Mine water treatment, resource recovery and sustainability

Professor Devin Sapsford

UNESCO Chair in Developing a Sustainable Geoenvironment

Director, Geoenvironmental Research Centre, School of Engineering

Cardiff University, UK

UNESCO uniTwin unesco Chair

CARDIFF UNIVERSITY PRIFYSGOL CAERDYDD

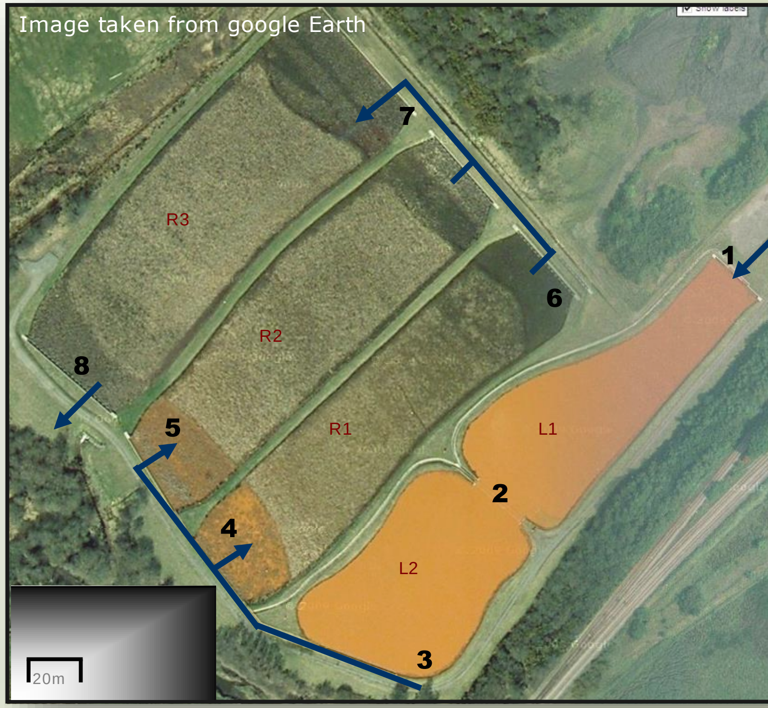




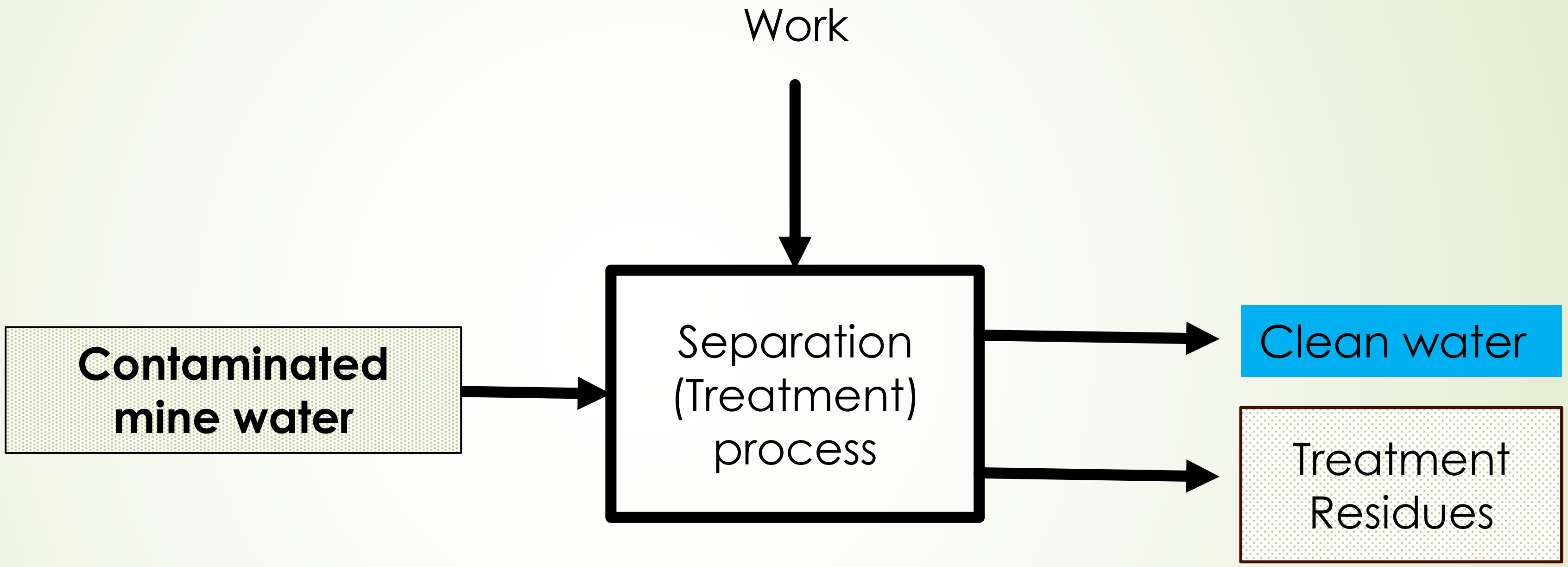




Mine water treatment: Passive v. Active and sustainability

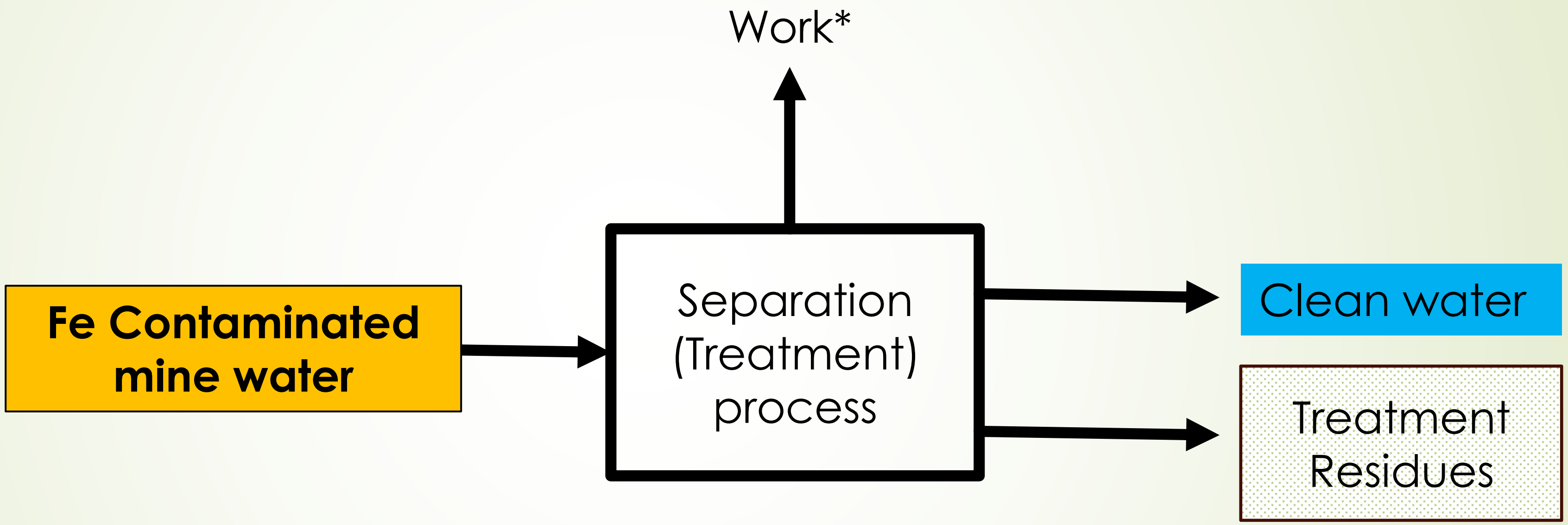


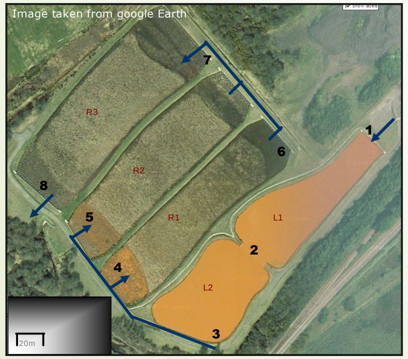
Mine water treatment process



....but not for all contaminants

*Cheng, S., Dempsey, B.A. and Logan, B.E., 2007. Electricity generation from synthetic acid-mine drainage (AMD) water using fuel cell technologies. Environmental Science & Technology, 41(23), pp.8149-8153.

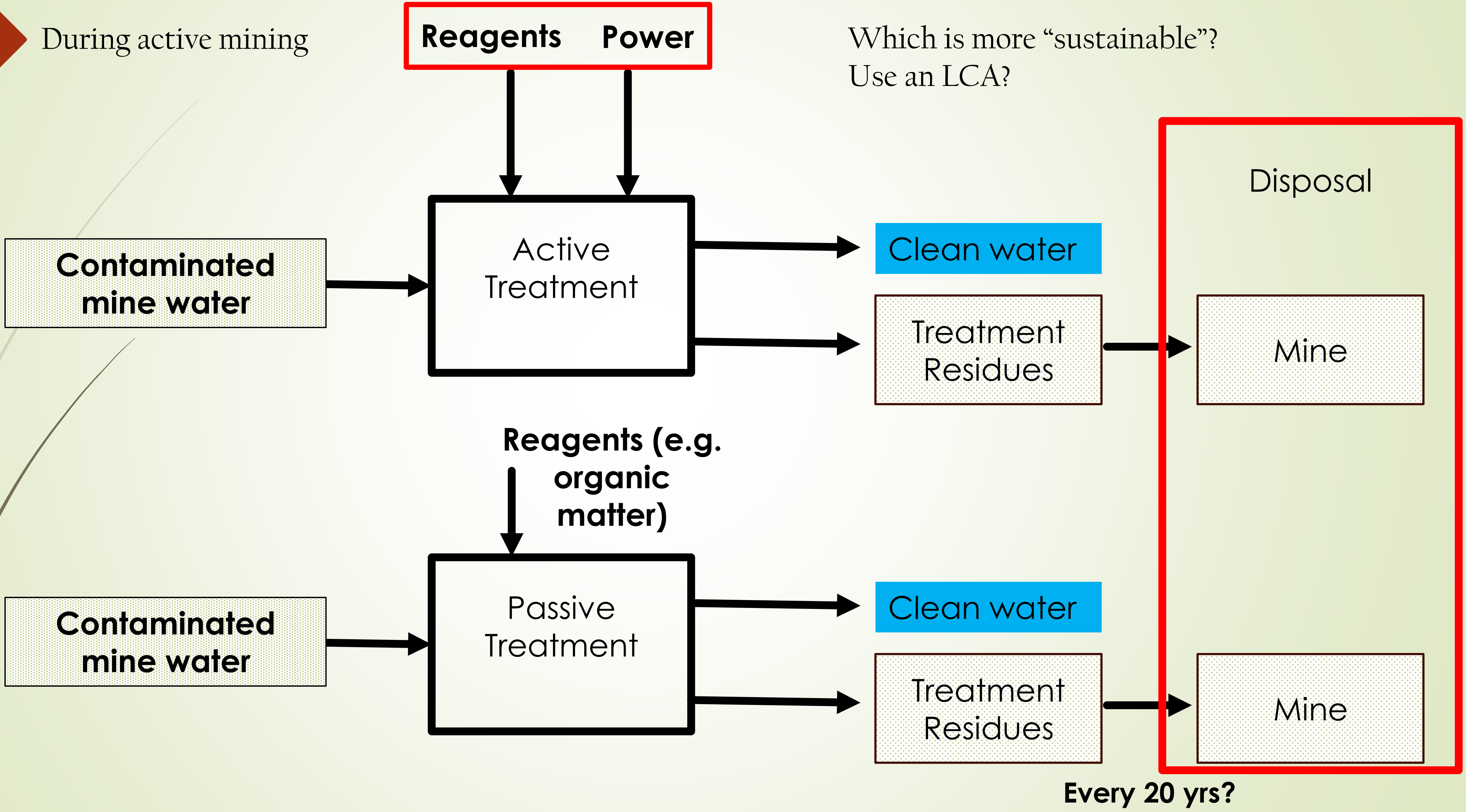




Which is lower cost?

During active mining

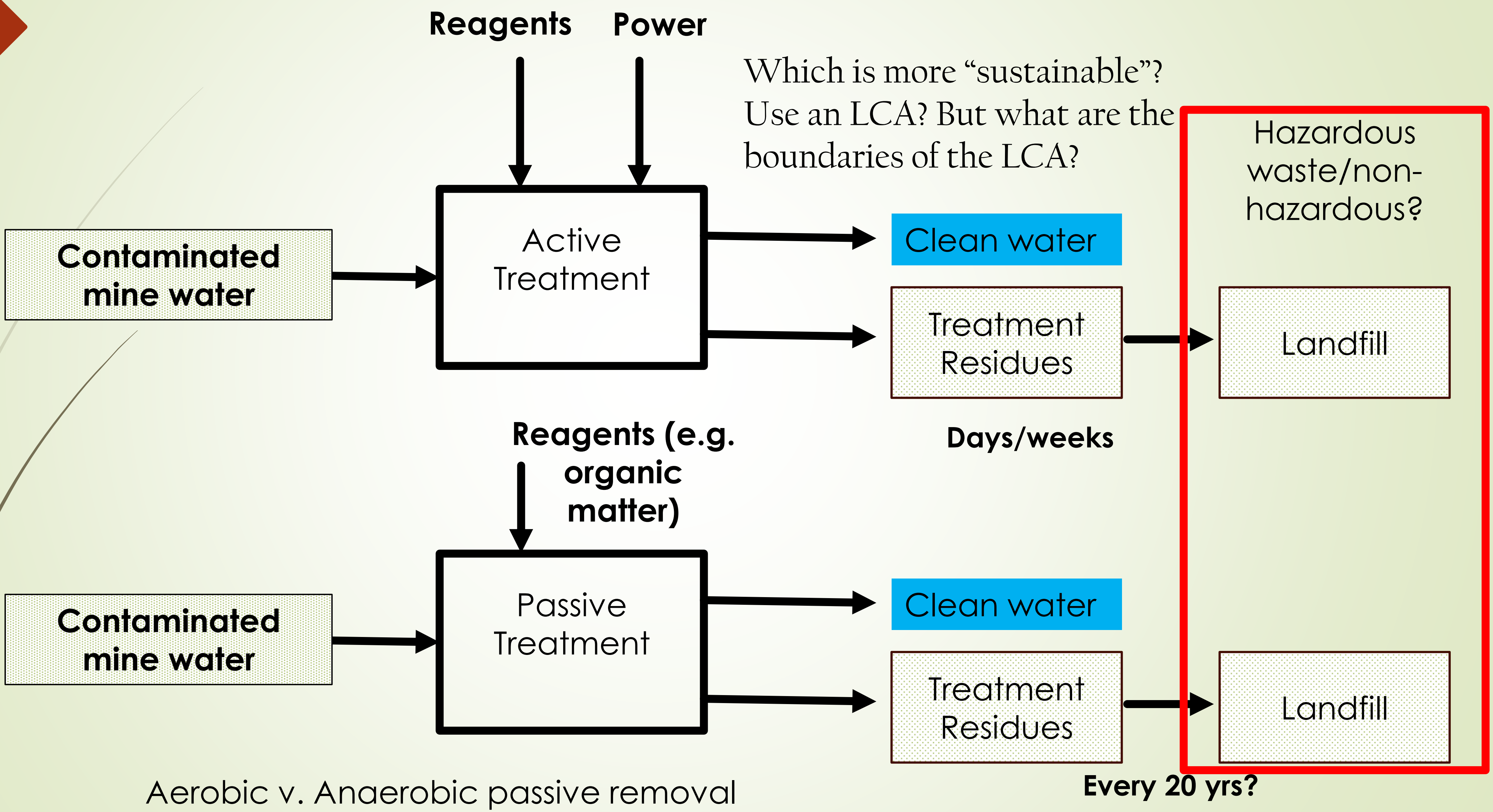
Which is more “sustainable”?
Use an LCA?



Legacy mine water in highly waste-regulated countries such as UK

Which is lower cost? Hazardous waste disposal a costly problem

Which is more "sustainable"? Use an LCA? But what are the boundaries of the LCA?



Aerobic v. Anaerobic passive removal

Outcomes from the METAL-SoVLER project

The central research questions are around cost and sustainability/circularity:

Can passive and semi-passive treatment options which produce residues which are either easy to recycle/reprocess or at least have improved waste disposal cost implications?

Semi-passive (or semi-active) treatment of circumneutral zinc-bearing drainage

Abbey Consols and sodium carbonate dosing – **why Na_2CO_3?**

Previous work

Field trial 2020 (NRW, WSP and Cardiff University)

1. Zinc concentration in effluent

- Dissolved zinc remaining in effluent 9-42%
- Total zinc remaining in effluent 39-73%

2. Precipitate properties

- Moisture content - 95%
- Zn content – 46%
- Inorganic carbon – 1.2%

Lab Research Objectives

1. Research methods to increase settling velocity/reduce sludge volume
2. Characterize precipitate

[1] Williams, T., Dent, J., Eckhardt, T., Riding, M. and Sapsford, D., 2020. Treatability Trials to Remove Zinc from Abbey Consols Mine Water, Wales, UK. Pope, J. et al, pp.225-230. [2] Dean, J., Alkhazraji, B. and Sapsford, D.J., 2021. Alternative reagents for the treatment of Pb-Zn mine drainage in Wales. In IMWA 2021–"Mine Water Management for Future Generations (pp. 109-114)..

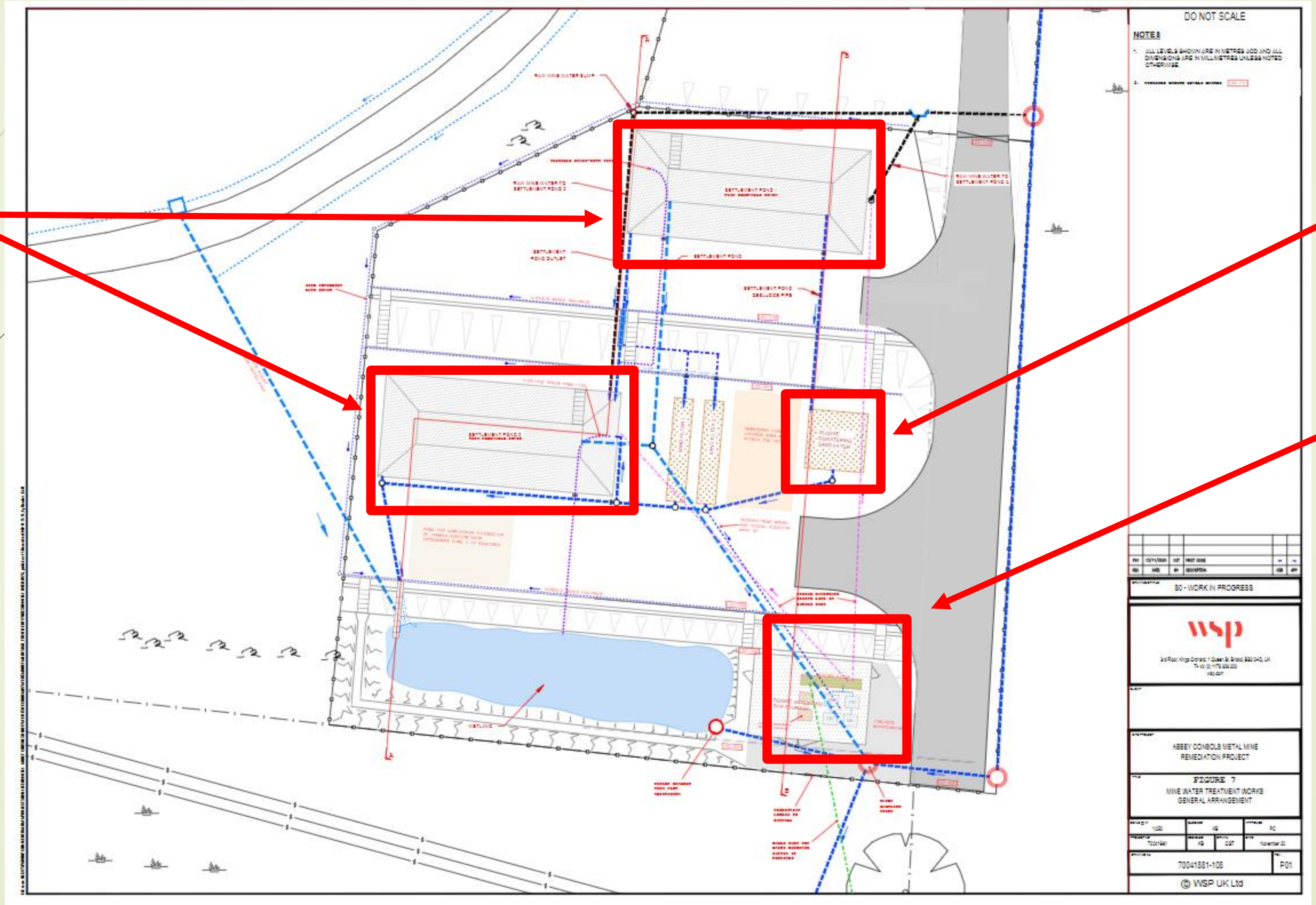
Reactor Design

Full scale demonstrator build

Settling ponds

Sludge dewatering

Dosing kiosk



Methods to increase settling velocity/reduce sludge volume

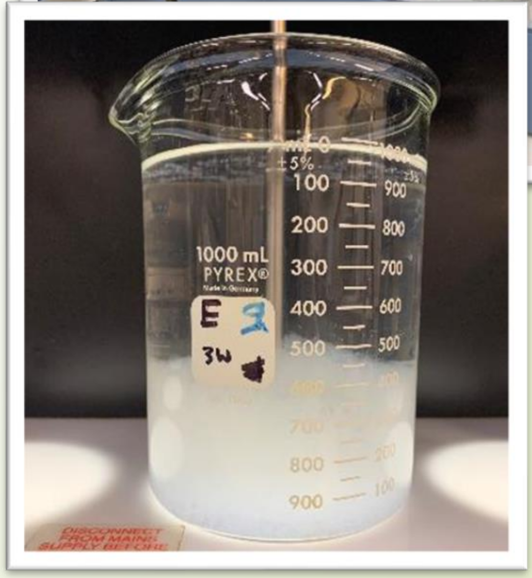
Jar tests

Established optimum dose and time to react

- 1:3.5
- Very fast reaction

Dosing rate

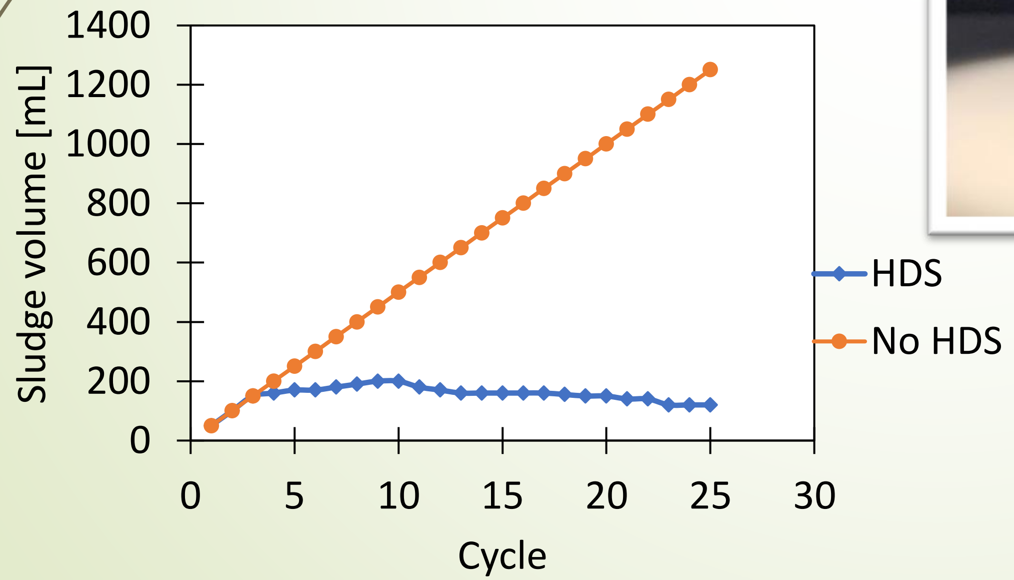
- Slower rate of addition halved sludge volume
- Potential to trial this at full scale
- Trial multipoint dosing within the settling ponds

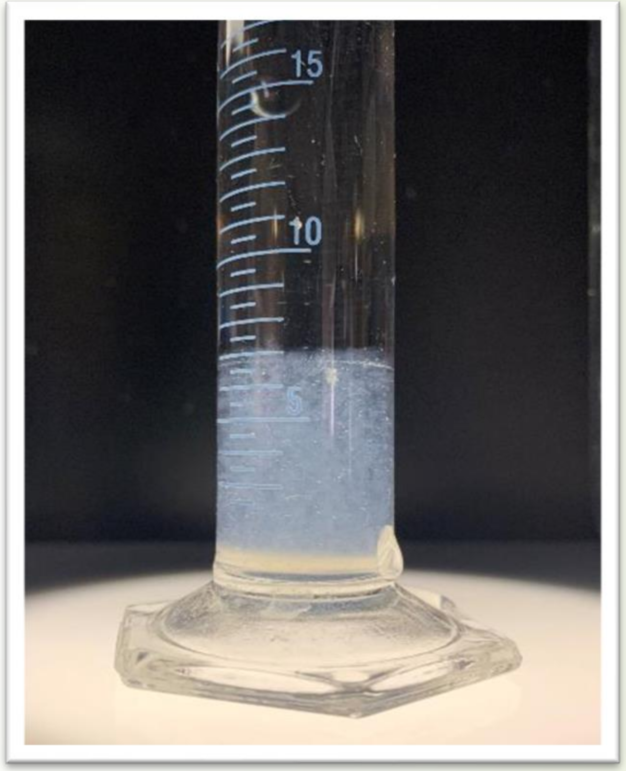


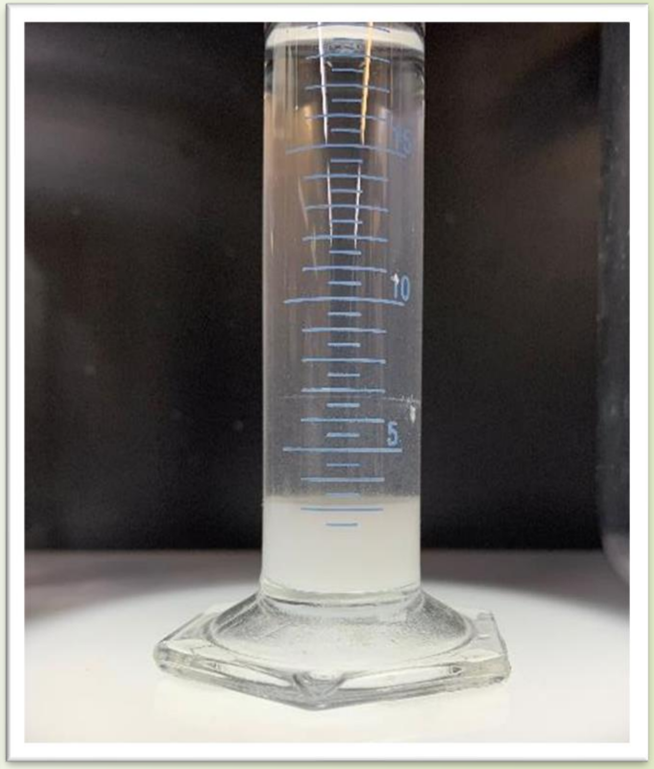
Methods to increase settling velocity/reduce sludge volume

High Density Sludge formation

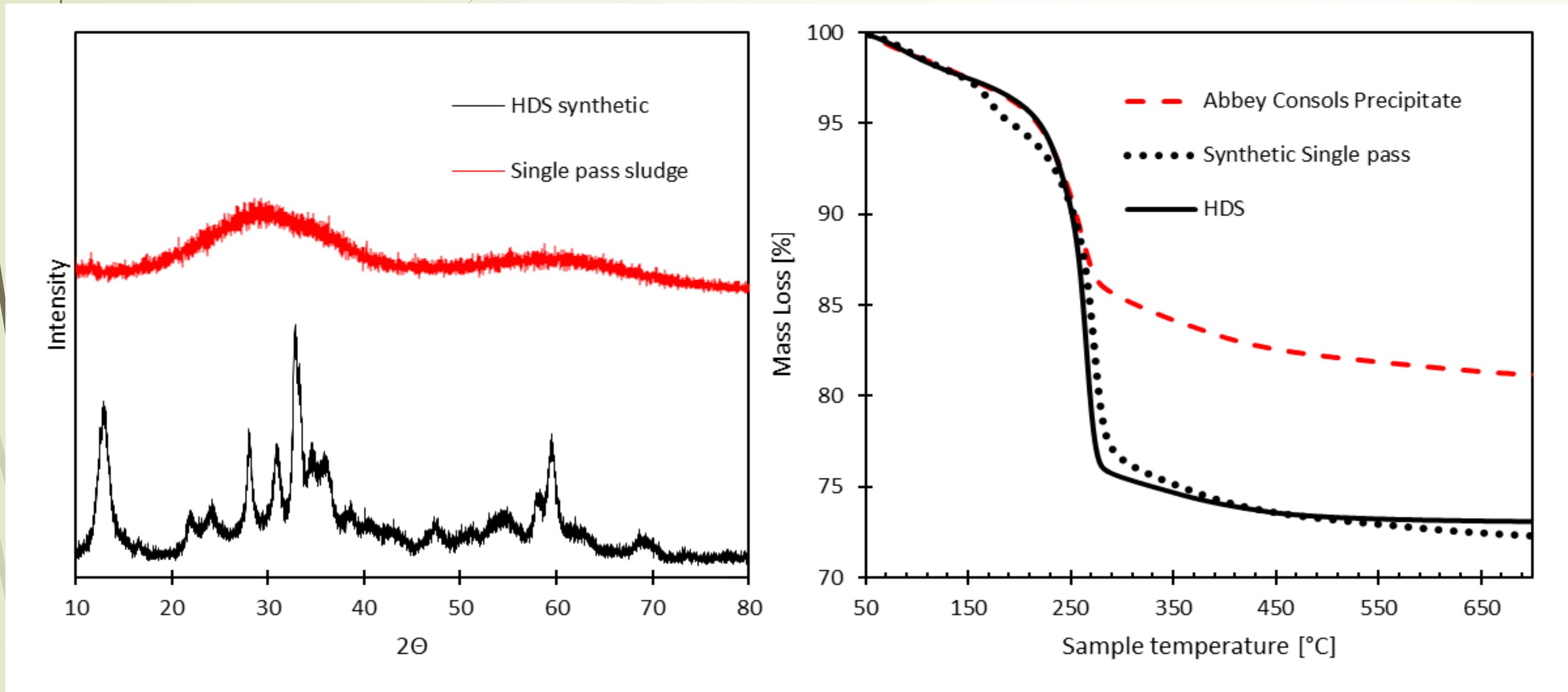
- Zn/Na_2CO_3 system readily forms HDS
- Reduce sludge volume *ca.* 10X
- **Without use of flocculant**
- Trial recycling of sludge at full scale

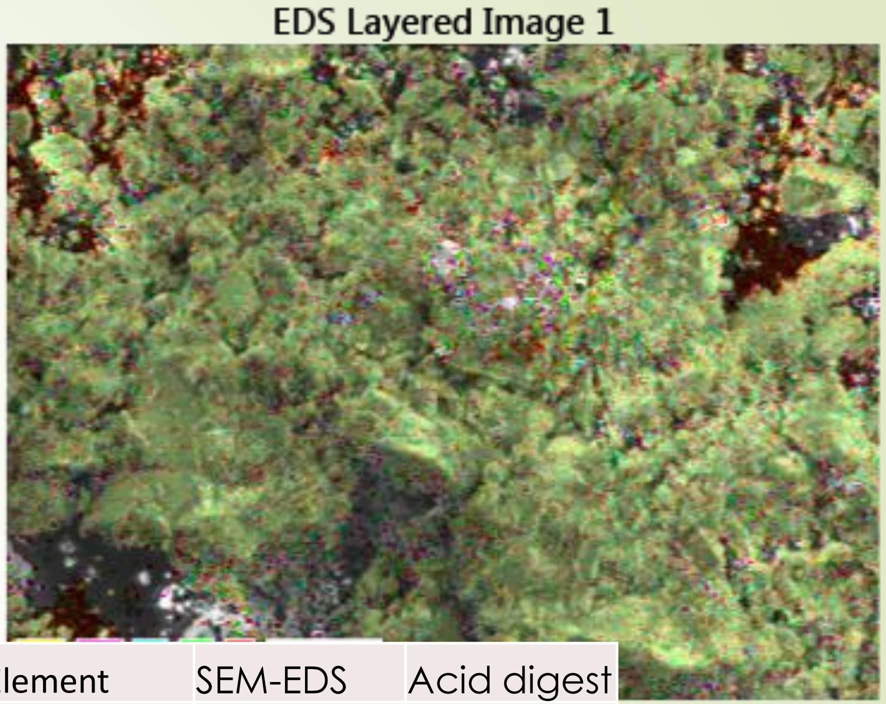






Characterization of sludge

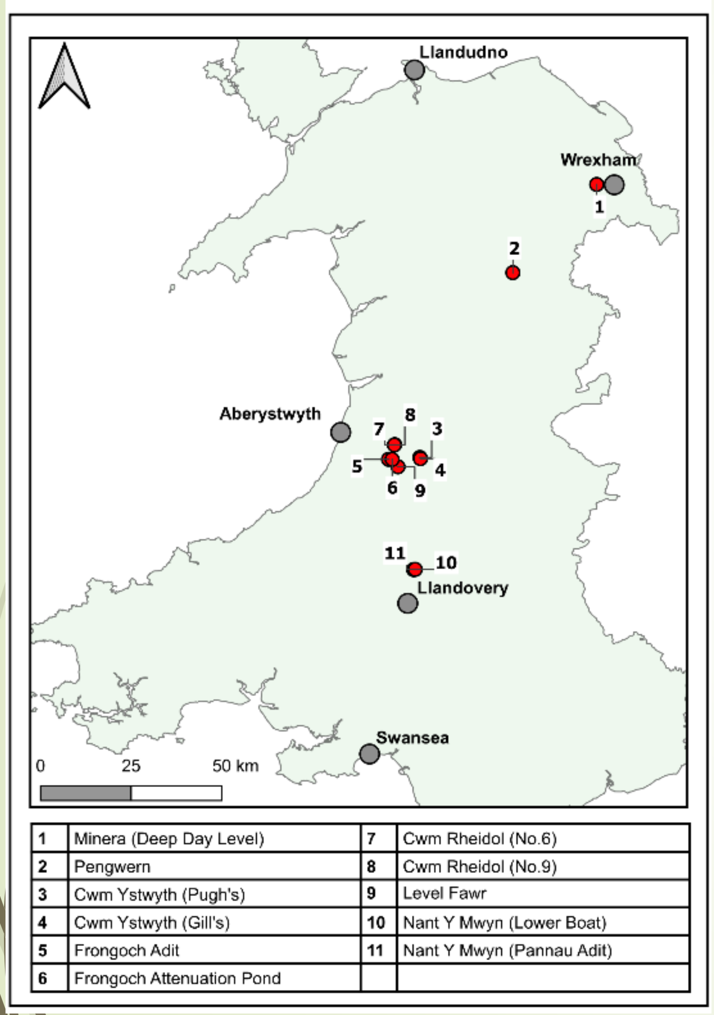




Element	SEM-EDS	Acid digest
Zn	45	48.90
O	30	NA
C	15	NA
Si	5	NA
Na	4	0.10
Pb	1	1.00
Ca	ND	0.20
Fe	ND	0.02
Al	ND	0.25

Recycle/reprocess or dispose?

Widescale trials



Site	pH	Alkalinity as $CaCO_3$ mgL^{-1}	Zinc mgL^{-1}	Iron mgL^{-1}	Estimated flow Ls^{-1}	Zn load kg yr^{-1}
Minera- Deep Day Level	7.4	235	1.62	0.23	50	2547
Pengwern (Llangynog)	7.4	35	4.43	N/A	15	2095
Cwmystwyth- Pugh's	6.6	14	31.8	0.40	9.6	9639
Cwmystwyth- Gill's	6.5	0	8.69	0.03	3.2	877
Frongoch Adit	7.0	13	17.9	0.03	17	9607
Frongoch attenuation pond	5.1	0	202	0.03	6	38146
Cwm Rheidol- No.6	3.7	0	51.4	3.4	8.3	13462
Cwm Rheidol- No.9	2.8	0	53.9	84	0.6	1020
Level Fawr	7.3	0	1.60	0.03	21	1058
Nant y Mwyn- Lower Boat	5.8	76	14.8	N/A	51	23787
Nant y Mwyn- Pannau Adit	7.2	76	5.70	N/A	3	539

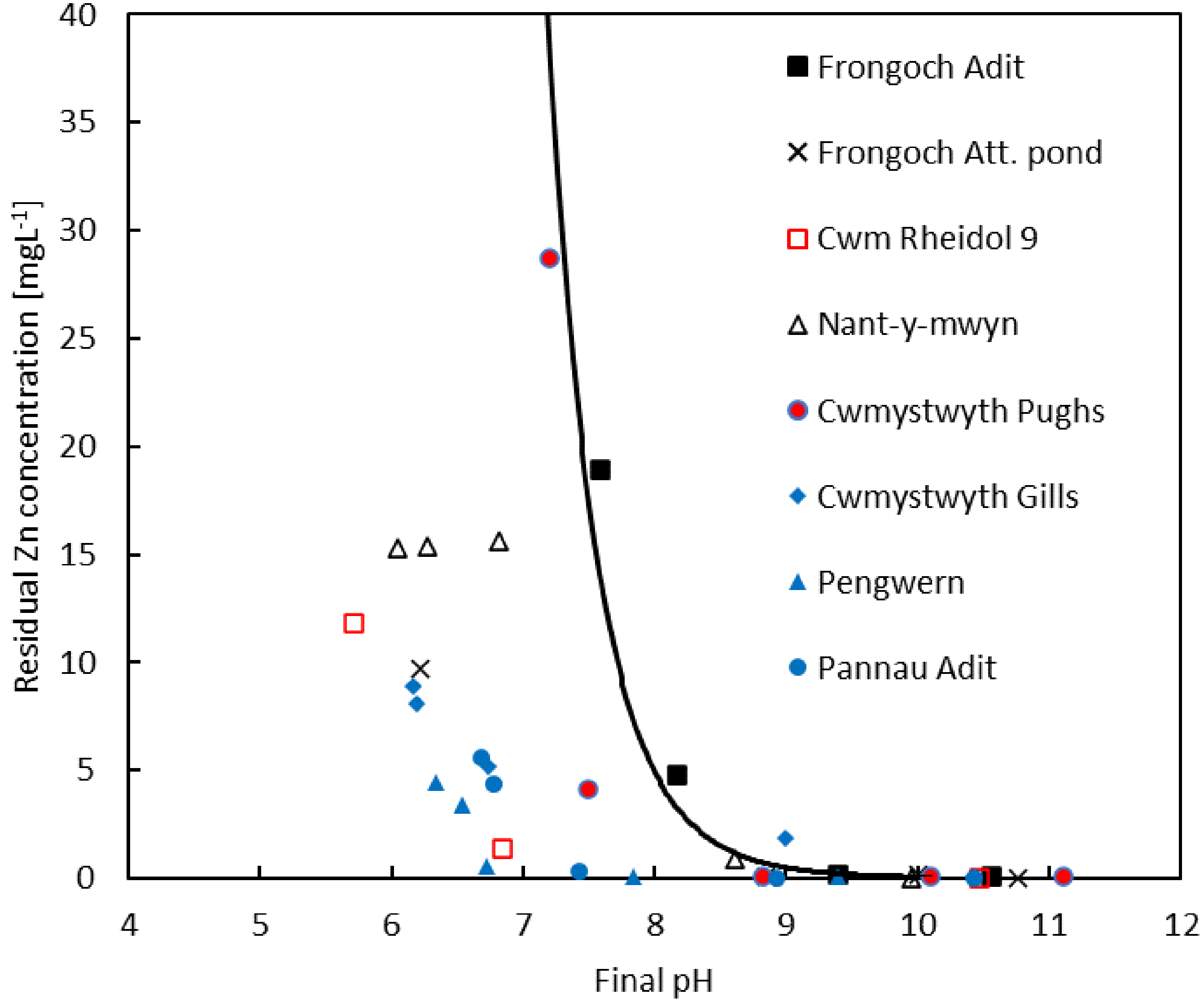
Field Campaign Results

Site	Zn removal %	Na_2CO_3 dose mgL^{-1}	Molar ratio $Zn:Na_2CO_3$	Zinc mgL^{-1}	Final pH mgL^{-1}
Minera- Deep Day Level*	25	74	1:28	1.210	7.4
Pengwern (Llangynog)	98	32	1:5	0.084	7.8
Cwmystwyth- Pugh's	>99	189	1:4	0.084	8.8
Cwmystwyth- Gill's	99	367	1:26	0.066	10.4
Frongoch Adit	99	224	1:8	0.145	9.4
Frongoch attenuation pond	>99	749	1:2	0.086	8.9
Cwm Rheidol- No.6	>99	209	1:3	0.056	9.1
Cwm Rheidol- No.9	99	6001	1:78	0.624	10.5
Level Fawr	95	88	1:34	0.073	9.3
Nant y Mwyn- Lower Boat	>99	874	1:37	0.876	9.9
Nant y Mwyn- Pannau Adit	>99	34	1:4	0.313	8.9

Site	As %	Cd %	Cu %	Mn %	Ni %	Pb %
Minera- Deep Day Level	41	12	18	0	3	84
Pengwern (Llangynog)	70	80	NA	19	11	85
Cwmystwyth- Pugh's	58	98	94	81	83	96
Cwmystwyth- Gill's	74	>99	86	92	94	97
Frongoch Adit	0	99	76	91	69	88
Frongoch attenuation pond	10	99	99	96	>99	99
Cwm Rheidol- No.6	83	>99	99	93	98	>99
Cwm Rheidol- No.9	82	>99	99	>99	>99	>99
Level Fawr	29	79	47	18	8	41
Nant y Mwyn- Lower Boat	NA	>99	95	NA	99	NA
Nant y Mwyn- Pannau Adit	NA	99	NA	NA	78	NA

Na_2CO_3 dosing successful for 10 out of 11 sites

Effective removal of Cd, Pb, Cu

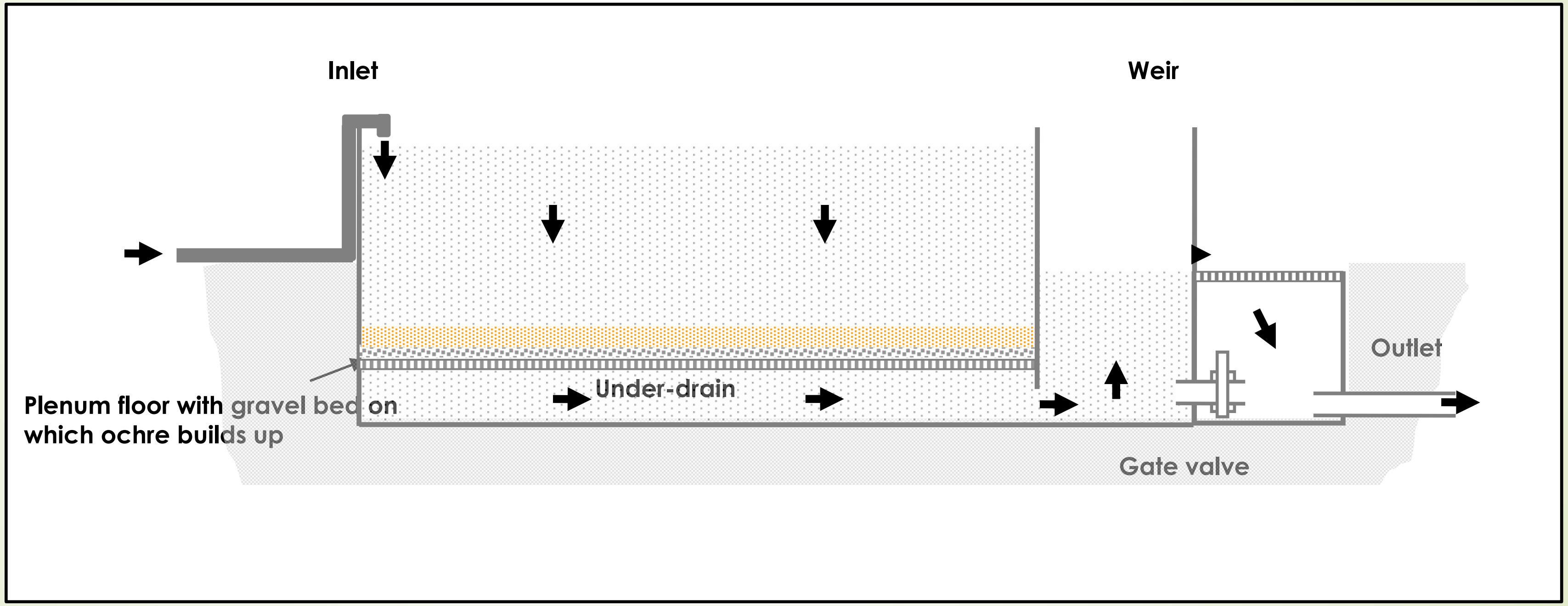


Measured residual Zn concentration at the final pH after Na_2CO_3 dosing. Line represents hydrozincite solubility curve (logK 9.1*) calculated using PHREEQC. Red symbols signify elevated Fe levels and blue symbols indicate mine water <15°C at time of on site dosing

* Medas et al. 2014. *Geochim Cosmochim Acta* (140)

Aerobic Passive Treatment: Vertical Flow Reactors (VFRs)

Enhanced iron removal by (self) filtration of ochre particles and surface-catalysed oxidation of dissolved iron – international trials have shown excellent removal of Feat circumneutral pH and in some cases at pH 3

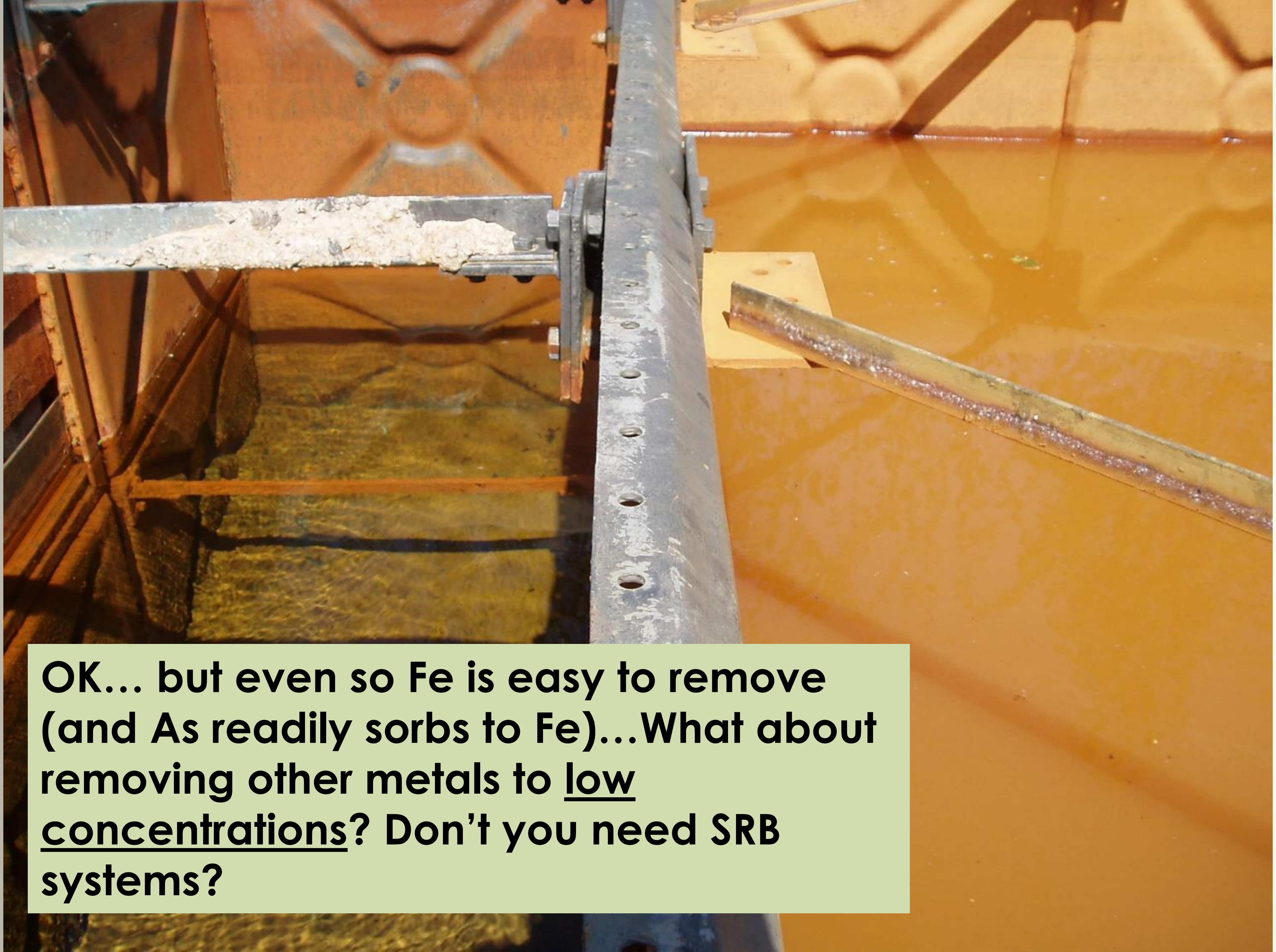


2007

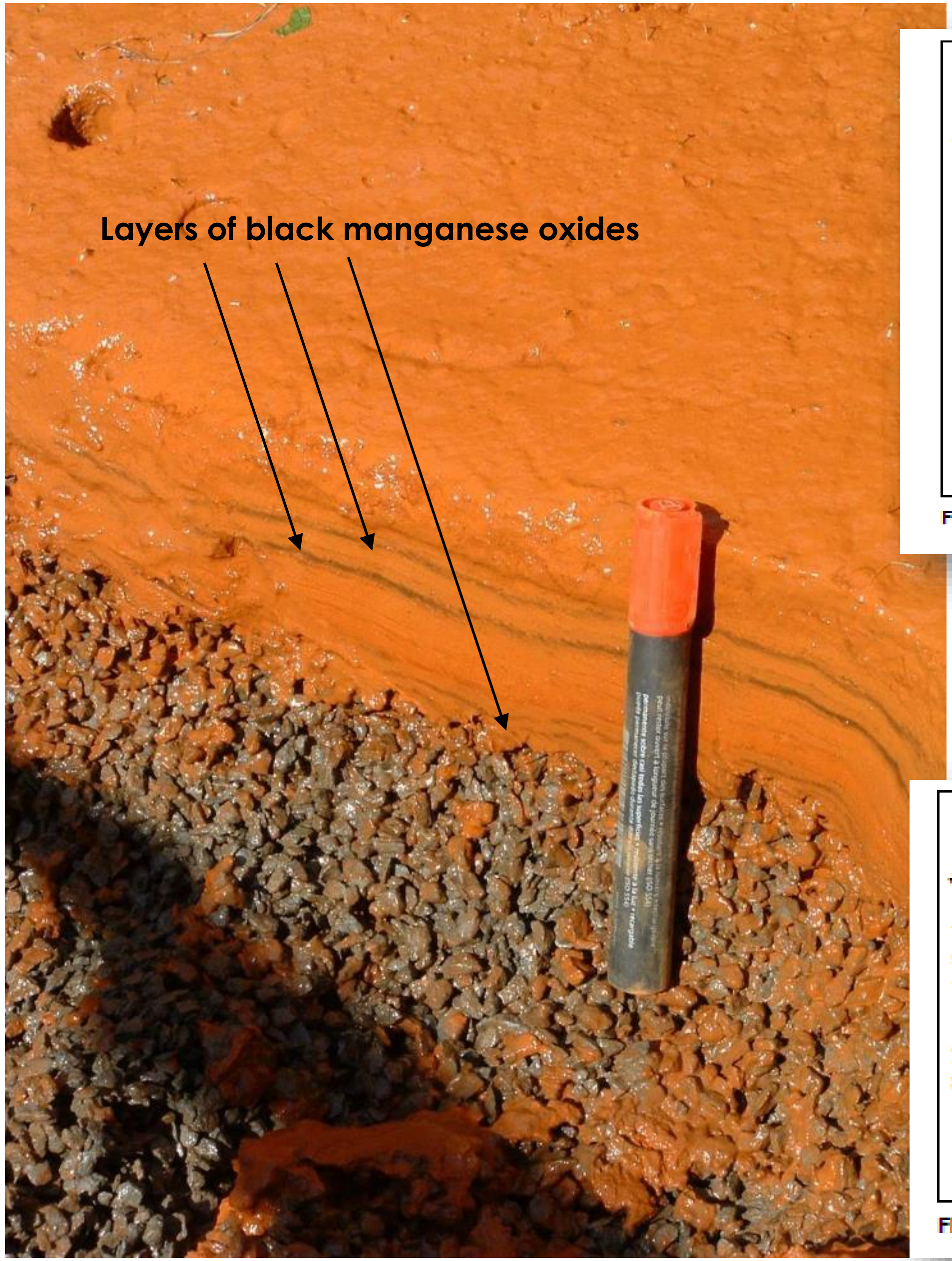
Developed originally on coal mine drainage

Heterogeneous Fe(II) oxidation
Cake filtration of particulate Fe(III)
Microbiological Fe(II) and Mn(II) oxidation

Shown for Fe to work for > pH 3



OK… but even so Fe is easy to remove (and As readily sorbs to Fe)…What about removing other metals to <u>low concentrations</u>? Don't you need SRB systems?



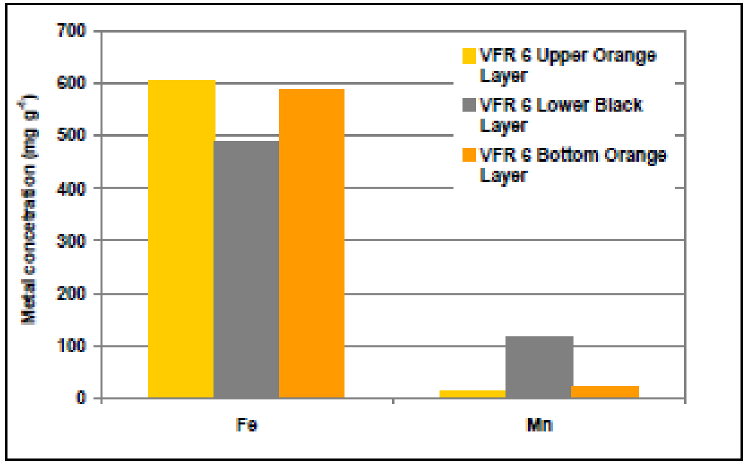


Figure 7-20: Fe and Mn concentrations in ochre bed layers

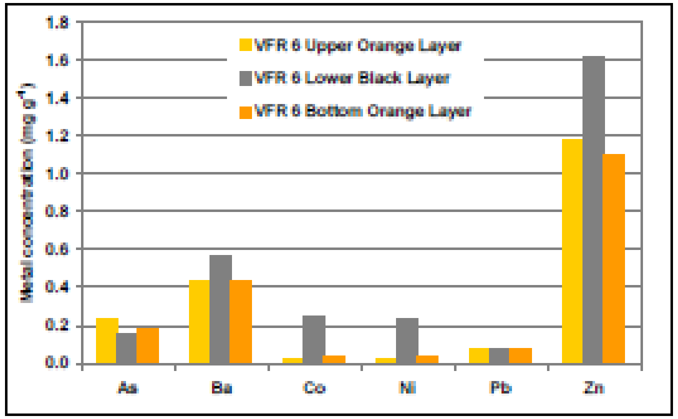


Figure 7-21: Al, As, Ba, Co, Ni, Pb and Zn concentrations in ochre bed layers

Promotion of autocatalysis and microbial oxidation (A. Barnes PhD thesis, 2008, Cardiff University)

IBC and Column Vertical Flow Reactors (VFRs) – can the mine water be self-cleaning?

IBC VFR:
Flow rate: 300 mL/min
Water head: 40 cm
20 mm gravel: 12 cm
6 mm gravel: 10 cm
Total nominal HRT: ~27 hrs (~22 hrs for the water head; ~5 hrs within media)

G: gravel only columns (5 cm)
GS: columns with gravel seeded with pyrolusite (2 cm)
C: control columns
MH: ManHole
HT: Header Tank
G1
C2
GS3
G4
GS5
G6
G7
C8

Flow rate:
3.0 mL/min for each column

Residence time:
G: ~20 hrs (~18 hrs for water head; ~1 hr within media
GS: ~19 hrs (~17.5 hrs for the water head; ~1.5 hrs within media)
C: ~21 hrs

Limestone Media

Day zero

LSR surface

LSR column wall

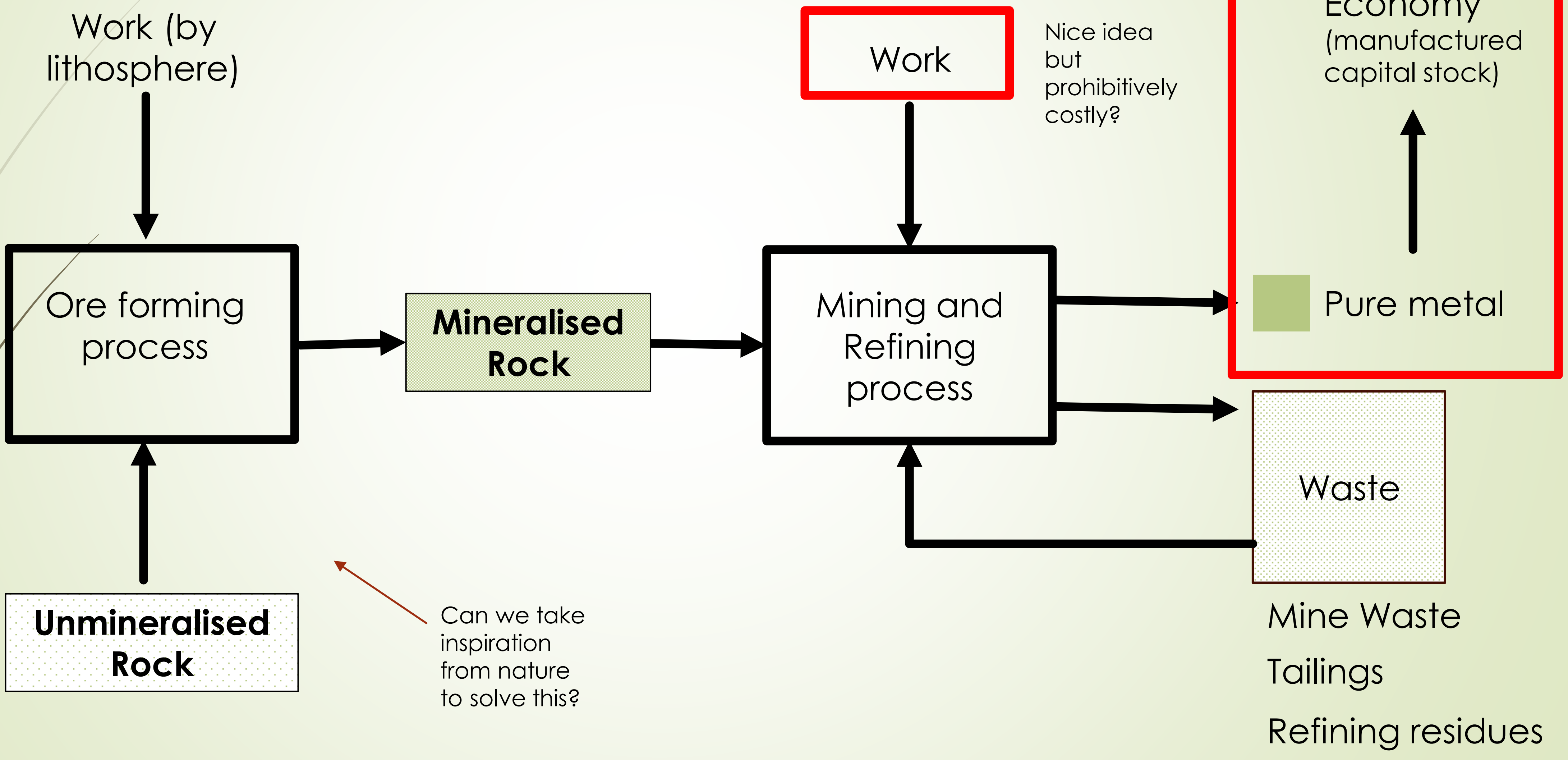
After about three months – excellent removal of Mn and Zn

dark coating indicates Mn removal.

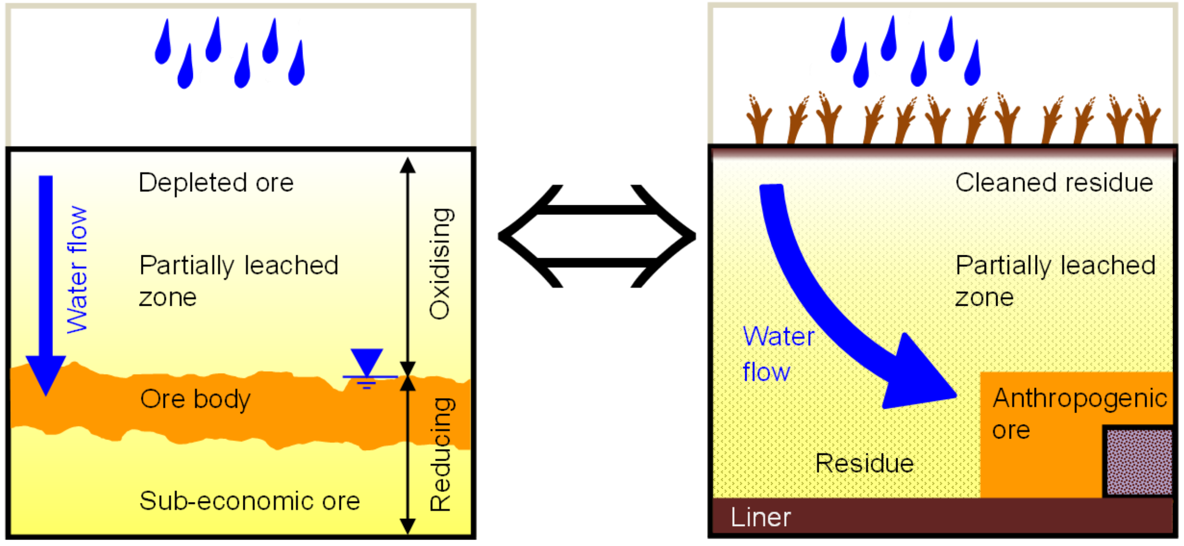
GS3 and **GS5:** gravel column VFRs seeded with pyrolusite
LSR4 and **LSR6:** limestone reactors

LSR Flow rate: 3.0 mL/min
LSR Residence time: ~3 hrs (1 hr for the water head; 2 hrs within media)

Alternative concept for mine waste management: Can we push as much of the metals as possible to the economy?



Use the prolonged time in storage to apply green low-intensity and low-cost processes



(a) Supergene ore forming processes

(b) ASPIRE repository

Now no longer AMD-ML threat and perhaps can be reused (e.g. aggregate)

Now at concentrations economically viable to process

ASPIRE

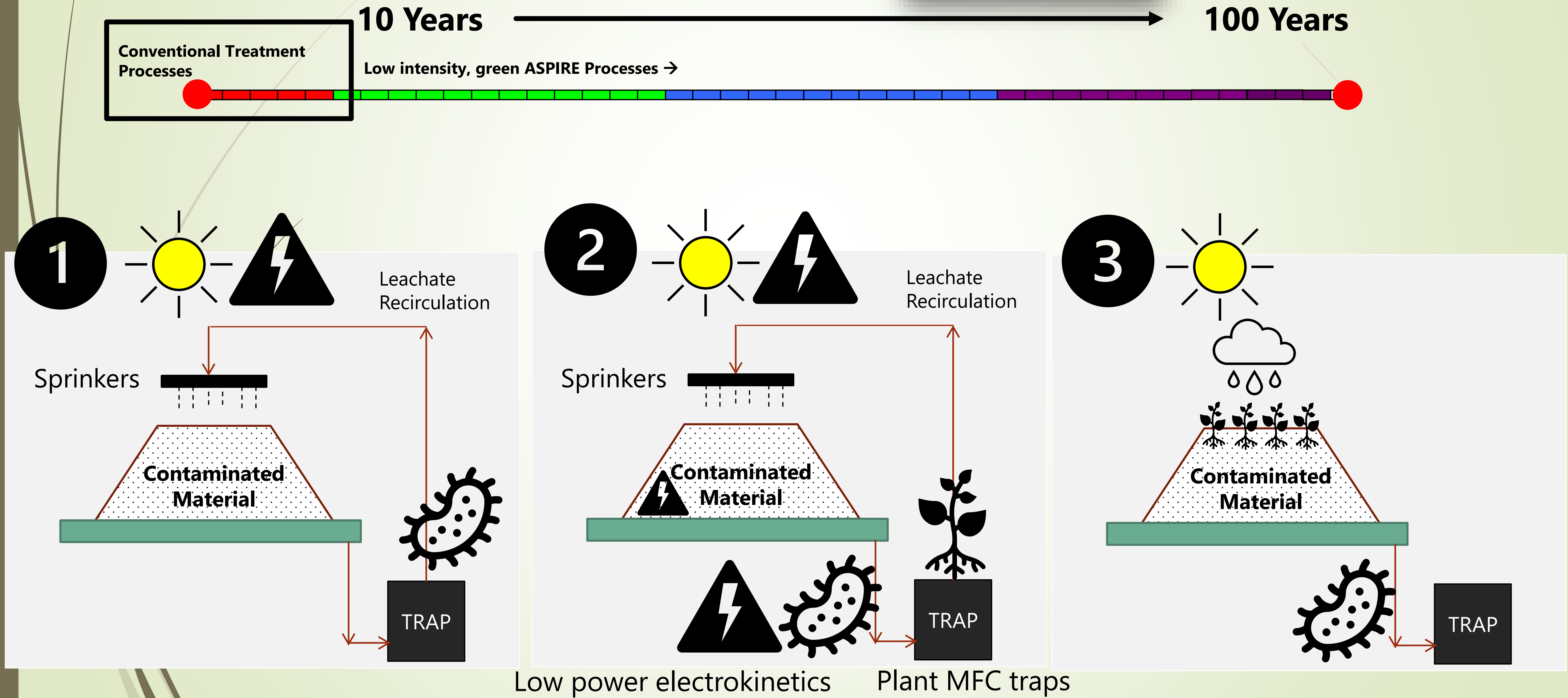
Accelerated Supergene Processes in Repository Engineering

"Developing self-cleaning, temporary storage landfills for returning materials to a Circular Economy"

Sapsford, D.J., Stewart, D.I., Sinnett, D.E., Burke, I.T., Cleall, P.J., Harbottle, M.J., Mayes, W., Owen, N.E., Sardo, A.M. and Weightman, A., 2023. Circular economy landfills for temporary storage and treatment of mineral-rich wastes. In *Proceedings of the Institution of Civil Engineers-Waste and Resource Management* (Vol. 176, No. 2, pp. 77-93). Thomas Telford Ltd.

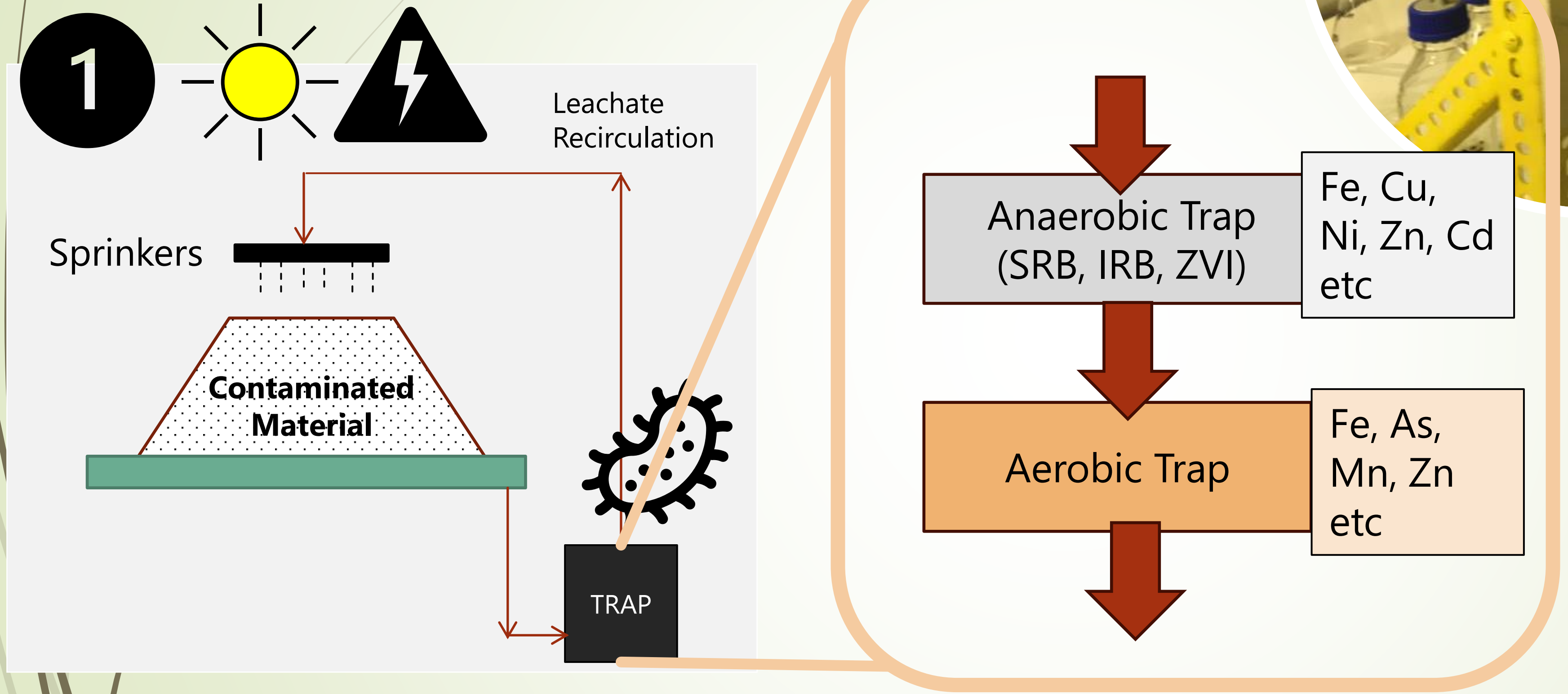
ASPIRE Concept

Carbon storage may become an important consideration

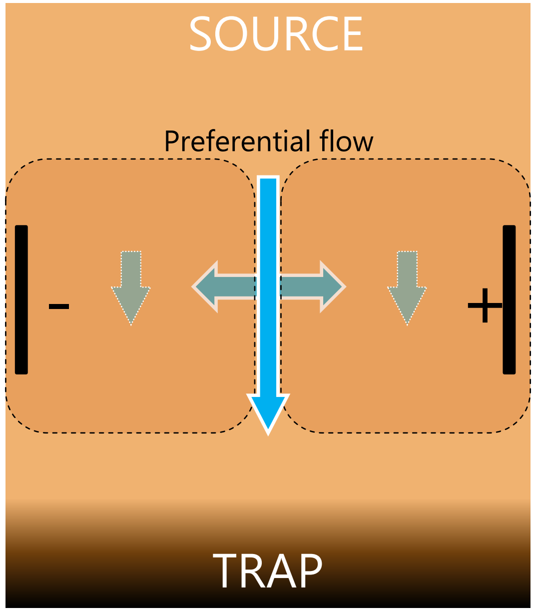


Trapping technologies

(a.k.a anthropogenic ore forming processes?)
(a.k.a mine water treatment!)



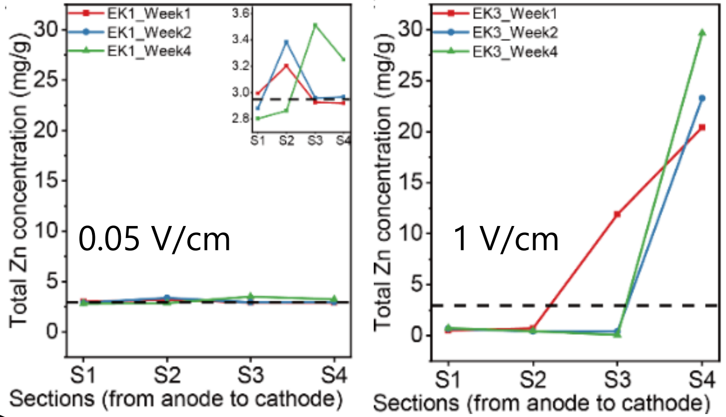
Bioelectrochemical systems for resource mobilisation, transport and recovery



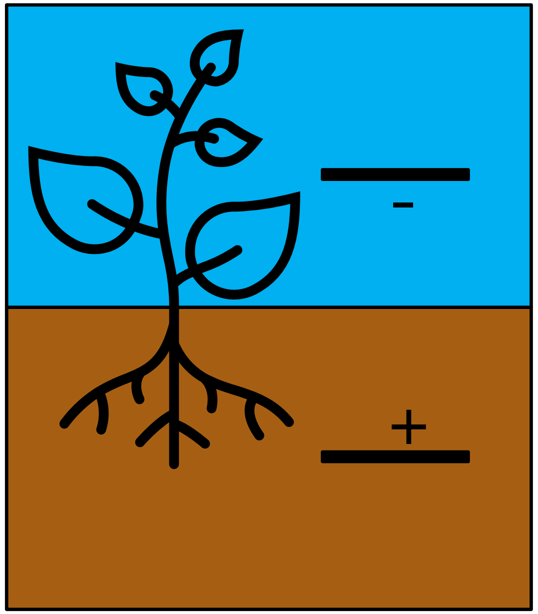
Transport – overcoming preferential flow to maximise transport through matrix

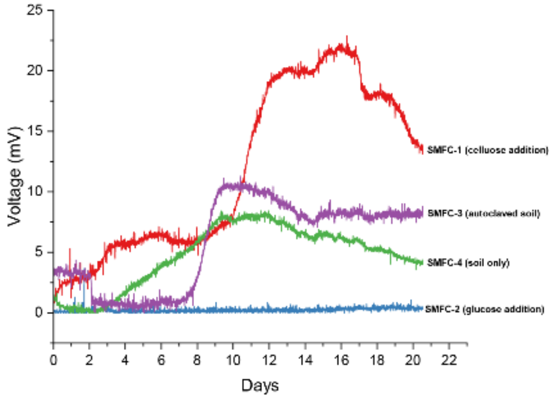
Bioelectrochemical systems – low power but self-sustaining

Low voltage gradients and their effects



Microbial & plant-microbial fuel cells can potentially mobilise, transport *and* trap resource.





Conclusions for mine waste treatment, resource recovery and sustainability

- Current passive treatment systems produce wastes which need disposal
- Disposal of mine water treatment residues and mine wastes in landfills potentially only postpones future problematic contaminant escapes
- Is there room for new more sustainable concepts which aim to push for metals to the economy. Not for economic reasons but to avoid/minimise the waste issue?
- The problem to solve becomes one of how to do this economically. This is what we're looking at with the ASPIRE concept.
- Value-adding propositions include reuse of cleaned residue and/or CDR
- Passive, semi-passive and bioelectrochemical technologies (many already used for mine water treatment) could offer solutions

References:

- Kennedy, J., Dean, J., Okeme, I. and Sapsford, D., 2023. An assessment of the efficacy of sodium carbonate for semi-passive treatment of circumneutral zinc-bearing mine waters. Journal of Water Process Engineering, 53, p.103764.
- Sapsford, D.J., Stewart, D.I., Sinnett, D.E., Burke, I.T., Cleall, P.J., Harbottle, M.J., Mayes, W., Owen, N.E., Sardo, A.M. and Weightman, A., 2023, January. Circular economy landfills for temporary storage and treatment of mineral-rich wastes. In Proceedings of the Institution of Civil Engineers-Waste and Resource Management (Vol. 176, No. 2, pp. 77-93). Thomas Telford Ltd.
- Sapsford, D.J., Crane, R.A. and Sinnett, D., 2019. An exploration of key concepts in application of in situ processes for recovery of resources from high-volume industrial and mine wastes. Resource Recovery from Wastes: Towards a Circular Economy, pp.141-167.
- Peppicelli, C., Cleall, P., Sapsford, D. and Harbottle, M., 2018. Changes in metal speciation and mobility during electrokinetic treatment of industrial wastes: Implications for remediation and resource recovery. Science of the total environment, 624, pp.1488-1503.
- Crane, R.A., Sinnett, D.E., Cleall, P.J. and Sapsford, D.J., 2017. Physicochemical composition of wastes and co-located environmental designations at legacy mine sites in the south west of England and Wales: Implications for their resource potential. Resources, Conservation and Recycling, 123, pp.117-134.
- Sapsford, D., Cleall, P. and Harbottle, M., 2017. In situ resource recovery from waste repositories: exploring the potential for mobilization and capture of metals from anthropogenic ores. Journal of Sustainable Metallurgy, 3, pp.375-392.
- Florence, K., Sapsford, D.J., Johnson, D.B., Kay, C.M. and Wolkersdorfer, C., 2016. Iron-mineral accretion from acid mine drainage and its application in passive treatment. Environmental Technology, 37(11), pp.1428-1440.
- Blanco, I., Sapsford, D., Trumm, D., Pope, J., Kruse, N., Cheong, Y., McLauchlan, H., Sinclair, E., Weber, P. and Olds, W., 2018. International trials of vertical flow reactors for coal mine water treatment. Mine Water and the Environment, 37(1), pp.4-17.

Professor Devin Sapsford, UNESCO Chair in Developing a Sustainable Geoenvironment

Director, Geoenvironmental Research Centre, School of Engineering, Cardiff University, UK

sapsforddj@cardiff.ac.uk