B3: Beyond Biorecovery:
Environmental win-win by Biorefining of metallic wastes into new functional materials

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Objectives of B³ Catalyst and full project

Apply microbial conversion technologies to:

1. Biorecover valuable and strategic materials from wastes
2. Manufacture high value minerals and nanomaterials from biorecovered products
3. Evaluate biogenic nanomaterials in real end user & novel green energy applications
4. Carry out a life cycle and sustainability analysis within extant framework

Four ‘horses’ of B³:
Base metal mining wastes into upgraded concentrates for onward refining
Base metal mining wastes into potential photonic materials
Rare earth elements from magnet scraps into upgrade concentrates (onward refining)
Rare earth elements into new catalysts
Uranium wastes upgraded into potential nuclear fuel
Platinum group metal/gold wastes (mining, scraps) into catalysts for energy, environment, green chemistry
PGM/BM/REE bimetallics: photonics, fuel cells, catalysts (esp intractable reactions)
Outcomes of catalyst award

1. Supply chains put in place: CANADA

PGMs from street sweepings (Toronto) into catalysts for heavy oil upgrading
REEs from waste dumps (U. mines) into catalysts for the rubber industry

SOUTH AFRICA (PGM wastes from Anglo American):

PGMs from mine wastes into catalysts for green chemistry (U. Cape Town)
PGMs from mine wastes into fuel cell catalysts for electricity (U. W. Cape)

UK:
WEE scraps (PGMs) + Road dusts (company); REE wastes + U wastes
(Companies) into catalysts and nuclear fuel precursors

2. Biomaterials testing set up via external Partners who have bought-in
3. LCA via PDRA secondment to C-Tech Innovation (18 months); REKTN
4. Photonic material was shown in principle using biogenic H₂S to manufacture
5. New Partner to help develop photonic materials from wastes for a new clean technology application (£12M multinational previous support to them)
6. Method development: all areas
Catalysts for green chemistry; no toxic byproducts; fuel cells; waste cleanup; petrochemical wastes valorisations/upgrades

Quantum dots for ‘upgrading’ and using waste light

Light emitting Materials

Catalysts eg rubber industry

Access high value element components. Nuclear fuel precursors from leftovers

Value level 3: new functional materials made from biorefined metallic wastes

Value level 2: solid products into commercial refining; lower energy/less waste/environmental impact

Value level 1: conserve natural resources via materials recovery from wastes

Four linked ‘horses’ of B3

PGMs/Au

Base metals

REEs

Uranium

Road dusts (PGM) Mining wastes (PGM) Used catalysts (PGM) Printer cartridges (Pd/Au) Mining wastes UK & overseas (e.g. (Ni, Cu) Magnet scraps (UK) Mine wastes (Canada) Ti production waste (UK) Waste producers; mining & metals sectors

See support letters

Link2Energy: Facilitator’ honest broker

Environ. Sustain. KTN

Life cycle analysis at C-Tech Innovation

Supply chains for each: (i) waste producer; (ii) B3; (iii) end user (see letters)

UK: scraps/wastes (from suppliers) via B3 to new catalysts tested by UK Partner

SA: mine wastes via B3 into catalysts, valorise petrochemical wastes; make electricity

Canada: road dusts into new catalysts via B3 for heavy oil upgrading

UK: mine wastes via B3 into quantum dots, application tested with UK Partner

Canada: recovery of Ni from mine wastes via B3; separate from U, Th

UK: magnet scraps/Ti wastes via B3 into concentrates (and Nd, new catalyst; Eu QDs)

Canada: REE from U-mine tailings ponds via B3; REE concentrate into refining

UK: recovery of U from Ti processing waste via B3 into nuclear fuel cycle

Canada: recovery of U from mine tailings ponds via B3 into nuclear fuel cycle

ESRC alignment
Primary waste

Secondary waste

Mineralogy (XRD)

Composition (ICP-MS, XRF)

Characterisation

Physical pre-concentration

Physical mineralogy (Qemscan)

Sulphides

Mixed oxides/sulphides

Oxides

Pre-leach/sulphidisation

Leaching

Flocculation

Flotation

Flocculation

next slide
Leaching

Leaching agent
Duration
Temperature
Pressure

Microwave processing
C-Tech Innovation

Green leaching process definition

Qemscan

Characterisation

Functional materials production

Functional biomaterials production

Properties
Methods of biorecovery of metals

- (may need to amend metal solution, e.g. ‘mask’ unwanted metals; for example bicarbonate ion holds back uranium in a mix)
- Metal sulfide within the primary recovery process (below)
- Metal biomineralisation as the phosphate; some metal phosphate crystals are catalytically useful, others have light-emitting properties
- Metal reduction to make metallic nanoparticles e.g. Pd(0), Pt(0), Au(0) and bimetallics; those made from wastes (can be MORE active catalytically)

- Level 1 success: metal recovered
- Level 2 success: recovery in a potentially useful form (‘one pot’)
- Level 3 success: show activity of biorefined material
- Level 4 success: show competitive LCA economics PLUS environment
- Level 5 success: end-user evaluation and adoption post B³
Bioleaching and bio-recovery of copper from tailings wastes

Tailings dump and AMD pond; Bor copper mine (Serbia). The mine waste contains more Cu than many primary ores currently being mined.

Phase I: Bioleaching of Cu using consortia of acidophilic bacteria
(Cu$_2$S + 2 Fe$^{3+}$ $\rightarrow$ 2 Cu$^{+}$ + S$^0$ + 2 Fe$^{2+}$)

Phase II: selective capture of copper produced in phase I using biosulfidogenesis
(2 Cu$^{+}$ + H$_2$S $\rightarrow$ Cu$_2$S + 2H$^+$)

- [Cu] increased from ~ 0.5 to 80% (and therefore a commercially viable product)
- Concurrent remediation of a major environmental hazard
Metal sulfides generated on-line and off-line by acidophilic sulfidogens

Integrated system developed to simultaneously remove and recycle metals and bioremediate acidic metal-rich wastewaters

- System allows both direct and indirect bio-precipitation of metal sulfides
- The properties of metal (Cu, Zn, Co etc.) sulfides so formed will be compared
Plan of B³: how it will deliver

Timeline 0 mo..... (each WP is continuous and iterative; 4 ‘trains’: red/blue/green/yellow on different tracks)..... 36 mo

WP1 CSM/UB: analyse raw materials, intermediates, products; product specifications

WP2 CSM, UB, C-T Green Leaching (computer assisted). Microwave processing wastes/catalysts

WP3 BU/UB/CSM, Preparation/ modifications of materials. Informed from WP1 & 2

WP4: UB/BU/Partners B³ Making biomaterials from wastes

WP5: UB/Partners B³ Biomaterials evaluation

WP6 UB/ BU Bio refinery development

WP7 C Tech REKTN/UB Life Cycle Analysis

PRODUCTS OUT

WASTES IN

WP8: Link2Energy bring new industrial problem holders (+ specific waste materials) and end users into B³ (UK) Supply chains set up in UK, South Africa and Canada
**Bottlenecks, risks and mitigations**

- Leaching needs strong chemicals
  - Microwaves allow more dilute leachants
  - Biorecovery systems are proven robust

- Materials may not be active
  - Proven already for PGM biomaterials

- Q-dots may not emit correctly
  - Light emission adjusted by doping

- REE may not make catalysts
  - Bio-conversion to other REE mineral forms

- Uranium may be bio-enriched (unlikely!)
  - Isotope analysis done before marketing product (potentially game-changing)

- Economics may fall down
  - Economic analysis is done already (PGMs from road dust into fuel cell catalysts)

- Company Partner may fold
  - Each service and supply chain has redundancy so task can be re-allocated.

- New joiners are embraced!