B3: Beyond Biorecovery:

Environmental win-win by Biorefining of metallic wastes into new functional materials

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Objectives of B^3 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 B^3:
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 H_2S 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

3 levels of NERC remit alignment

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

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

PGMs/Au

Base metals

REEs

Uranium

Four linked 'horses' of B3

1 Road dusts (PGM) Mining wastes (PGM) Used catalysts (PGM) Printer cartridges (Pd/Au)

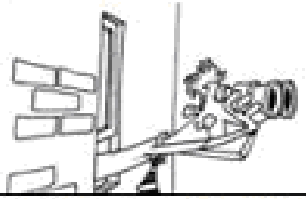
2 Mining wastes UK & overseas (e.g. (Ni, Cu)

3 Magnet scraps (UK) Mine wastes (Canada) Ti-prod'n wastes (UK)

4 Mine wastes (Canada) Ti production waste (UK)

See support letters

Environ. Sustain. KTN



Link2Energy:Facilitator' honest broker'

Waste producers; mining & metals sectors

Life cycle analysis at C-Tech Innovation

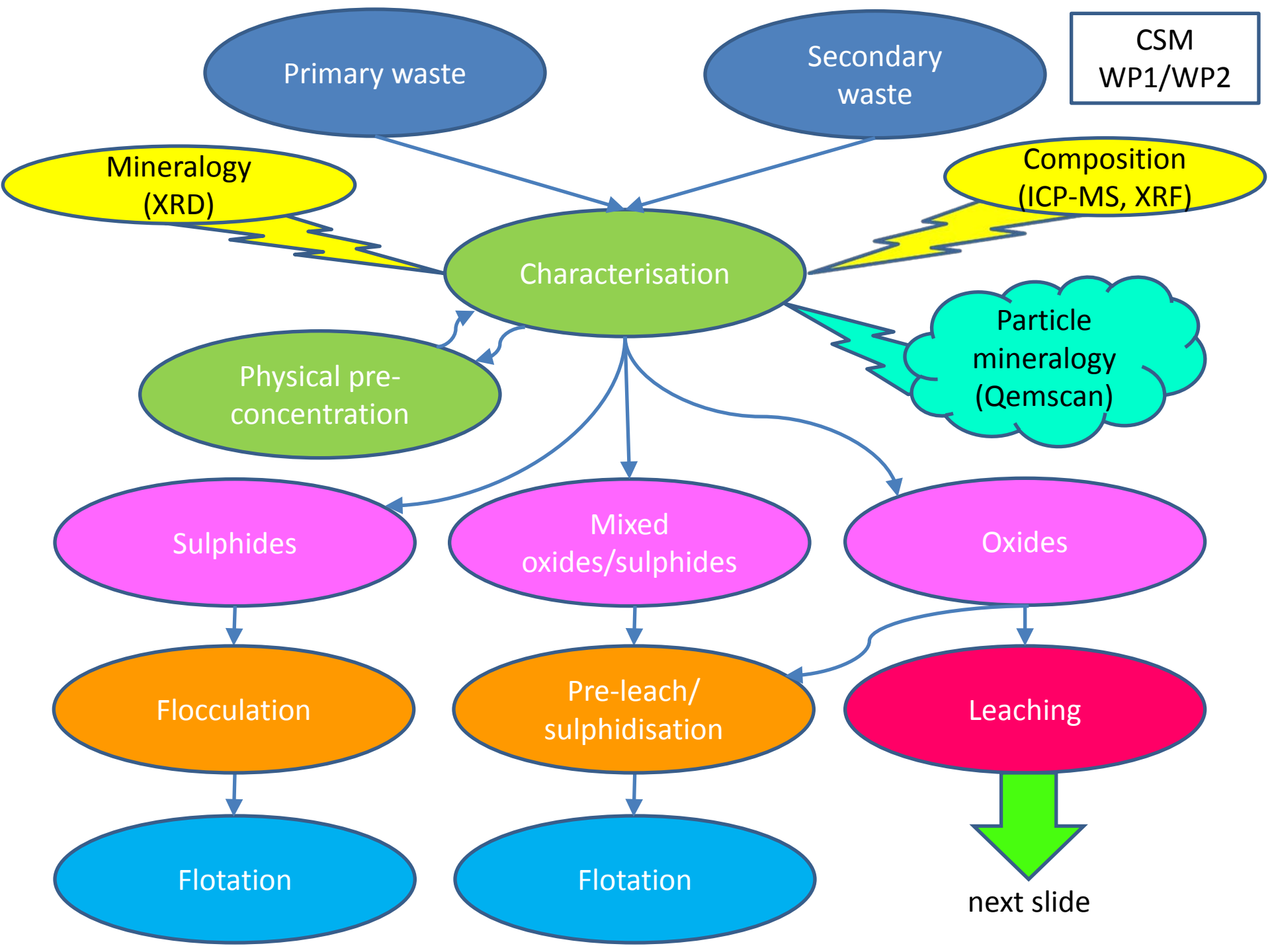
ESRC alignment

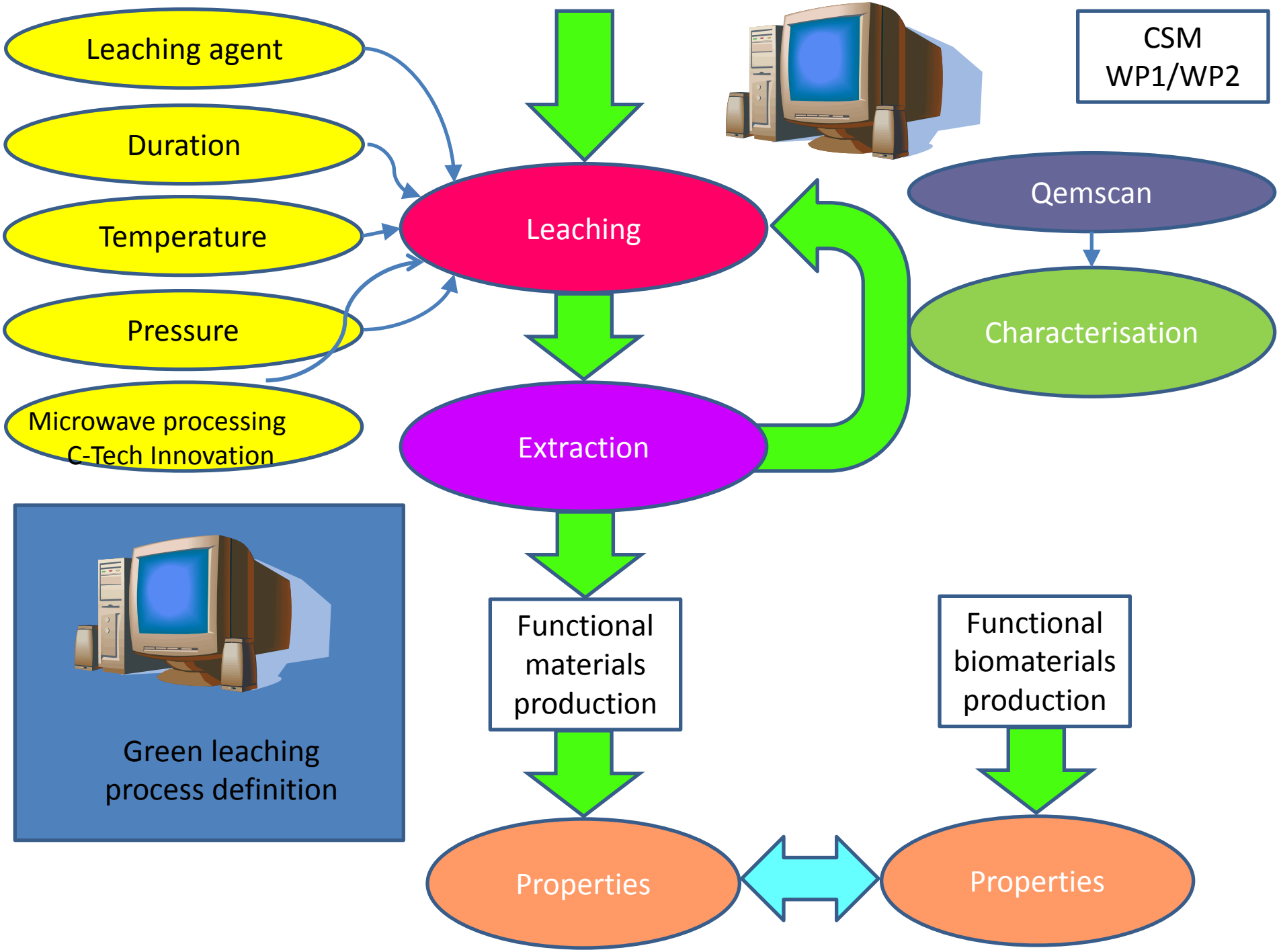
1 **Supply chains for each: (i) waste producer; (ii) B³; (iii) end user (see letters)**
UK: scraps/ wastes (from suppliers) via B³ into new catalysts tested by UK Partner
SA: mine wastes via B³ into catalysts: valorise petrochemical wastes; make electricity

2 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

3 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

4 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


CSM
WP1/WP2
Primary waste
Secondary waste
Mineralogy (XRD)
Composition (ICP-MS, XRF)
Characterisation
Physical pre-concentration
Particle mineralogy (Qemscan)
Sulphides
Mixed oxides/sulphides
Oxides
Flocculation
Pre-leach/ sulphidisation
Leaching
Flotation
Flotation
next slide


Leaching agent
Duration
Temperature
Pressure
Microwave processing
C-Tech Innovation
Leaching
Extraction
CSM
WP1/WP2
Qemscan
Characterisation
Green leaching
process definition
Functional
materials
production
Functional
biomaterials
production
Properties
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)

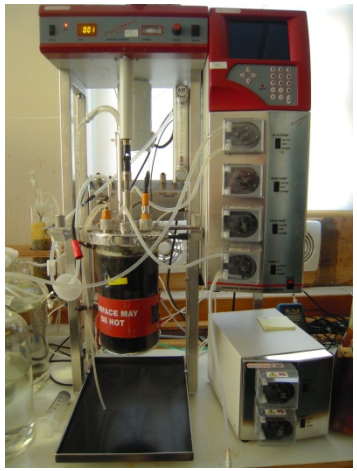
- Level 1 success: metal recovered
- Level 2 success: recovery in a potentially useful form (‘one pot’)
- Level 3 success: show activity of biorefined material
- Level 4 success: show competitive LCA economics PLUS environment
- Level 5 success: end-user evaluation and adoption post B^3

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
($Cu_2S + 2\ Fe^{3+} \rightarrow 2\ Cu^{+} + S^{0} + 2\ Fe^{2+}$)

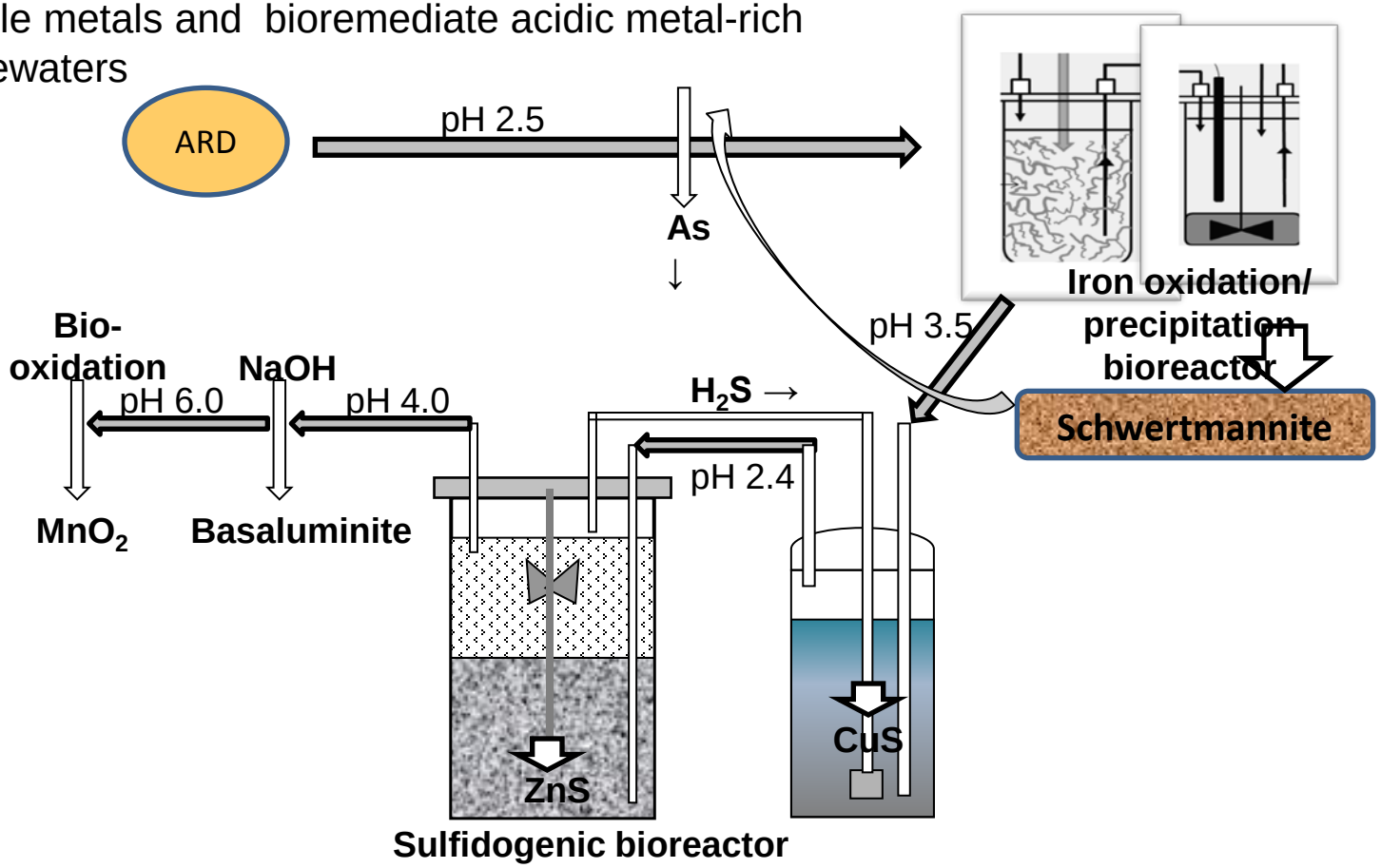
Phase II: selective capture of copper produced in phase I using biosulfidogenesis
($2\ Cu^{+} + H_2S \rightarrow Cu_2S + 2H^{+}$)



- [Cu] increased from ~ 0.5 to 80% (and therefore a commercially viable product)
- Concurrent remediation of a major environmental hazard

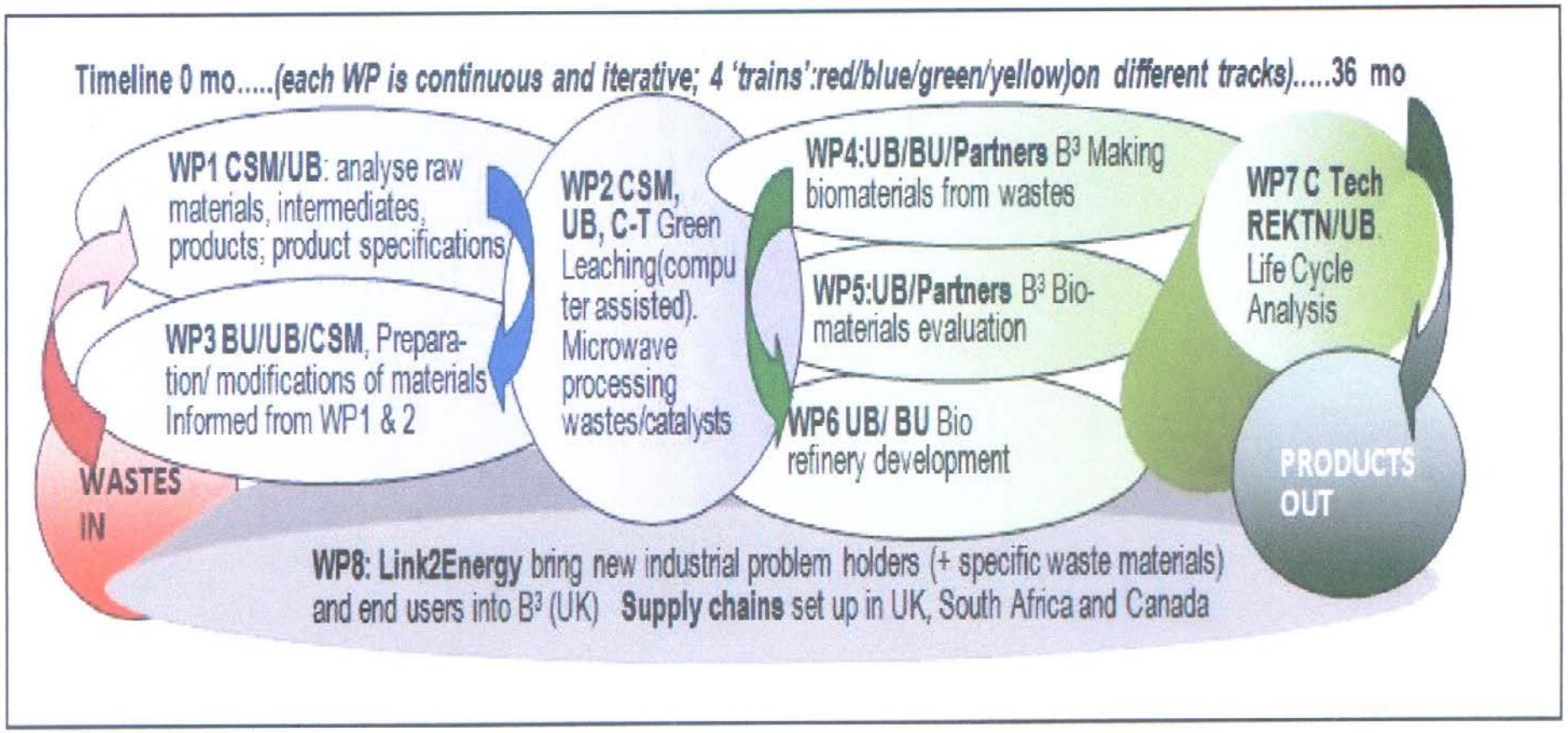
Metal sulfides generated on-line and off-line by acidophilic sulfidogens

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 B^3: how it will deliver



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 New joiners are embraced!	Each service and supply chain has redundancy so task can be re-allocated.