Fresh urine treatment with bio-mineral phosphorus recovery and nitrification with biocatalysts

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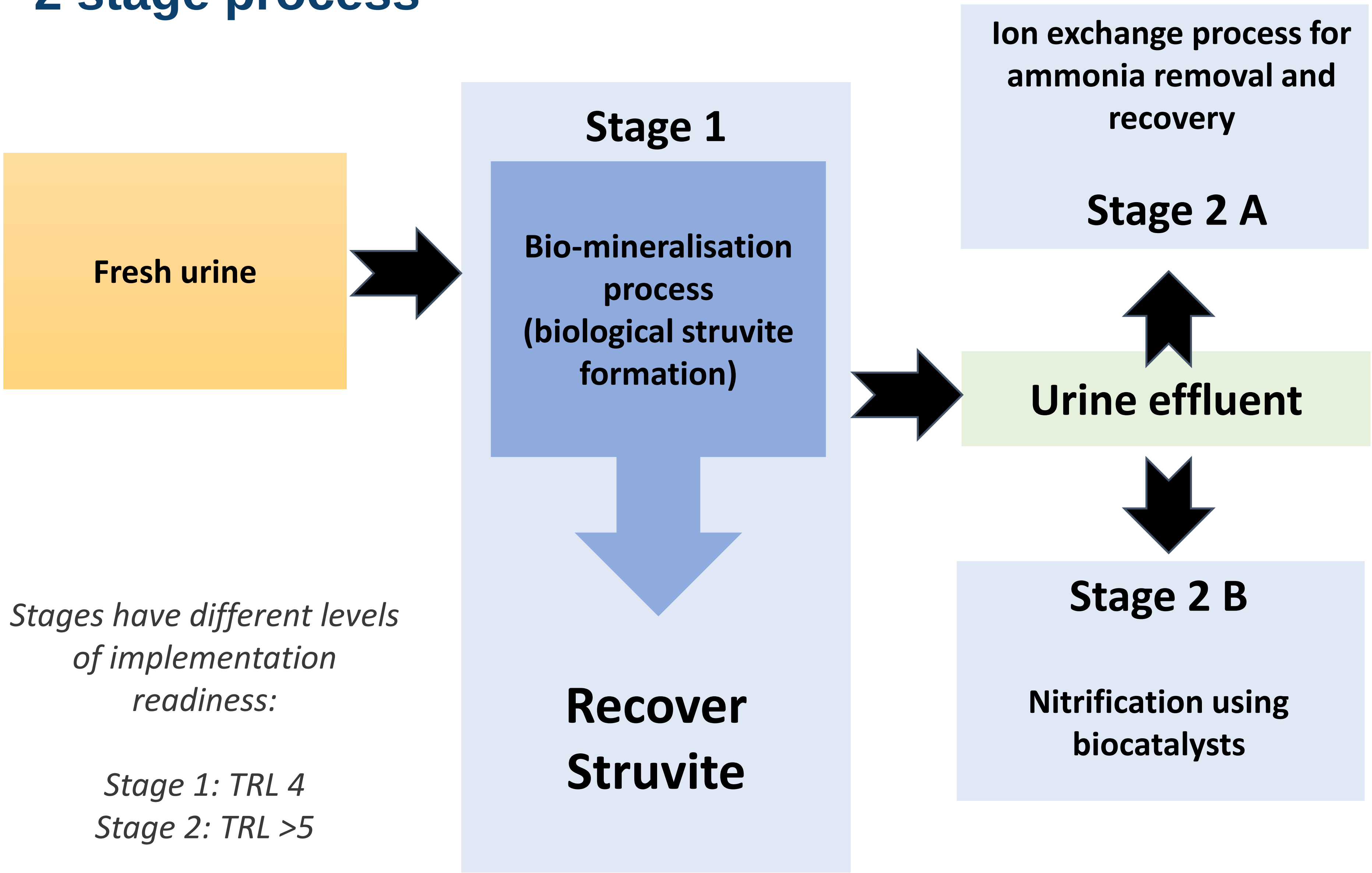
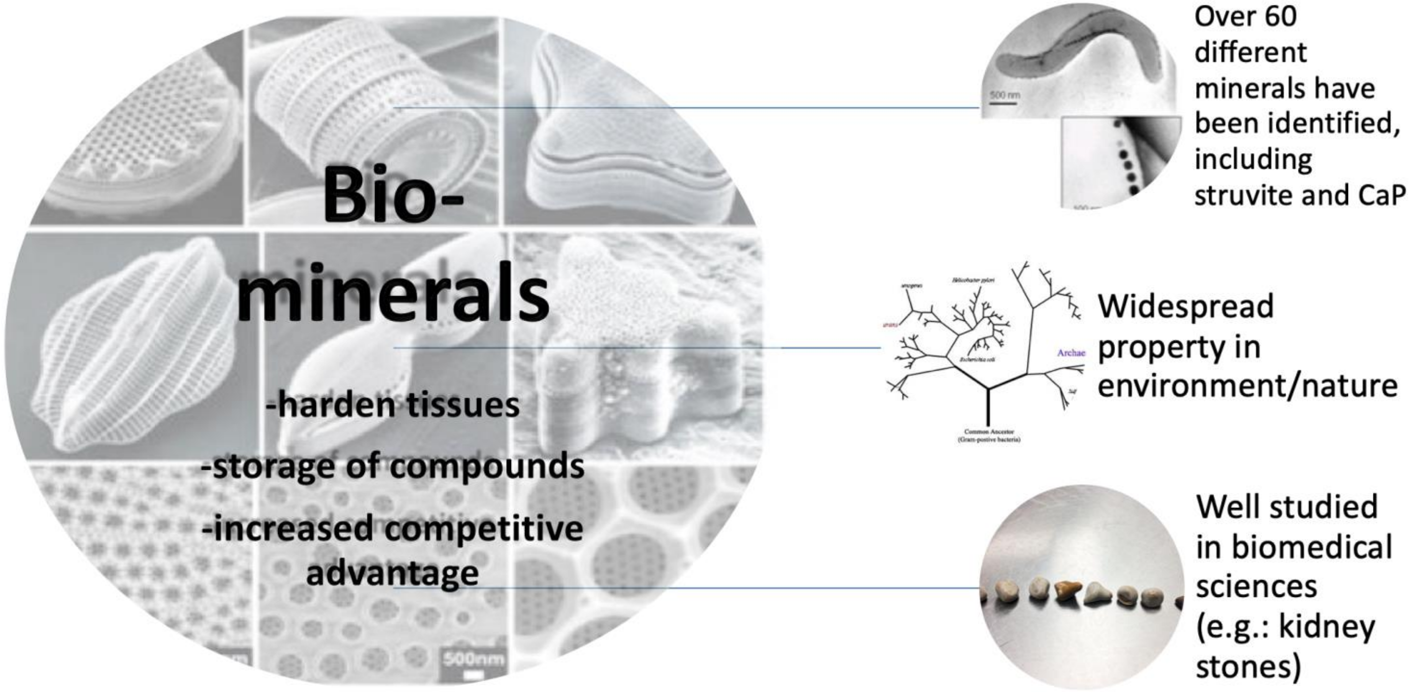
The concept: Urine treatment for life support systems
2 stage process



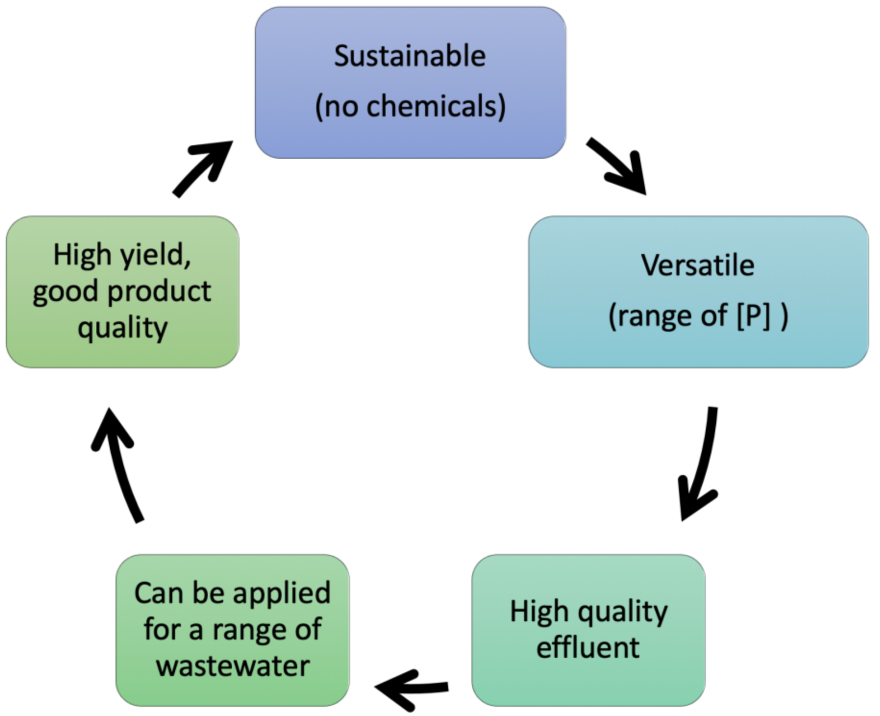
Stages have different levels of implementation readiness:

Stage 1: TRL 4
Stage 2: TRL >5

Stage 1: What is biological struvite formation



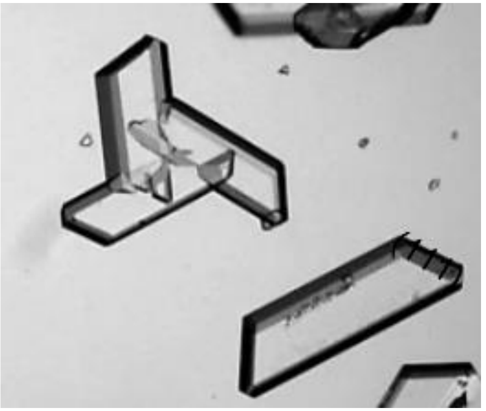
Advantages of bio-mineral formation

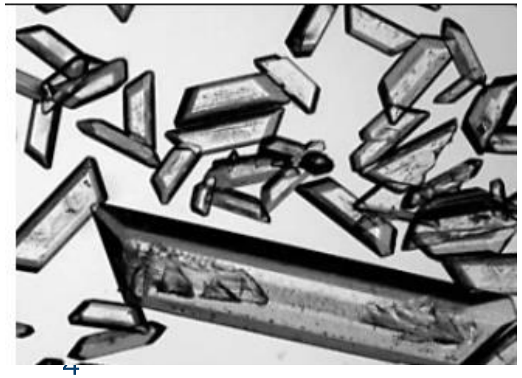


Bio-mineral formation is a widespread phenomenon in nature.
It refers to a series of processes involving selective extraction, uptake and incorporation of elements from the local environment into functional structures under strict biological control.

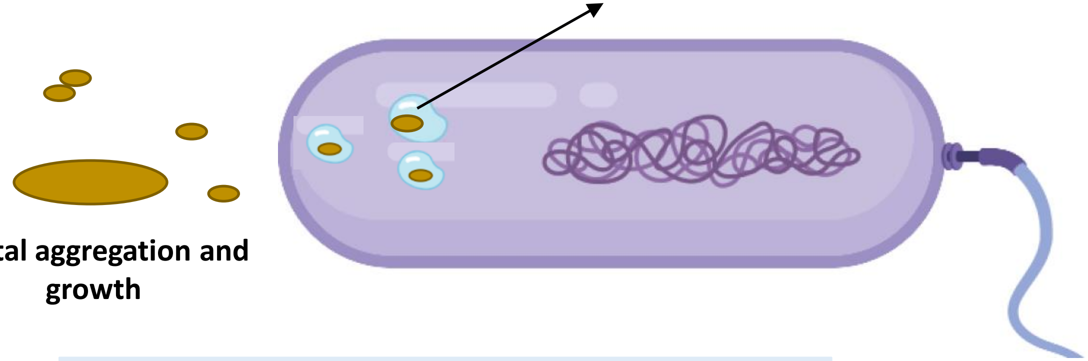
Stage 1: Bio-mineral formation mechanisms

Bacteria metabolism where there is concentration of specific elements in microenvironments, promoting nucleation and crystal growth

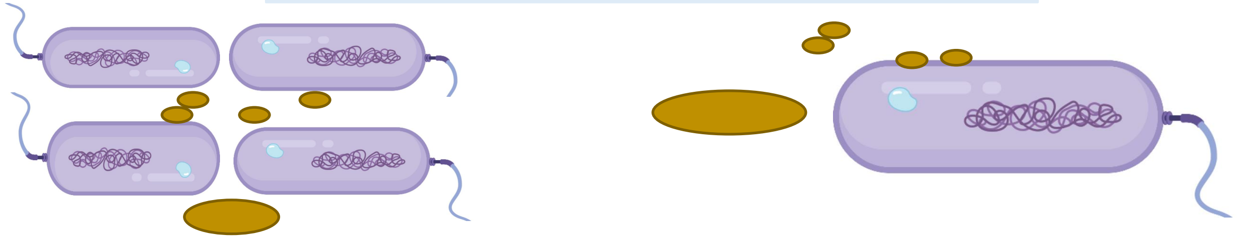




Biological controlled mineralisation



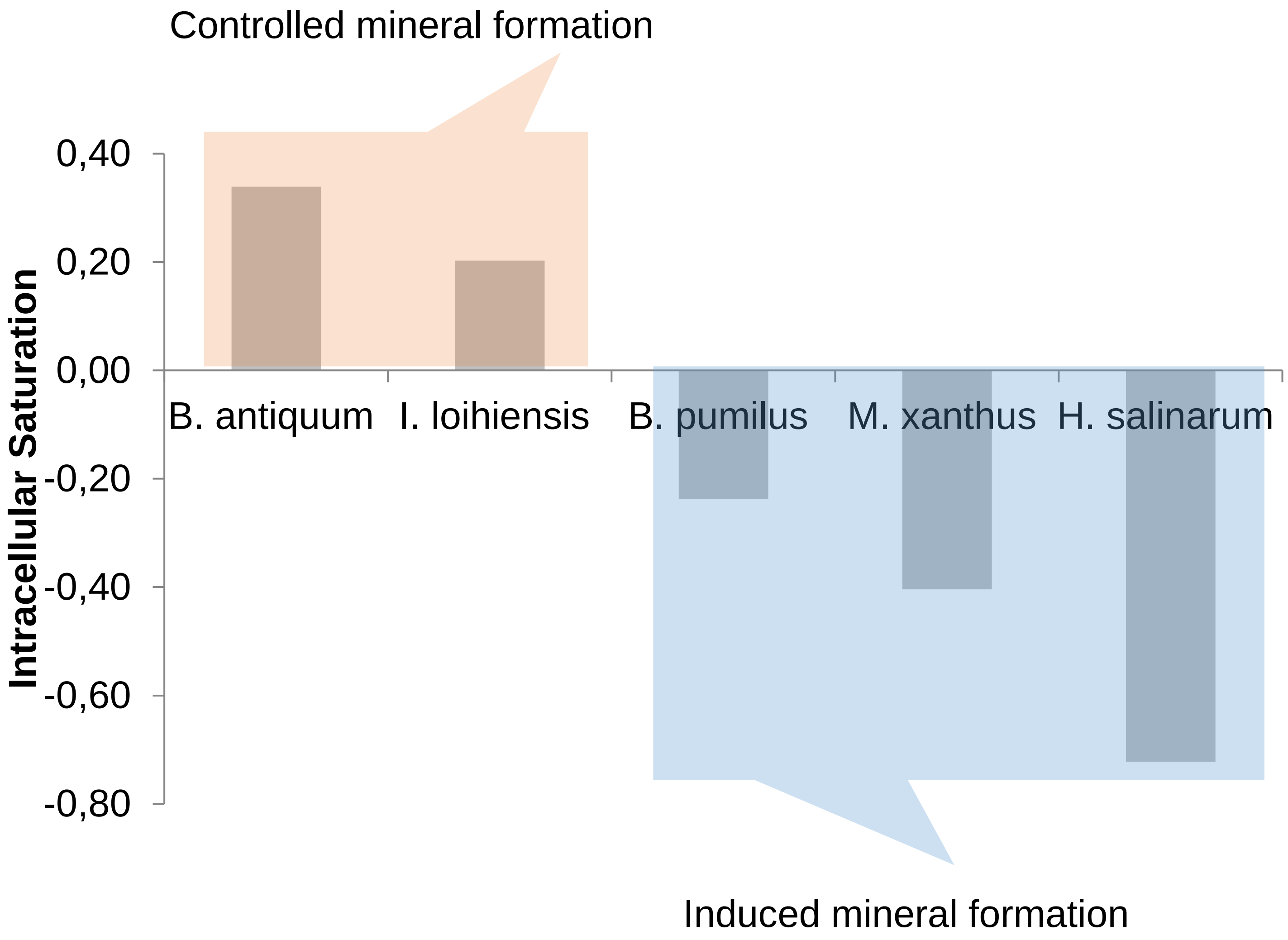
Biological induced mineralisation

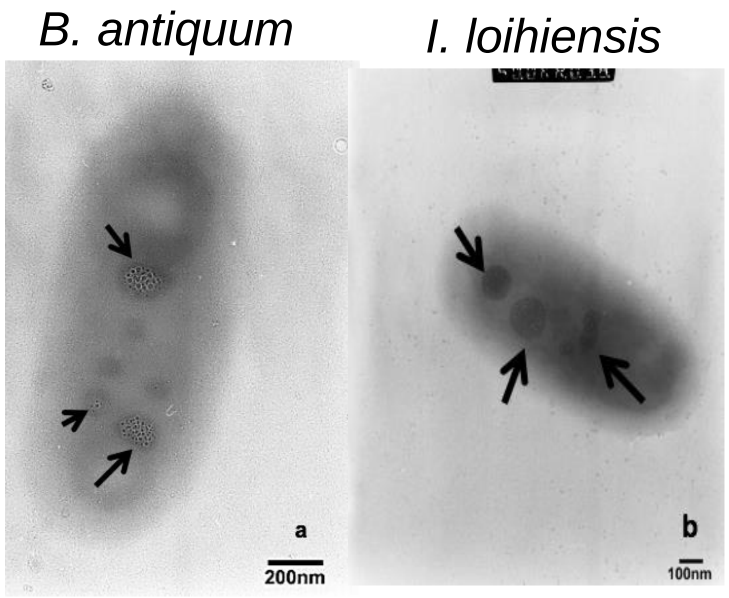


Crusted cell structures epicellular mineralisation

Cell membrane epicellular mineralisation

Mechanism investigation

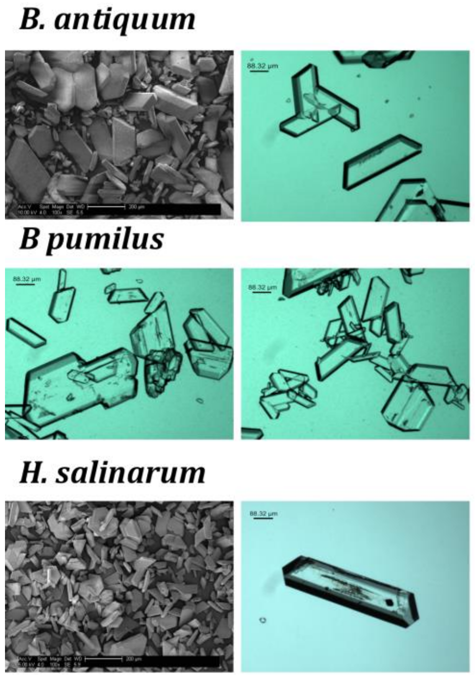




Leng, Y., & Soares, A. (2021). The mechanisms of struvite biomineralization in municipal wastewater. Science of the Total Environment, 799. https://doi.org/10.1016/j.scitotenv.2021.149261

Research to date in municipal wastewater

- PO_4-P removal reached 80-90% in liquors with initial concentrations from 30-120 mg P/L.
- Struvite production yield was 93-154 mg struvite/L liquors and large crystals (210-480 mg/L) with high purity were observed.
- The bio-mineral formation was promoted by the bacteria metabolism that increased the nutrients supersaturation in specific microenvironments, promoting nucleation, and crystal growth in the liquors.
- Using selected bacteria mineral salt formation could take place even at low nutrients concentration (<30 mg/L PO_4-P), a feature that is unachievable in chemical based struvite precipitation processes
- Urine is rich in phosphate, ammonia, calcium etc. and it is practically sterile. Ideal feedstock for bio-mineral formation

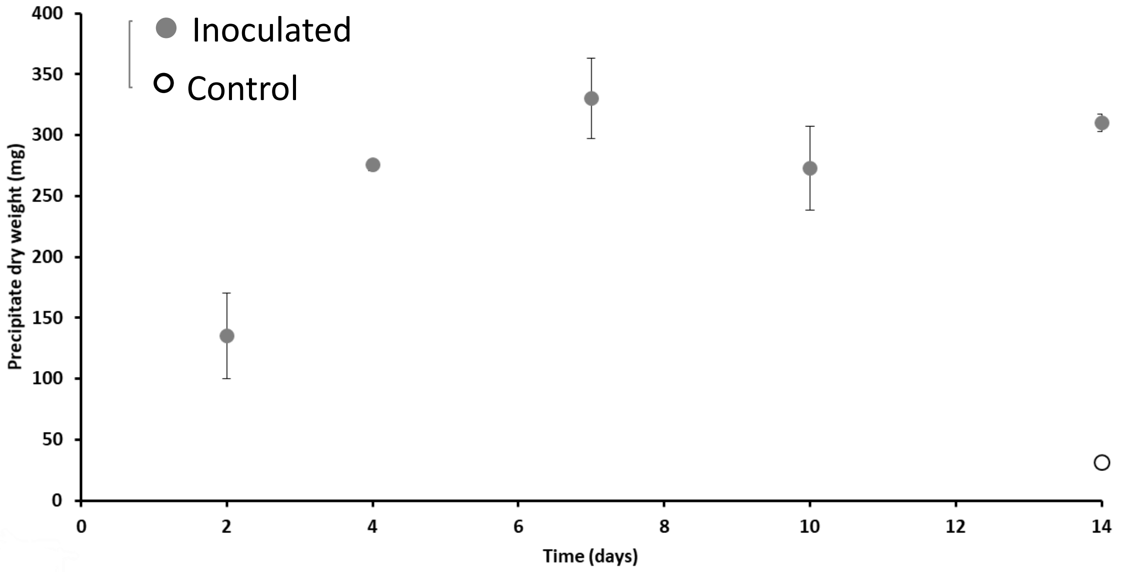


Stage 1: Bio-struvite production from fresh urine

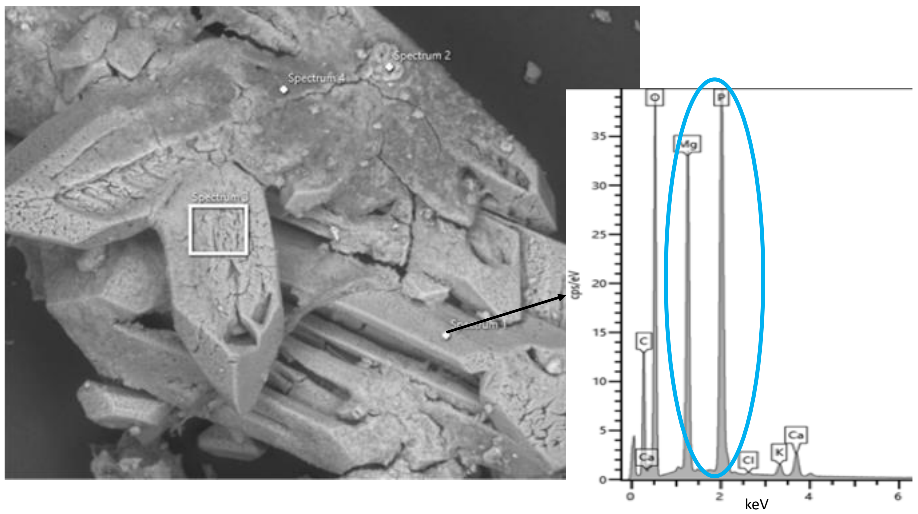
- Purpose: To assess the ability of selected bacteria to grow in fresh urine and potential for nutrient recovery as bio-struvite
- Bacteria tested: *B. antiquum*, *B. pumilis*, *H. salinarum*, *I. ioihiensis* and *M. xanthus*
- Urine source: Collected at Cranfield University (no storage)
- Methods: Measured growth rates using flowcytometry, measured urine dynamic chemistry, precipitates and characterised the precipitates

Stage 1: Bio-struvite production from fresh urine

	Fresh urine (day 0)	Urine incubated for 4 days: Inoculated with *B. antiquum*	Urine incubated for 4 days: Non-inoculated control
pH	6.8	7.8	8
SCOD (mg/L)	1750	310	1200
PO_4-P (mg/L	100	30	80
NH_4-N (mg/L	100	850	250
Urea (mg/L)	3100	1900	2800
Mg (mg/L)	70	2	60
K (mg/L)	1250	850	ND



***B. antiquum* precipitates** **SEM- EDX**

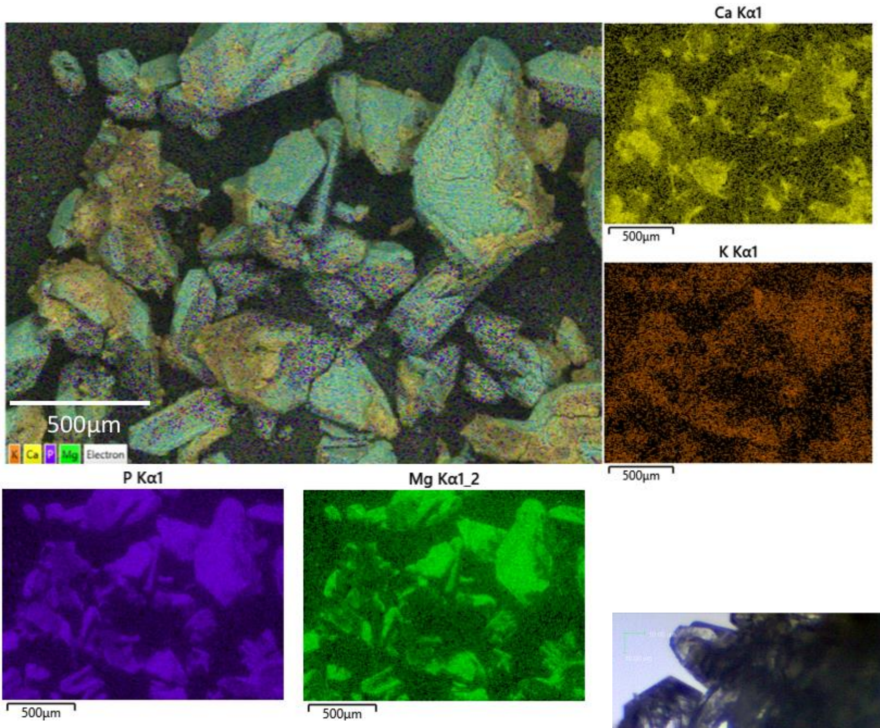


Bio-mineral producing bacteria:

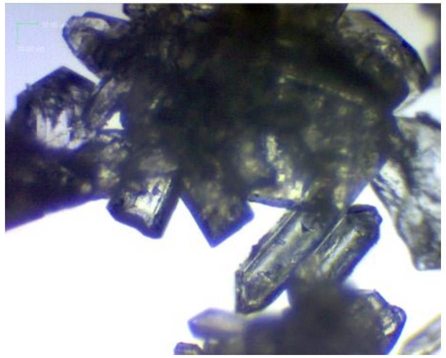
- accelerate ureolysis
- use organic compounds from urine as carbon source
- produce large precipitates rich in P, Mg and K
- Good removal P (70% P; 97% Mg – limiting; 82% sCOD; 32% K)

Stage 1: Bio-struvite production from fresh urine

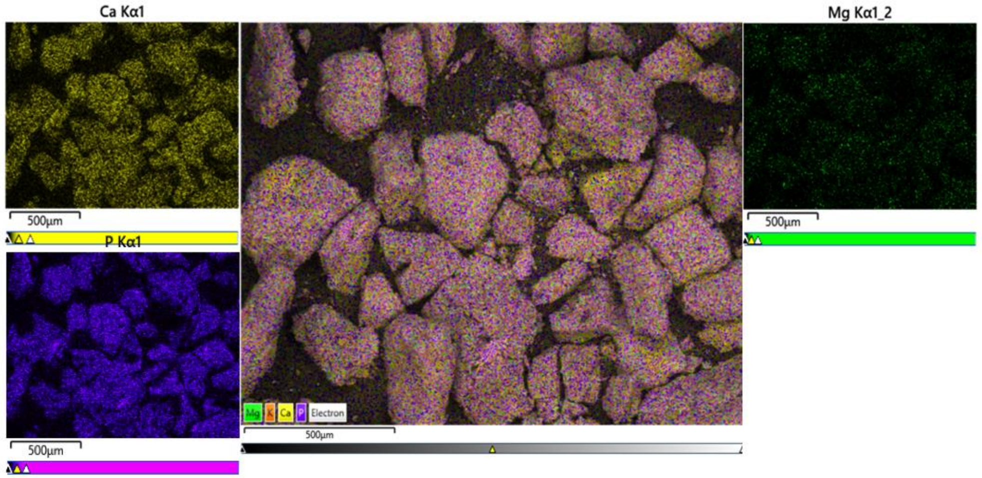
Inoculated with *B. antiquum*
(3 days incubation, Struvite rich in P)



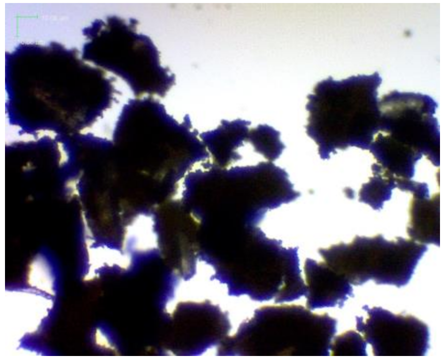
Crystals produced by *B. antiquum* (optical microscope)



Control
(10 days incubation, mainly CaP)



Amorphous precipitates in controls (optical microscope)

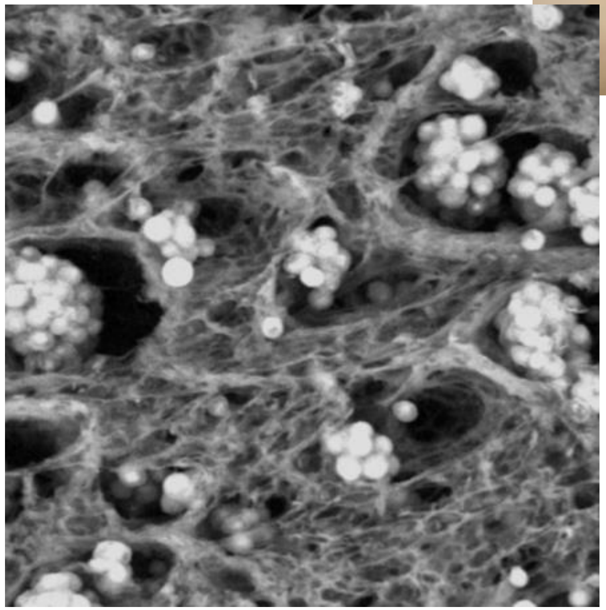


Stage 2: Nitrifying biocatalyst

- Nitrifying cultures are encapsulated in smart materials
- Encapsulation involves suspending a pure culture of microbes within a media that allows the mass transfer of nutrients or pollutants across the media
- Encapsulation enables significant intensification of biological processes and attaining high effluent quality
- Standard *Nitrosomonas* sp/*Nitrobacter* sp used
- The catalysts are specially suitable for processes and streams that are adverse (or limited) for traditional biological reactions to take place

Advantages

- Turn-on/off
- Long-term operational stability
- Easy to recover and reuse biomass
- Protection of microorganisms
- High mechanical strength
- High resistance to toxic chemicals
- Improving genetic stability



Stage 2: Urine nitrification using the biocatalyst

- **Purpose:** Investigate urine post-treatment after struvite precipitation

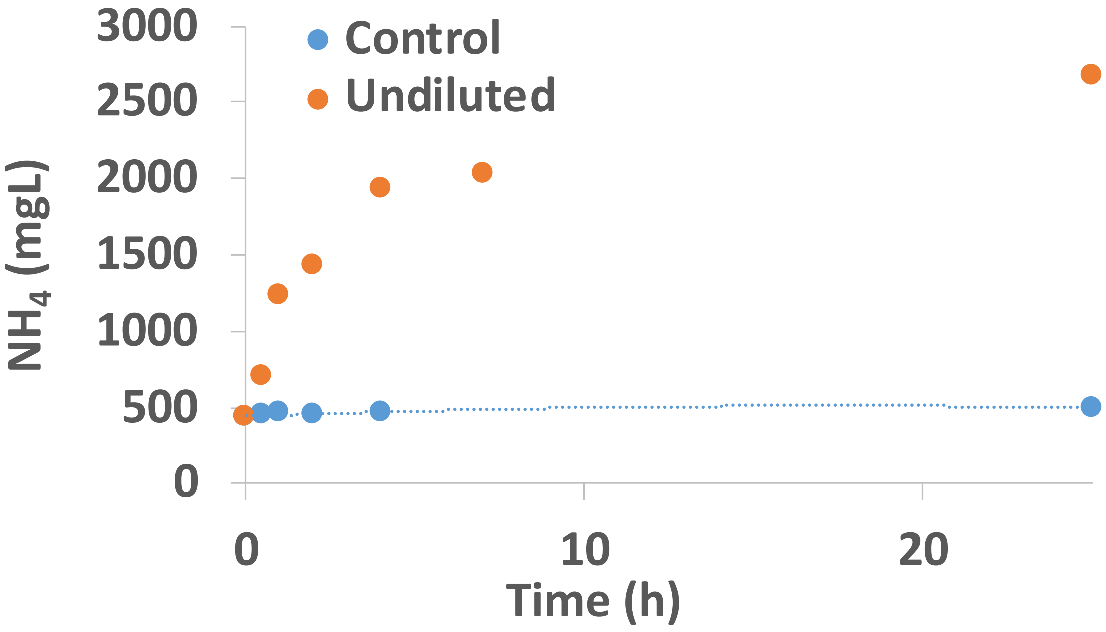
- **Process tested:** Microvi biocatalyst rich in nitrifying bacteria and some heterotrophs

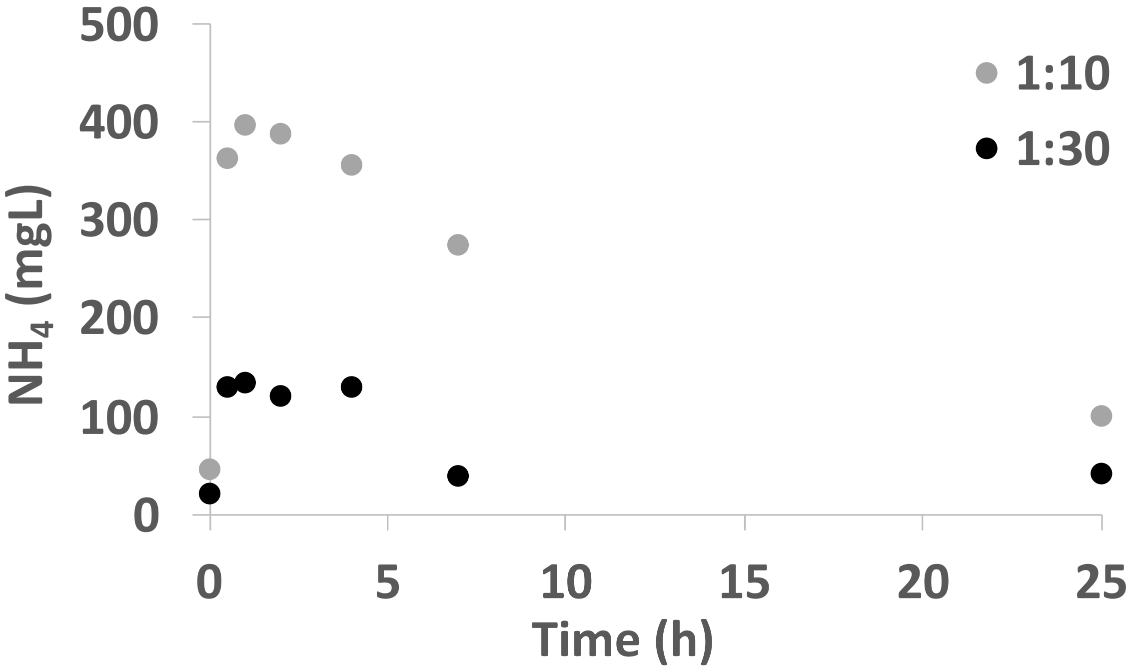
- **Methods**: Incubate urine with 40% V/V biocatalyst at room temperature (18-22C) and measure NH_4 and NO_3 at frequent intervals. Controls contained just urine.

Key observations when working with the biocatalyst:

- Can be stored for long periods of time (months) and re-activation takes hours
- Nitrifying bacteria are protected from shock loads
- Process can be easily intensified by increasing catalysts ratio in urine
- Experience in industrial and municipal wastewater indicate that nitrification of 100 mg/L of ammonia can take place in just 20 min contact time

Stage 2: Urine nitrification with biocatalysts

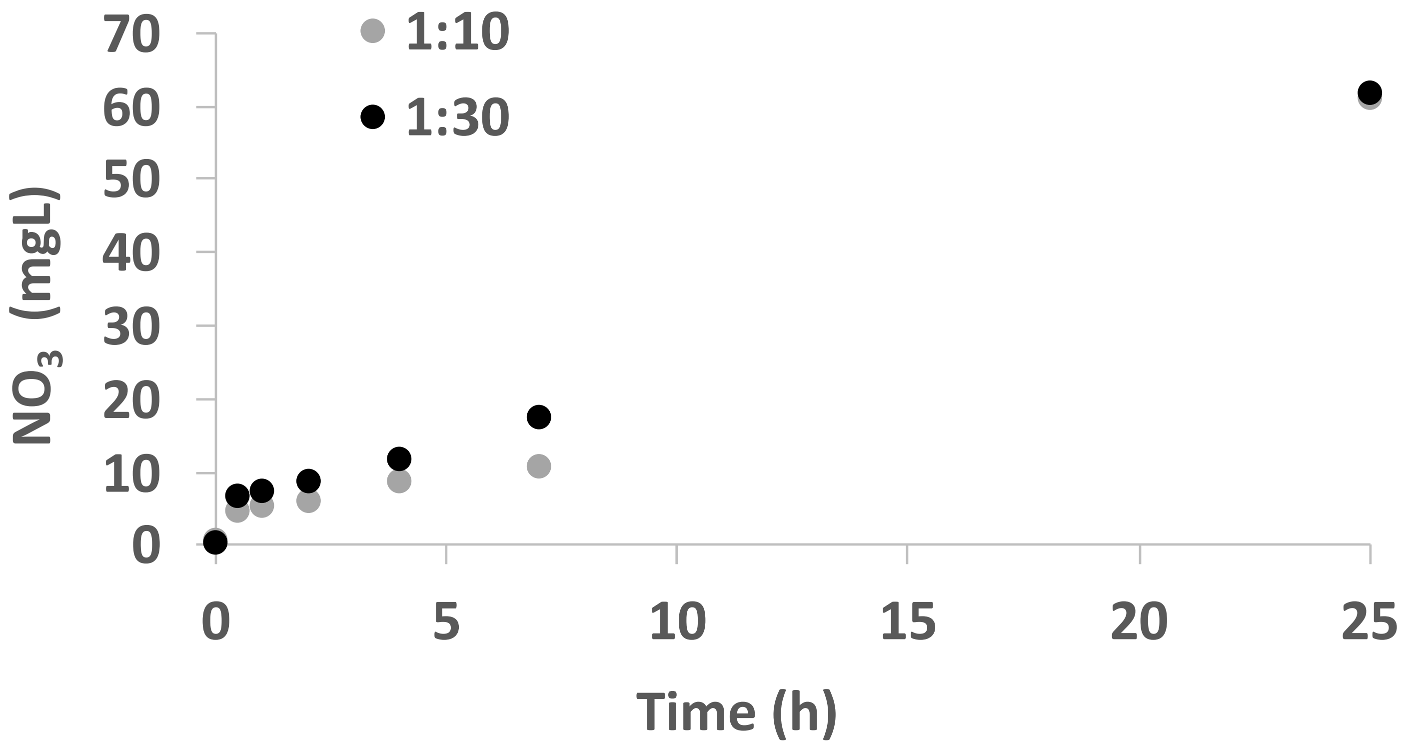




Ureolysis re-starts as soon as mixing of urine takes lace

Some dilution is needed for nitrification with biocatalysts, but not yet optimsed

Stage 2: Urine nitrification with biocatalysts



When the urine was diluted (1:10 and 1:30) ureolysis and nitrification were observed, given the changes in NH_4 and increase in NO_3 over time. The process was quick.

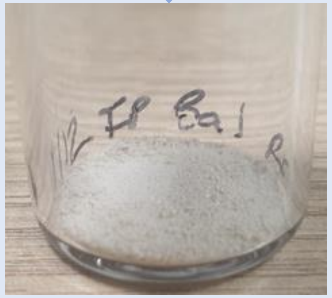
Urine dilution or catalyst ratio have not been optimised and alkalinity requirement needs to be investigated.

Urine treatment for LSS: 2 stage process

Fresh urine (real):
pH: 5.6-6.9
COD: 1.3-1.9 g/L
PO_4-P: 39-504 mg/L
NH_4-N: 110-595 mg/L
Urea: 2.0-3.5 g/L
TN: 2.8-4.2 g/L
Mg: 23-70 mg/L

Stage 1

Bio-mineralisation process (biological struvite formation)



Up to 685 mg struvite/L urine

Urine effluent:
pH: 7.0-7.8
COD: 0.3-0.6 g/L
PO_4-P: 15-330 mg/L
NH_4-N: 600-1800 mg/L
Urea: 1.0-1.8 g/L
Mg: 1-5 mg/L

Stage 2

Nitrification using biocatalysts

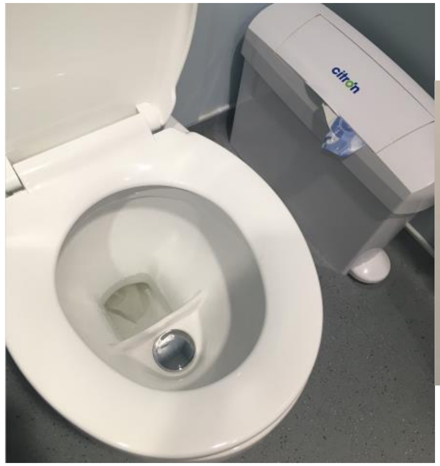
Biocatalysts nitrification at a rate of 23 mg/L.h with nitrate.

These initial findings are promising to develop sustainable resource recovery from source urine

Next stages

Urine collection system at Cranfield



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Thank you