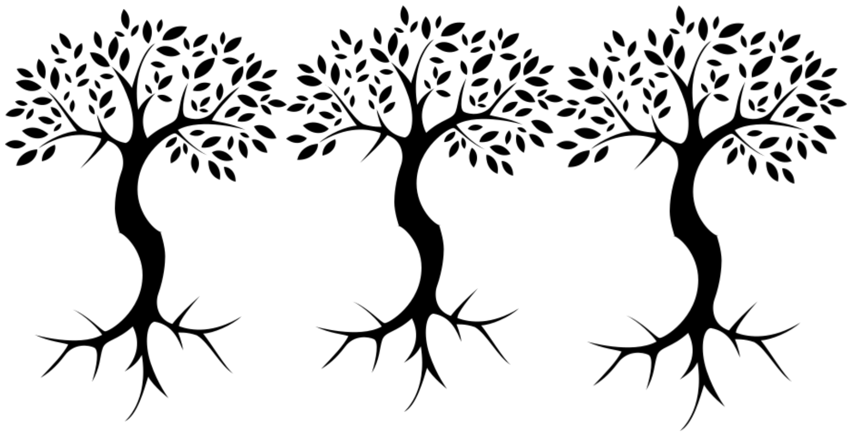
* Considering the shoot harvest only or the entire plant harvest respectively

Desktop case study – Combined hyperaccumulator & fibrous plant system (preliminary results) (cont.)

2) Value from Hemp fibre price ($ 260/ton) and Seed price ($ 1.38/kg)

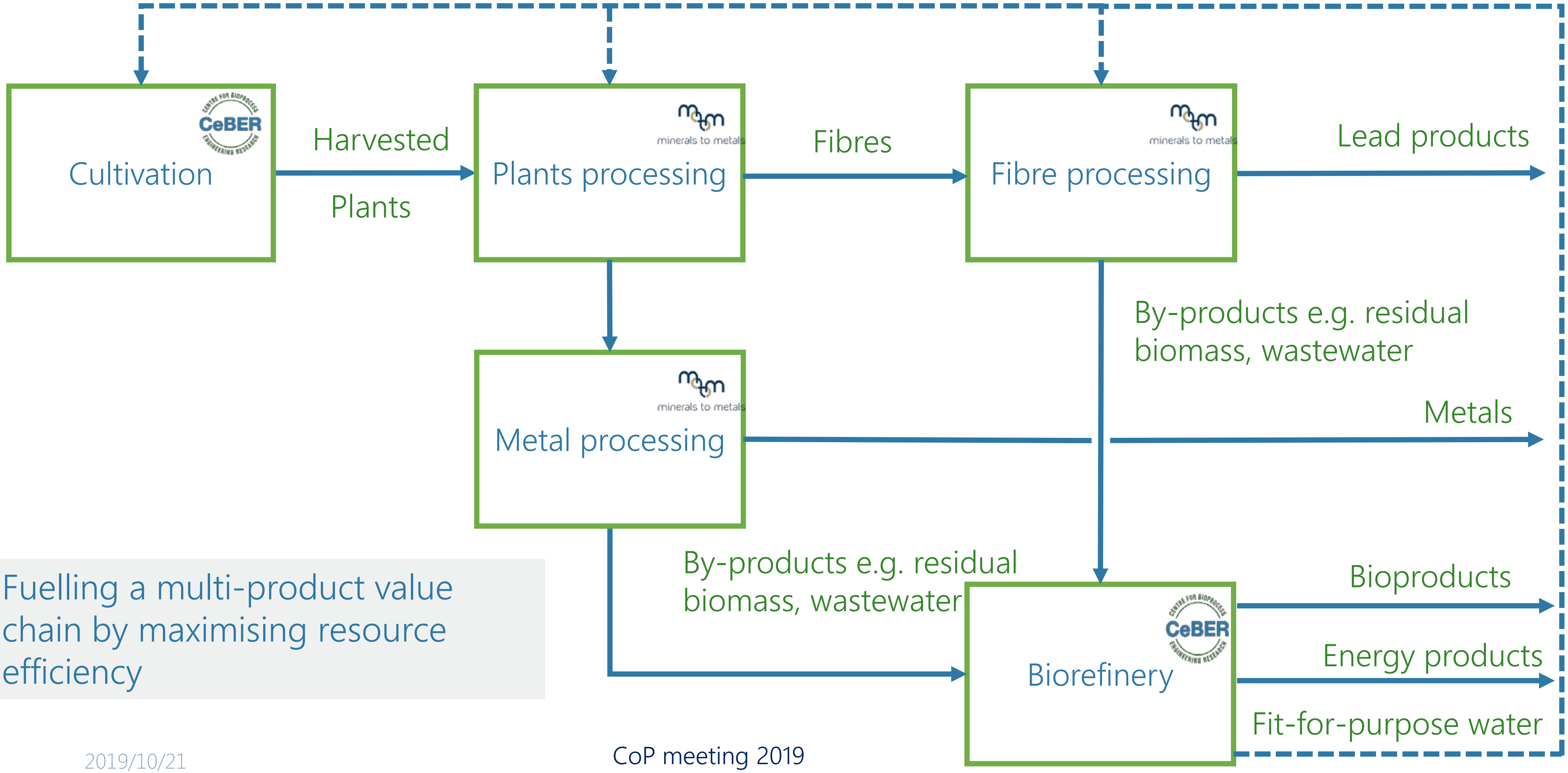
Production system	Low productivity		Medium low productivity	
	Fibre yield (ton/ha)	Seed yield (kg/ha)	Fibre yield (ton/ha)	Seed yield (kg/ha)
Fibre only	4.6		5.8	
Dual system	2.2	236	2.8	295
Seed only		272		340
Production system	Medium high productivity		High productivity	
	Fibre yield (ton/ha)	Seed yield (kg/ha)	Fibre yield (ton/ha)	Seed yield (kg/ha)
Fibre only	6.9		8.1	
Dual system	3.3	353	3.9	413
Seed only		408		476

Desktop case study – Combined hyperaccumulator & fibrous plant system (preliminary results) (cont.)



Production system	Low productivity	Medium low productivity	Medium high productivity	High productivity
Fibre only	R 171 028	R 215 644	R 256 542	R 301 158
Dual system	R 128 368	R 162 319	R 192 355	R 226 503
Seed only	R 53 676	R 67 095	R 80 515	R 93 933

Process integration – the Biorefinery concept



Fuelling a multi-product value chain by maximising resource efficiency

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