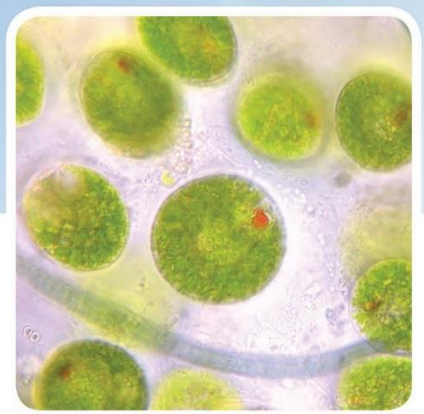
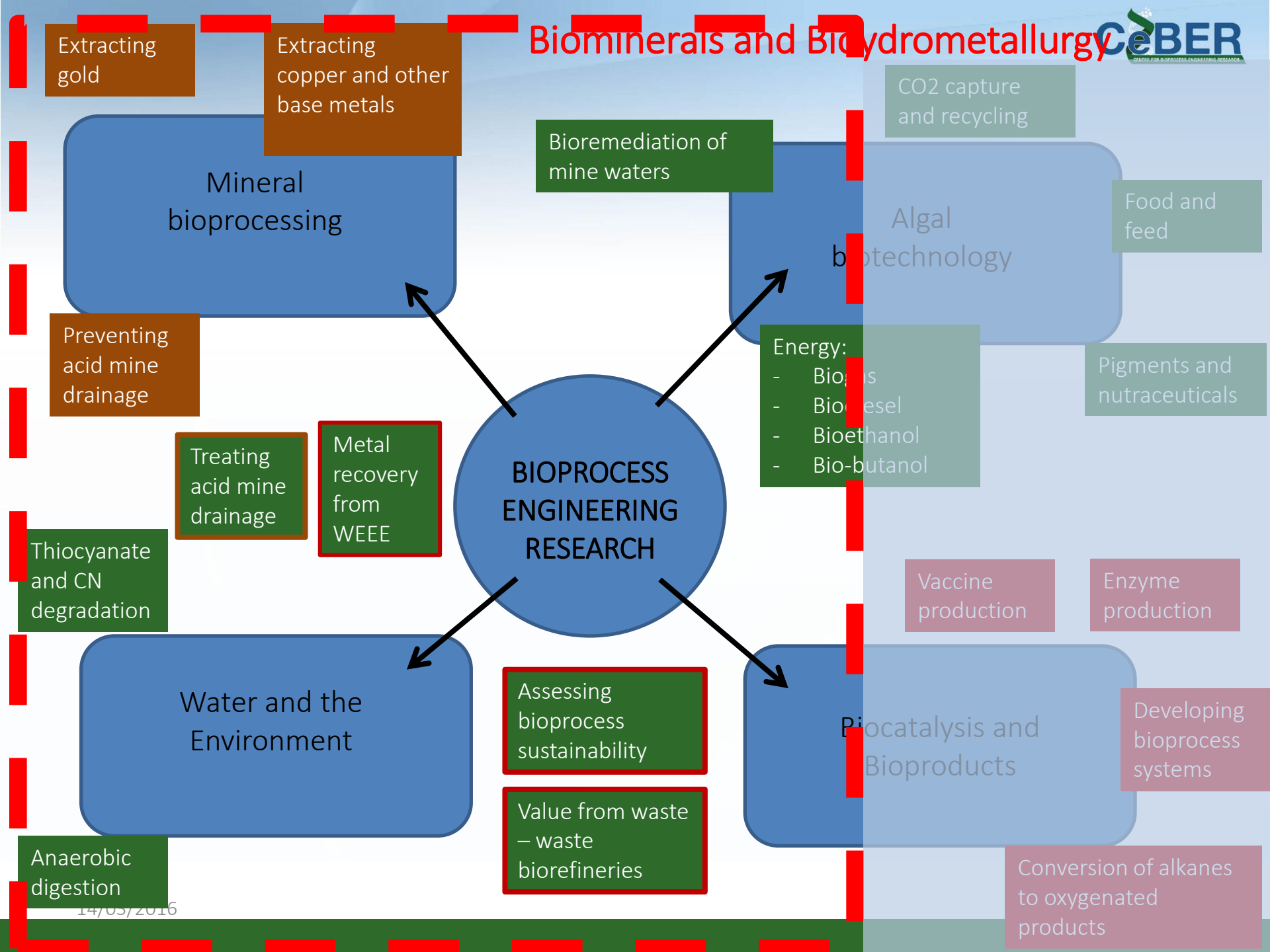
TECHNOLOGY SOLUTIONS FOR WEEE and BIOPROCESS ENGINEERING AT CeBER, UCT

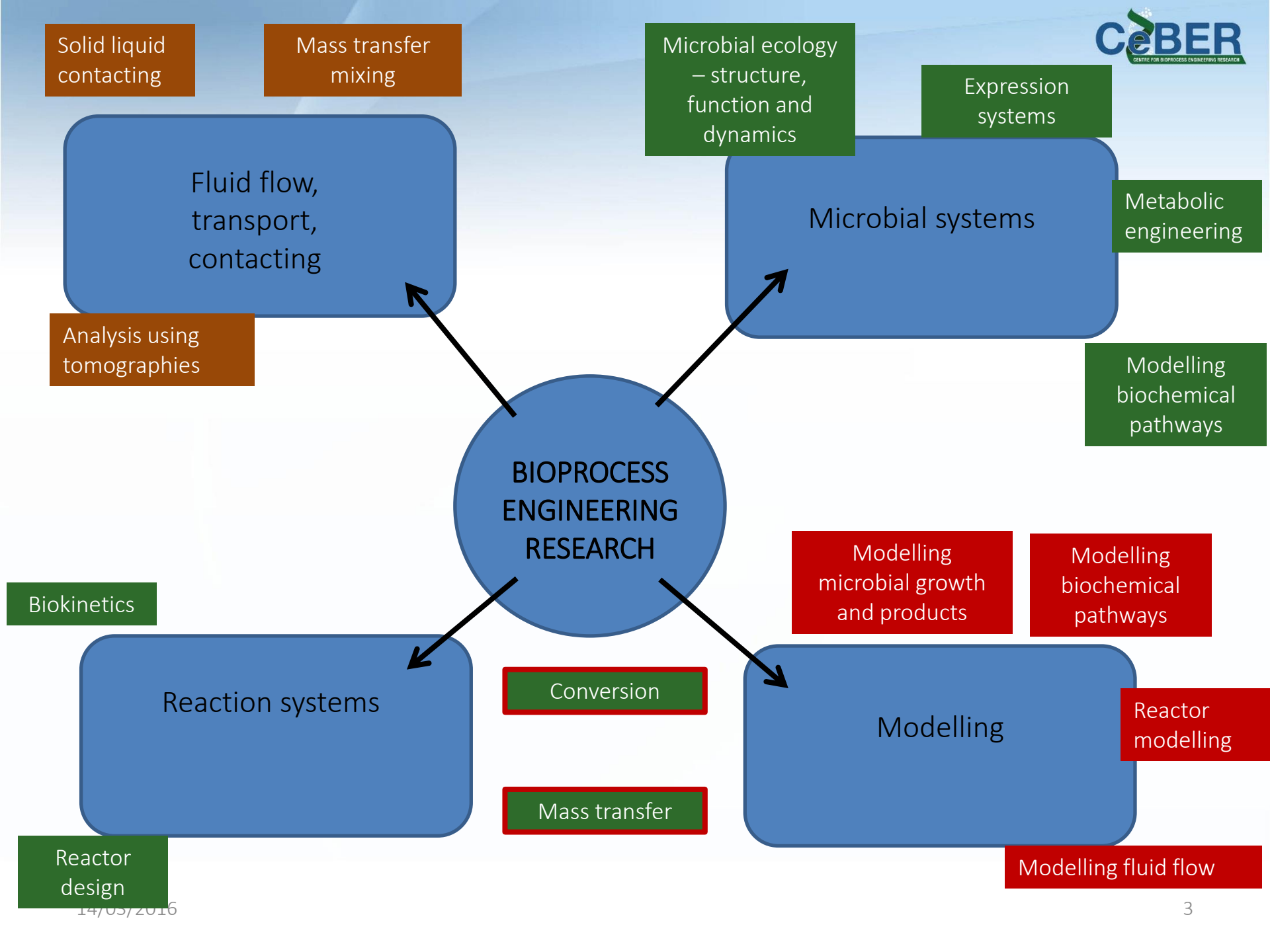
Approaches for maximising resource productivity

Centre for Bioprocess Engineering Research, UCT



Biominerals and Biohydrometallurgy




Solid liquid contacting
Mass transfer mixing
Microbial ecology – structure, function and dynamics
Expression systems
Fluid flow, transport, contacting
Microbial systems
Metabolic engineering
Analysis using tomographies
Modelling biochemical pathways
BIOPROCESS ENGINEERING RESEARCH
Modelling microbial growth and products
Modelling biochemical pathways
Biokinetics
Reaction systems
Conversion
Modelling
Reactor modelling
Mass transfer
Reactor design
Modelling fluid flow

Staff and Students

Academic Staff

Prof Sue Harrison	*SARChI Research Chair in Bioprocess Engineering*
A/Prof Jochen Petersen	*Chemical engineering / Hydrometallurgy*
Dr Siew Tai	*Chemical engineering/ Biotechnology*
Dr Caryn Fenner	*Microbiology / Biochemistry*
Dr Madelyn J-R	*Chemical Engineering*
Dr Marijke Fagan	*Chemical Engineering*
Dr Rob Huddy	*Molecular biology / Biotechnology*

Biominerals & Biohydrometallurgy team

Academic staff and Postdoctoral researchers :

Prof Sue Harrison	SARChI Research Chair in Bioprocess Engineering
Prof Jochen Petersen	Chemical engineering / Hydrometallurgy
Dr Marijke Fagan	Chemical Engineering
Dr Rob Huddy	Molecular biology / Biotechnology
Dr Thanos Kotsiopoulos	Chemical engineering
Dr Elaine Govender	Chemical engineering
Dr Mariette Smart	Biotechnology
Dr Palesa Diale	Chemical engineering
Dr Juarez Amaral-Filho	Hydrometallurgy

Students

PhD candidates: 9 candidates

Masters candidates: 10 candidates

Technical support:

Emmanuel Ngoma

Tich Samkange

Tolbet Mhlangabezi

AREAS OF RELEVANCE WRT BIOHYDROMETALLURGY

From virgin ores

From waste rock

From used goods, electrical & electronic waste

- **Metal extraction and recovery**
- **Prevention of environmental damage**

Prevent AMD

Treat AMD

Disposal of & re-use of waste materials

Remediation

Disposal of & re-use of used materials

EWASTE RECYCLING TECHNOLOGIES

- Pyrometallurgy – 70% of ewaste treated in smelters (Cui & Zhang, 2008).
  - ✓ Flexible feed stream (waste in any form)
  - ✓ Recovery of Au, Ag, Cu… alloys
  - ✘ Energy intensive
  - ✘ Lack of selectivity
  - ✘ Toxic emissions

- Hydrometallurgy (Ghosh et al. 2015)
  - ✓ Selective extraction of base metals followed by precious metals
  - ✓ Using acidic (H_2SO_4, HNO_3,…) and ammoniacal media - >95% extraction
  - ✘ Highly acidic leach solution – requires dilution for electrowinning
  - ✘ Hazardous lixiviants

BIOLEACHING AS AN ALTERNATIVE / ADDITIONAL TECHNOLOGY

- ✓ Selective extraction of base metals followed by precious metals
- ✓ Acidic environment with ferric iron as leaching agent

$$4Fe^{2+} + 4H^{+} + O_2 \xrightarrow{microbes} 4Fe^{3+} + 2H_2O$$

$$Cu + 2Fe^{3+} \rightarrow Cu^{2+} + 2Fe^{2+}$$

- ✓ Avoid thermal degradation of plastics (Barontini et al. 2005).
- ✓ Potential to reduce crushing requirements as lixiviant contacting can be promoted through reactor design.
- ✓ No need for physical or chemical separation of the non-metallic components – less hazardous fraction.
- ✘ Microbial toxicity to copper
- ✘ Slow reaction rate

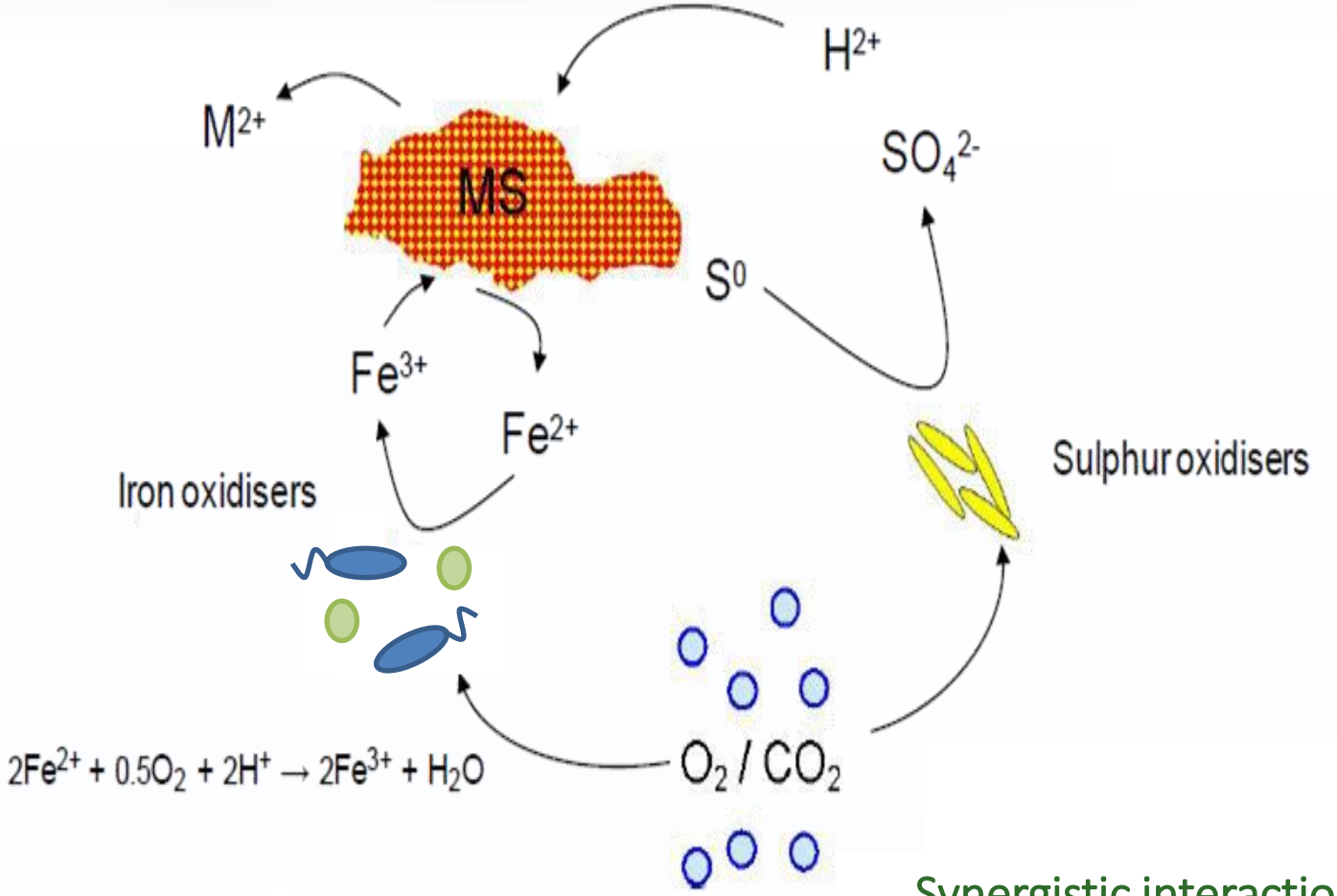
MICROBIAL REGENERATION OF FERRIC IRON

$$4Fe^{2+} + 4H^{+} + O_2 \xrightarrow{microbes} 4Fe^{3+} + 2H_2O$$

30°C, pH 2.2, *Acidithiobacillus ferrooxidans*, 20 g/L Fe^{2+}_{feed}

- Oxidation of Fe^{2+} is 500 000 times faster than chemical oxidation at same conditions (Lacey & Lawson, 1970)

Mechanism of Mineral Dissolution:
bioleaching of sulphide minerals



Synergistic interaction promotes catalytic dissolution of mineral

BIOLEACHING OF MINERAL SULPHIDES

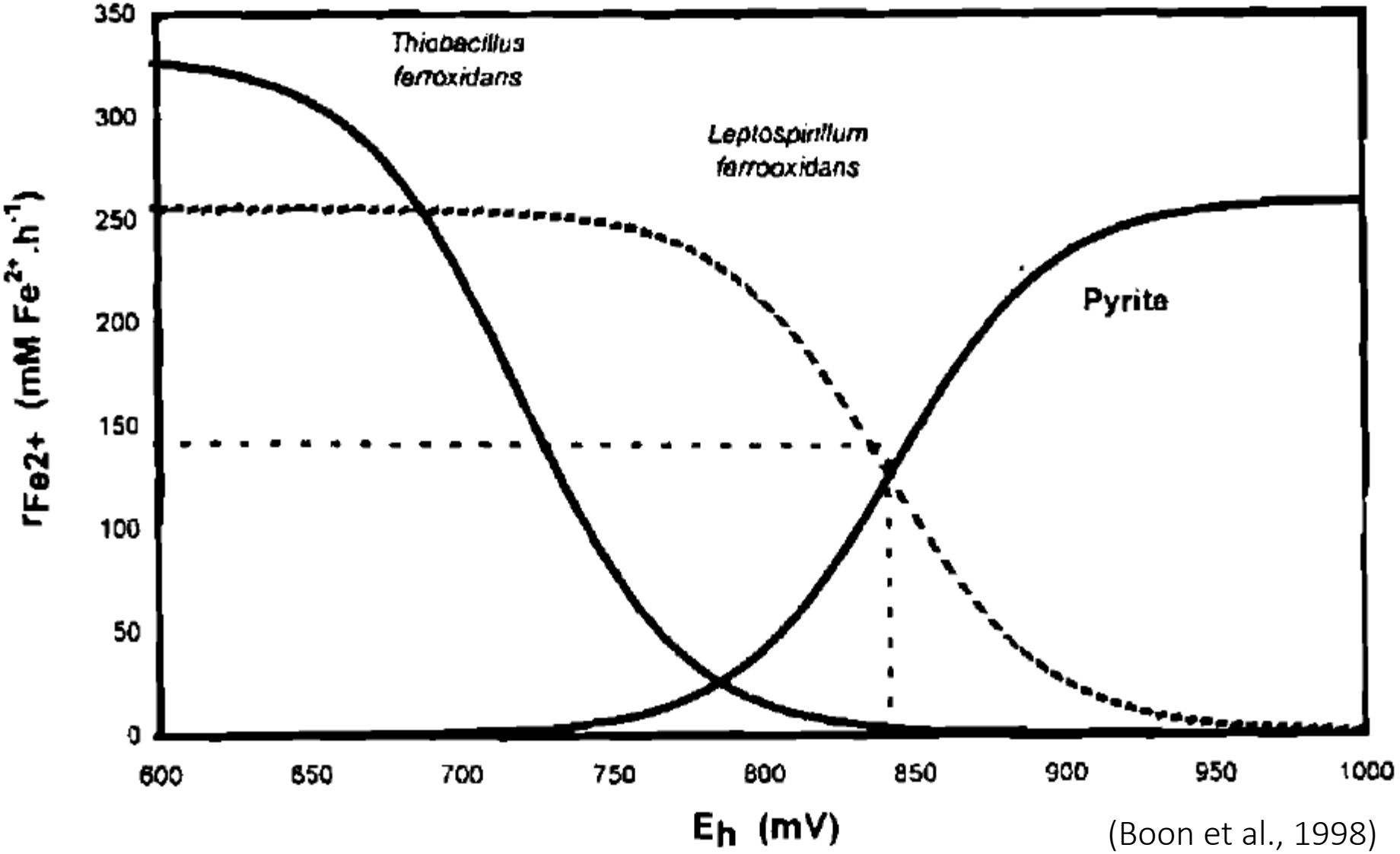
$$FeS_2 + 14Fe^{3+} + 8H_2O \rightarrow 15Fe^{2+} + 16H^+ + 2SO_4^{-2}$$

$$4Fe^{2+} + 4H^+ + O_2 \xrightarrow{microbes} 4Fe^{3+} + 2H_2O$$

30°C, pH 1.6, *Leptospirillum ferrooxidans*, 6-12 g/L Fe^{3+}_{feed}

- Pyrite dissolution rates 10 to 20 times faster than chemical leach rates.
- Facilitate optimum ferric to ferrous iron ratio in leach solution.

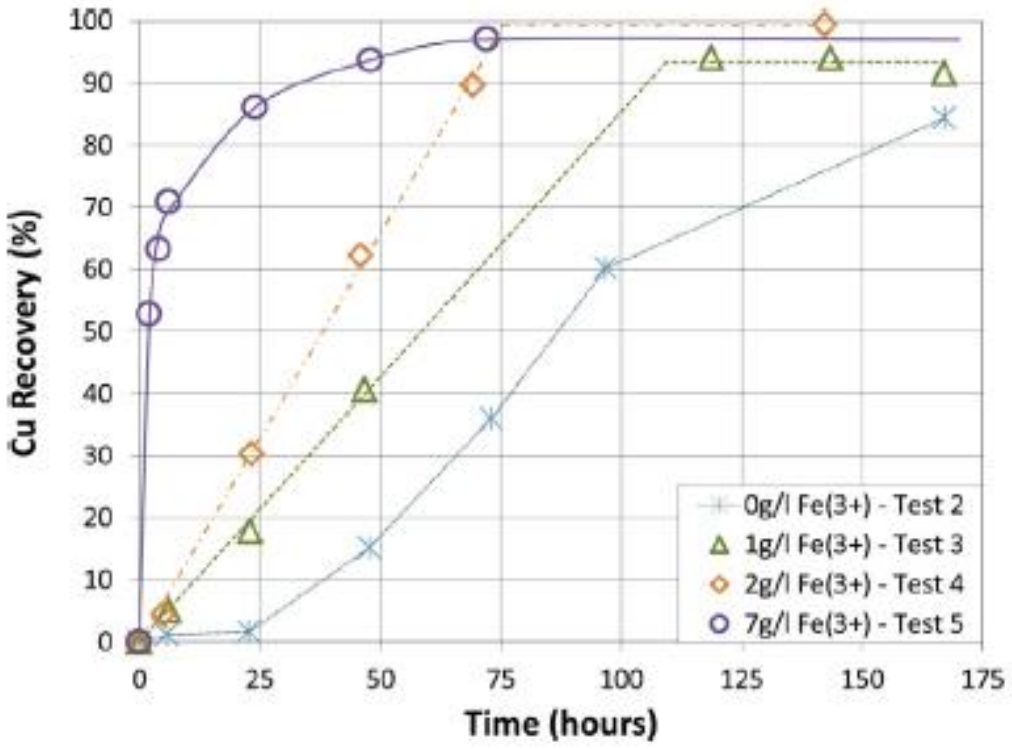
(Boon & Heijnen, 1998)



(Boon et al., 1998)

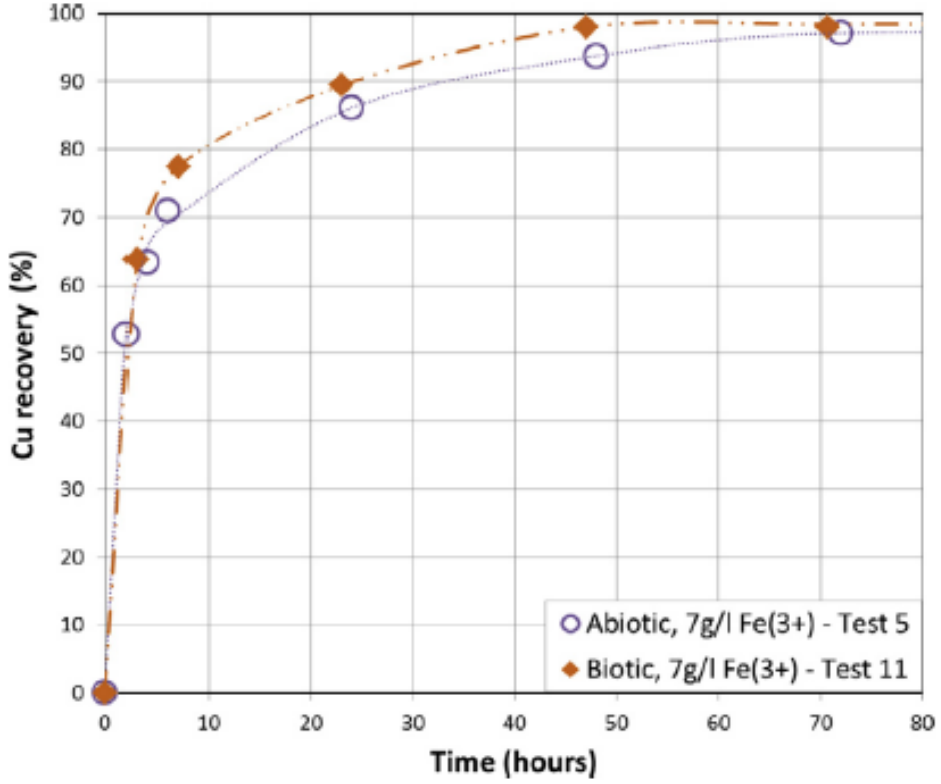
LAMBERT ET AL.(2015)

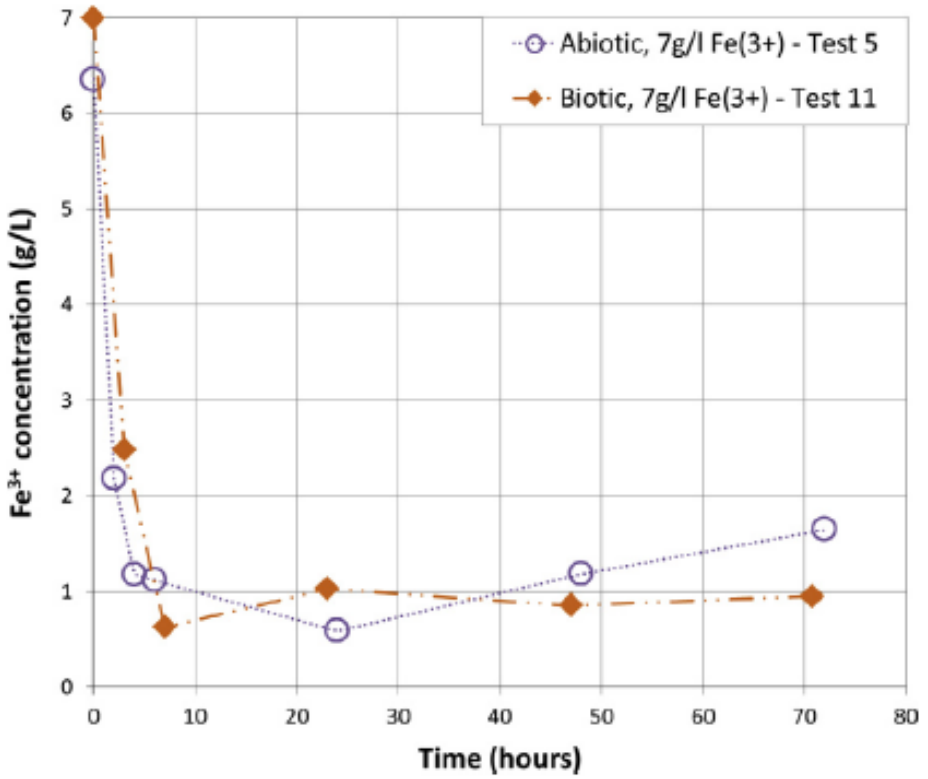
Chemical leaching



LAMBERT ET AL.(2015)

Microbial assisted leaching

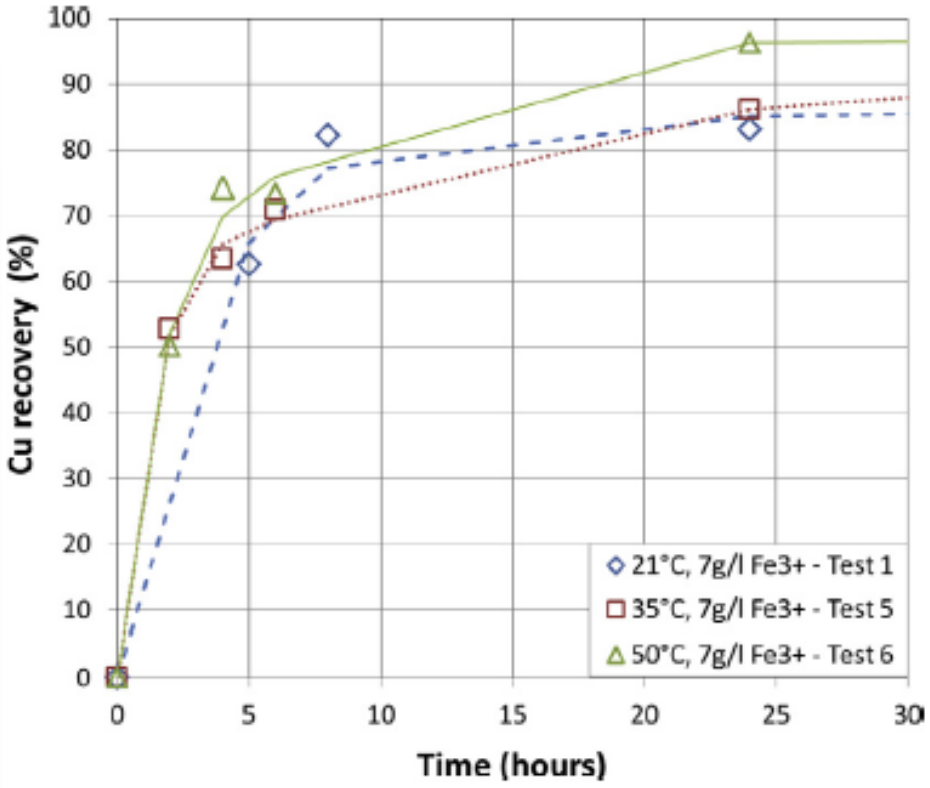




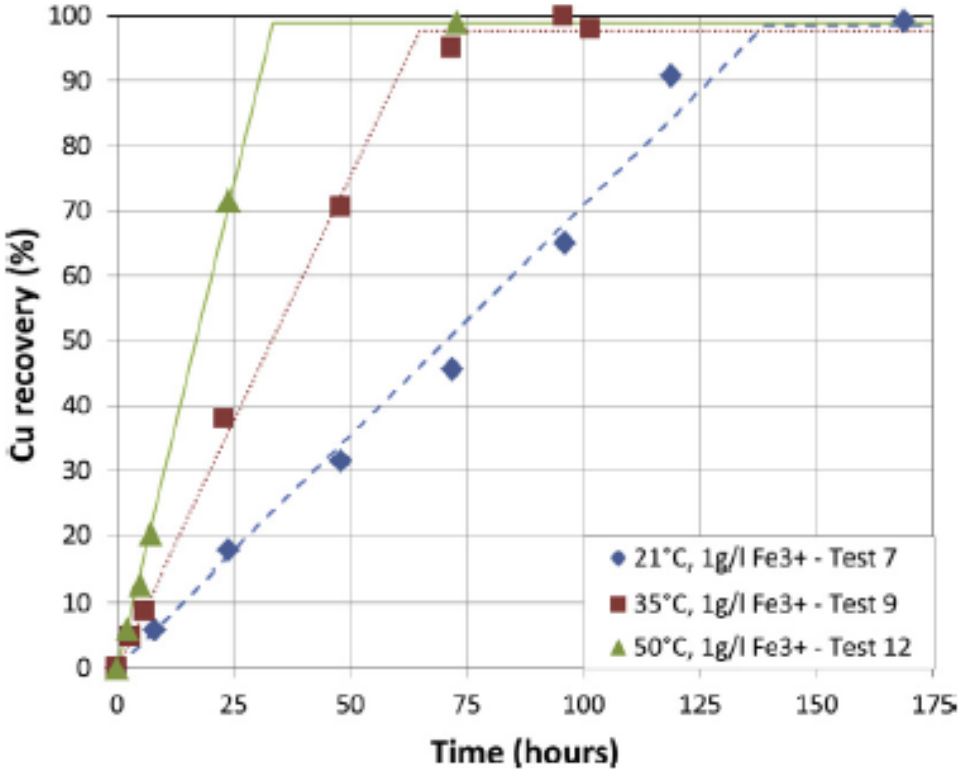
LAMBERT ET AL.(2015)

EFFECT OF TEMPERATURE

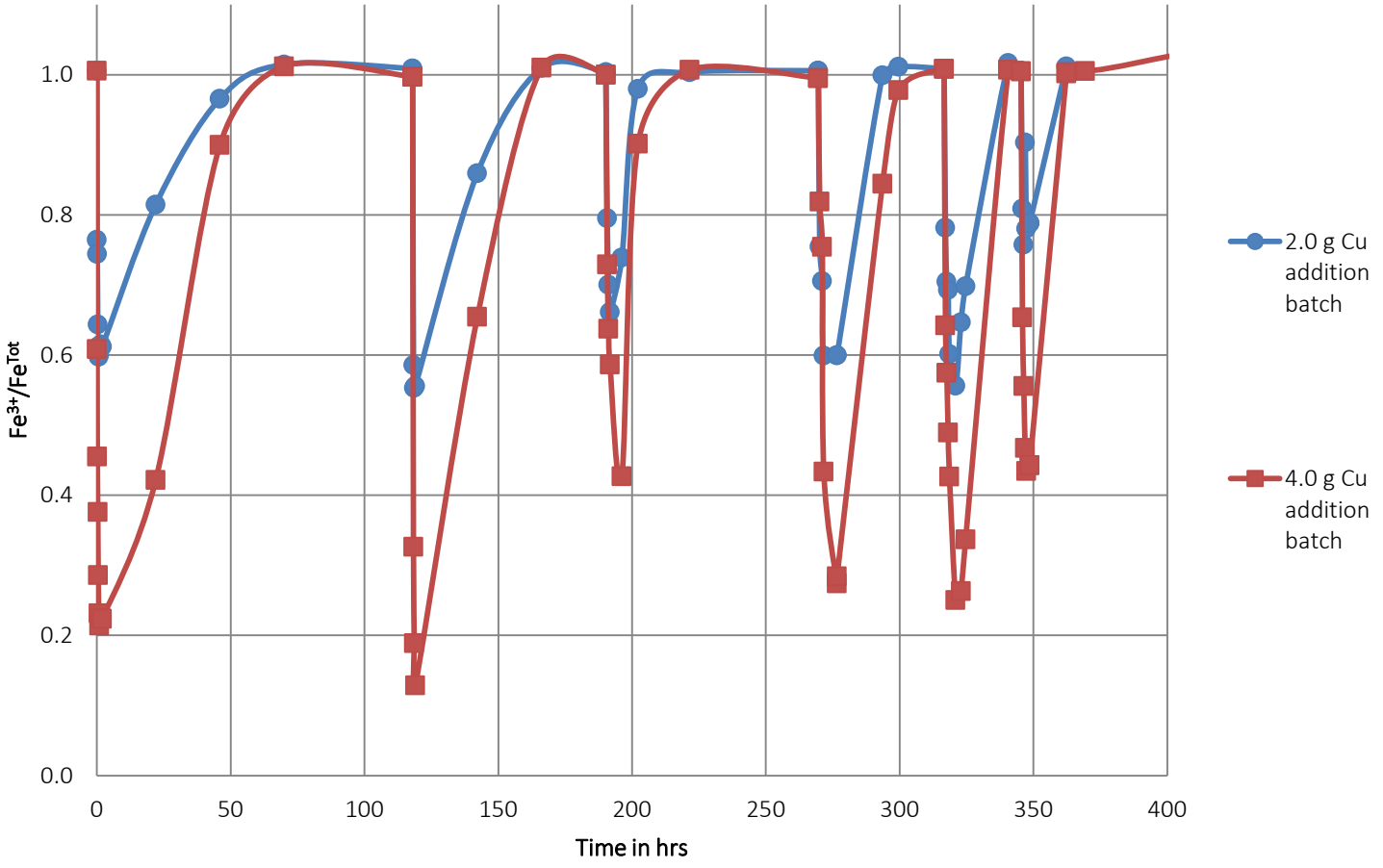
Chemical leaching



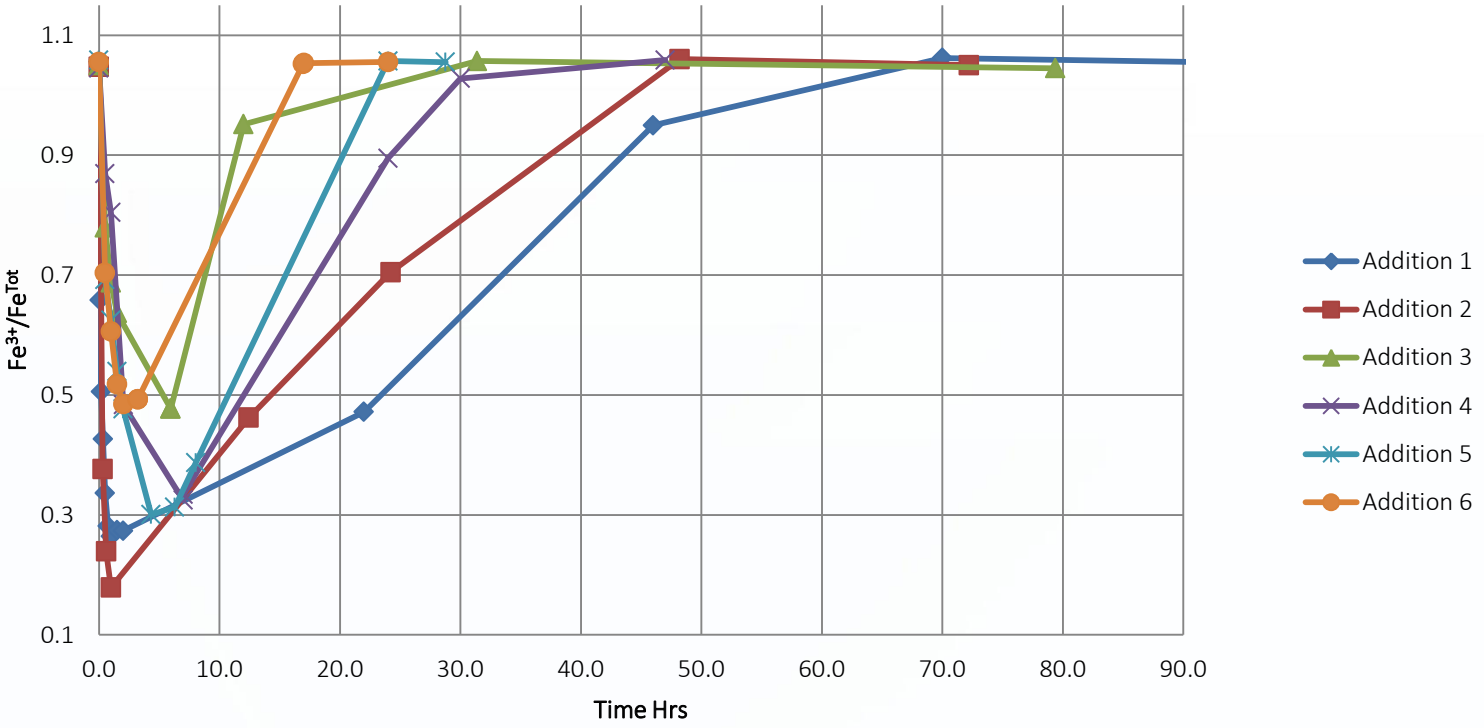
Microbial-assisted leaching



BIOLEACHING OF COPPER IN A FED-BATCH SINGLE STAGE SYSTEM



BIOLEACHING OF COPPER IN A FED-BATCH SINGLE STAGE SYSTEM



SOME RESULTS TO DATE

Demonstration of leaching with

- Copper
- Zinc
- Nickel
- Tin
- Chromium

Utilisation of waste pyrite as the source of ferric iron and acid

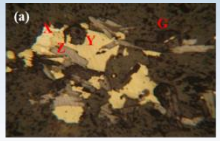
Process modelling

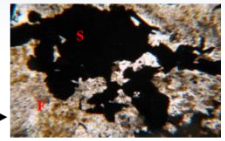
NEXT STAGE

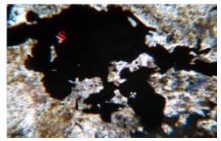
- Augmenting biological stage to enhance ferric iron regeneration
- Addressing the extent of pre-processing required and its impact on contacting
- Integrating base metal dissolution with metal recovery
- Optimising PCB pre-treatment prior to recovery of valuable metals by chemical leach processes

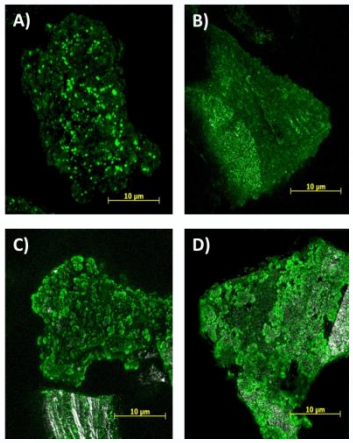
BIOHYDROMETALLURGICAL FACILITIES AT CEBER

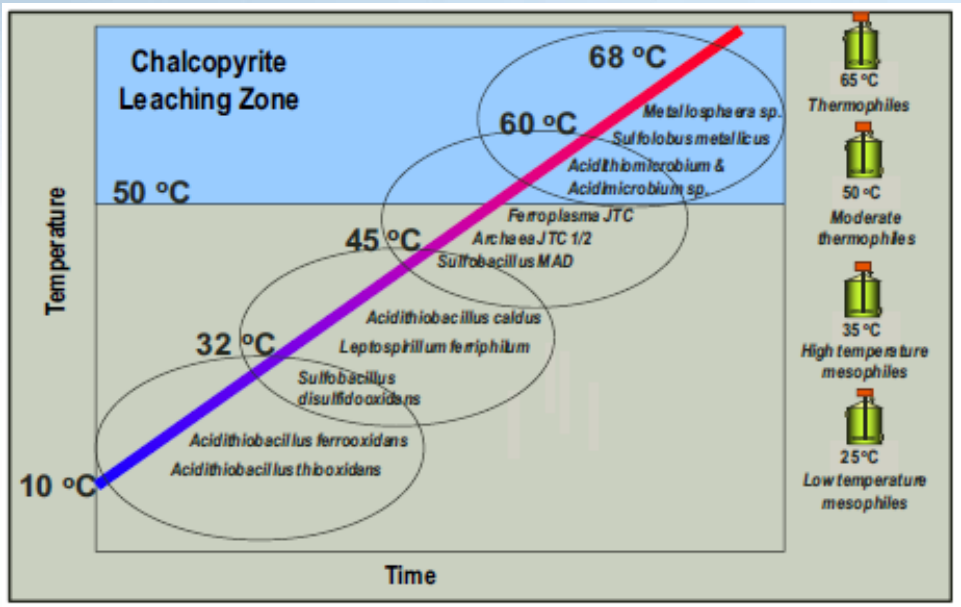
- Tank reactors (3 ml – 7 litre)
- Column reactors (4 – 200 kg)
- Electrochemical systems
- Tomography systems
- Access to SEM and QEMSEM
- qPCR and other molecular facilities
- Fluorescent and light microscopy
- Off-gas analysis
- HPLC, IC, ICP, AA
- ARD characterisation
- Process modelling – HeapSim, Phreeq


(a)





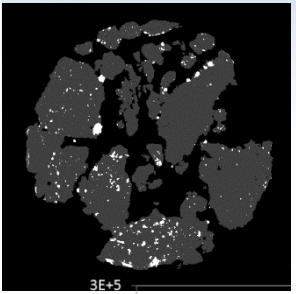

A)
B)
C)
D)


Chalcopyrite
Leaching Zone
68 °C
60 °C
50 °C
45 °C
32 °C
10 °C
Metallosphaera sp.
Sulfolobus metallicus
Acidithiomicrobium &
Acidimicrobium sp.
Ferroplasma JTC
Archaea JTC 1/2
Sulfobacillus MAD
Acidithiobacillus caldus
Leptospirillum ferriphilum
Sulfobacillus
disulfidooxidans
Acidithiobacillus ferrooxidans
Acidithiobacillus thiooxidans
Temperature
Time
65 °C
Thermophiles
50 °C
Moderate
thermophiles
35 °C
High temperature
mesophiles
25°C
Low temperature
mesophiles

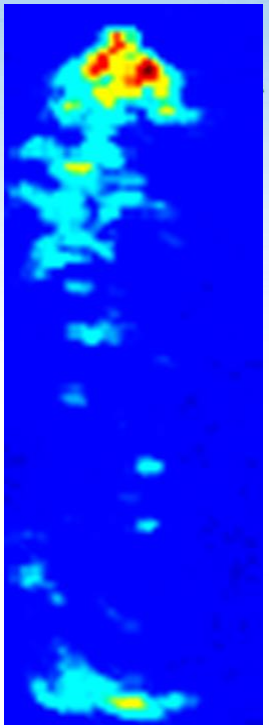
a

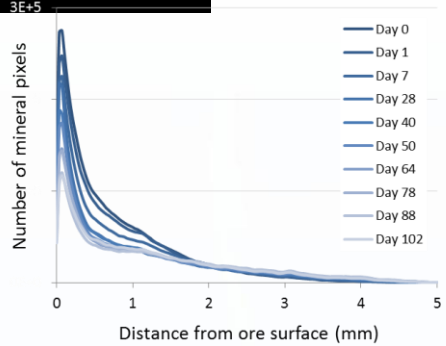
b

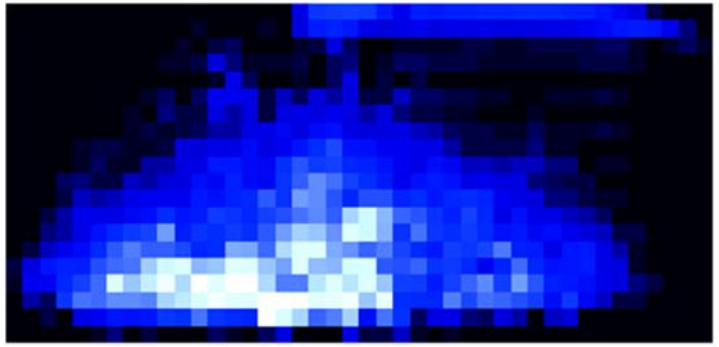
HEAP BIOLEACHING: MINERAL-LEACHATE CONTACTING AND LIBERATION



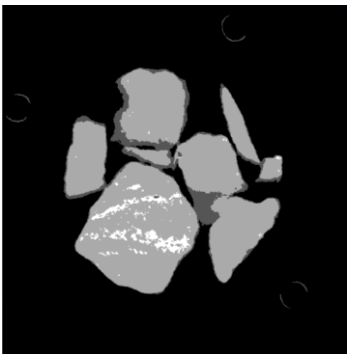
- Study through a range of tomographies:
  - X-ray CT
  - Positron emission tracking (PET)
  - MRI







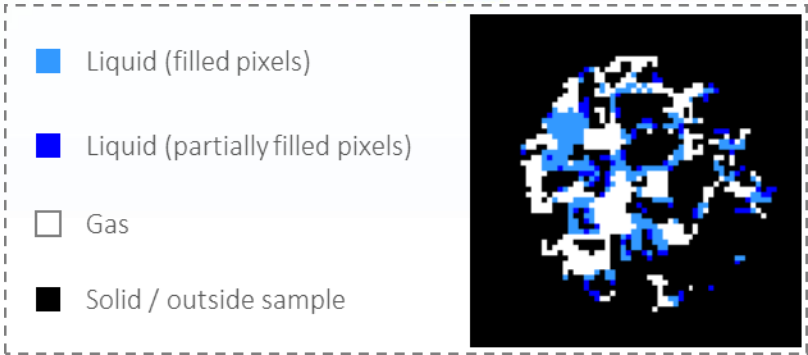
SESPI: novel MRI protocol to image ferromagnetic ores



X-Ray CT

Traditional MRI

SESPI



Our forward focus

- Metals from complex ores
- Metals from low grade ores
- Metals from unconventional resources – mining waste, e-waste, MSW for value recovery
- Minimising pre-processing of WEEE
- Fundamental contacting knowledge for heaps, waste rock dumps & WEEE
- Integrated metal dissolution and recovery systems
- Process modelling
- Novel metal recovery processes
- Microbial ecology for enhanced and robust metal recovery or remediation
- Water remediation and recycle

Acknowledging…

CeBER
CENTRE FOR BIOPROCESS ENGINEERING RESEARCH

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CSIR
our future through science

WATER RESEARCH COMMISSION

AngloAmerican

BIOMIN
sustainability • innovation • delivery

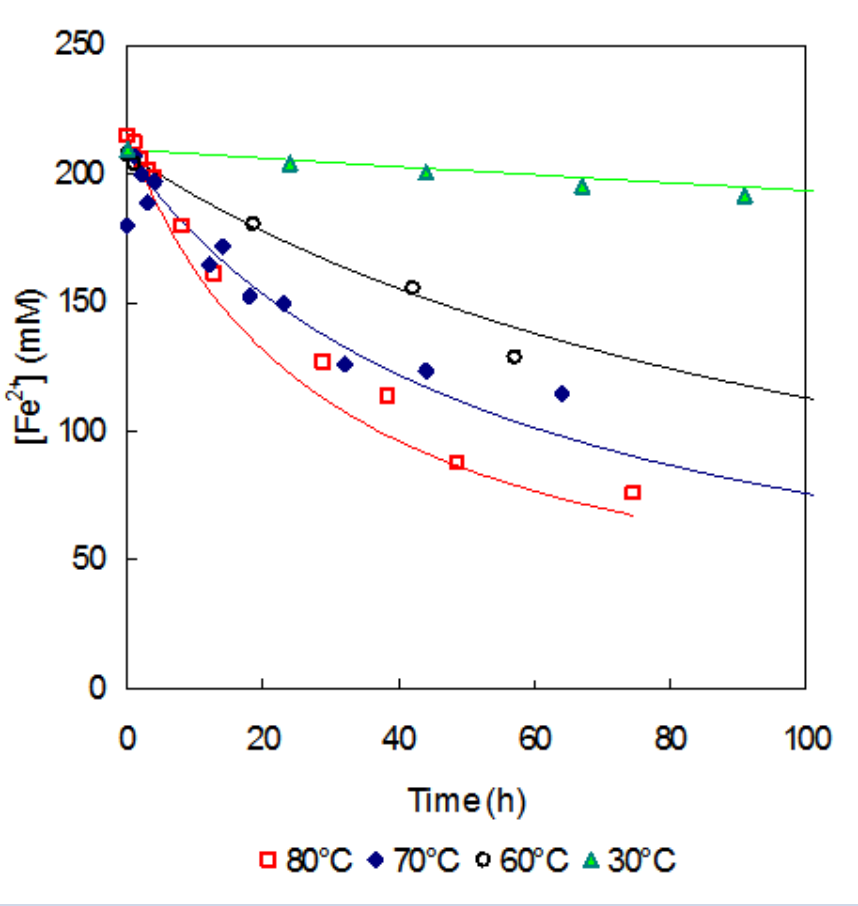
NRF National Research Foundation

the dti
Department:
Trade and Industry
REPUBLIC OF SOUTH AFRICA

science & technology
Department:
Science and Technology
REPUBLIC OF SOUTH AFRICA

EFFECT OF TEMPERATURE ON MICROBIAL REGENERATION OF FERRIC IRON

CHEMICAL	MICROBIAL



Searby (2006)

MICROBIAL-ASSISTED LEACHING OF COPPER

> 90% copper extraction in chemical and microbial assisted leach after 1 day.

- Chemical optimum at 50°C with 6.4 g/L Fe^{3+}
- Microbial-assisted optimum at 35°C with 7g/L Fe^{3+}
- $r_{Cu\ leach}$ ~ 5 times $r_{Fe3+\ regeneration}$
- Things to consider for optimisation:
  - ? Lower temperatures ↔ higher Fe^{3+} concentrations
  - ? Lower temperatures ↔ lower acid consumption
  - ? Lower Fe^{3+} concentration ↔ increase in residence time
    2 g/L leaches 90% copper over 3 days
  - ? Reactivity Al > Zn > Cu > Sn