Waste biorefinery technologies for accelerating sustainable energy processes

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Microbial biominerals: the challenges to resource recovery

Lucian Staicu

Faculty of Biology, University of Warsaw, Poland

https://staiculab.com/

Cottbus, Germany
04/10/2023

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- Recovery challenges

Biomineralization

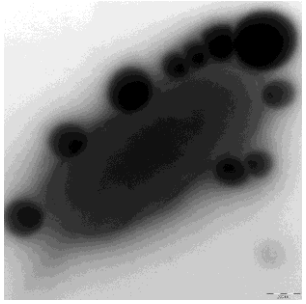
- Process by which living organisms produce **minerals** (crystalline/amorphous)
- Widespread phenomenon in **all six taxonomic kingdoms**
- **>60 biominerals described**
- **Bacteria** produce **biominerals** belonging to almost all **8 classes of minerals** (native elements, silicates, oxides, sulfides, sulfates, halides, carbonates, phosphates, and mineraloids)

Microbial biominerals

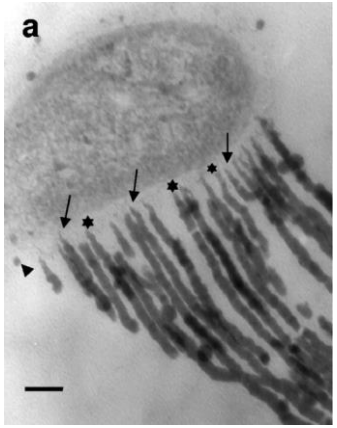
- **Fe minerals**: green rust - *Shewanella putrefaciens*, α-FeO(OH) - *Gallionella ferruginea*, Fe_3O_4 – *Magnetospirillum magnetotacticum*.
- **$CaCO_3$**: calcite (*Bacillus megaterium*, SRB), aragonite, vaterite
- **Struvite** ($NH_4MgPO_4 \cdot 6H_2O$): *Myxococcus xanthus*
- **Monoelements**: Au^0, S^0, Se^0
- **Sulfides:**

  PbS: *Bacillus* sp. Abq

  AsS: *Shewanella* etc



Biogenic Se^0 produced by a mixed-microbial community (Staicu & Barton, 2021. J Inorg Chem 222, 111509)



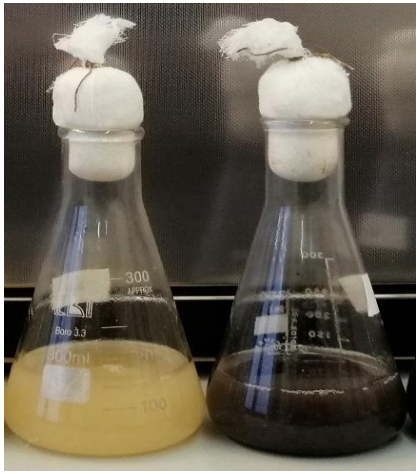
Gallionella ferruginea forming **iron stalks** (Suzuki et al. 2010. Appl Environ Microbiol 77, 2877-81)

Microbial biominerals for resource recovery?

Can microbial biomineralization be harnessed to recover added-value minerals from industrial effluents???

PbS biomineralization

- *Bacillus* sp. Abq* (*B. cereus*) - Novel strain
- It degrades cysteine to H_2S
- H_2S + Pb(II)acetate -> PbS (K_{sp} = 10^{-28})

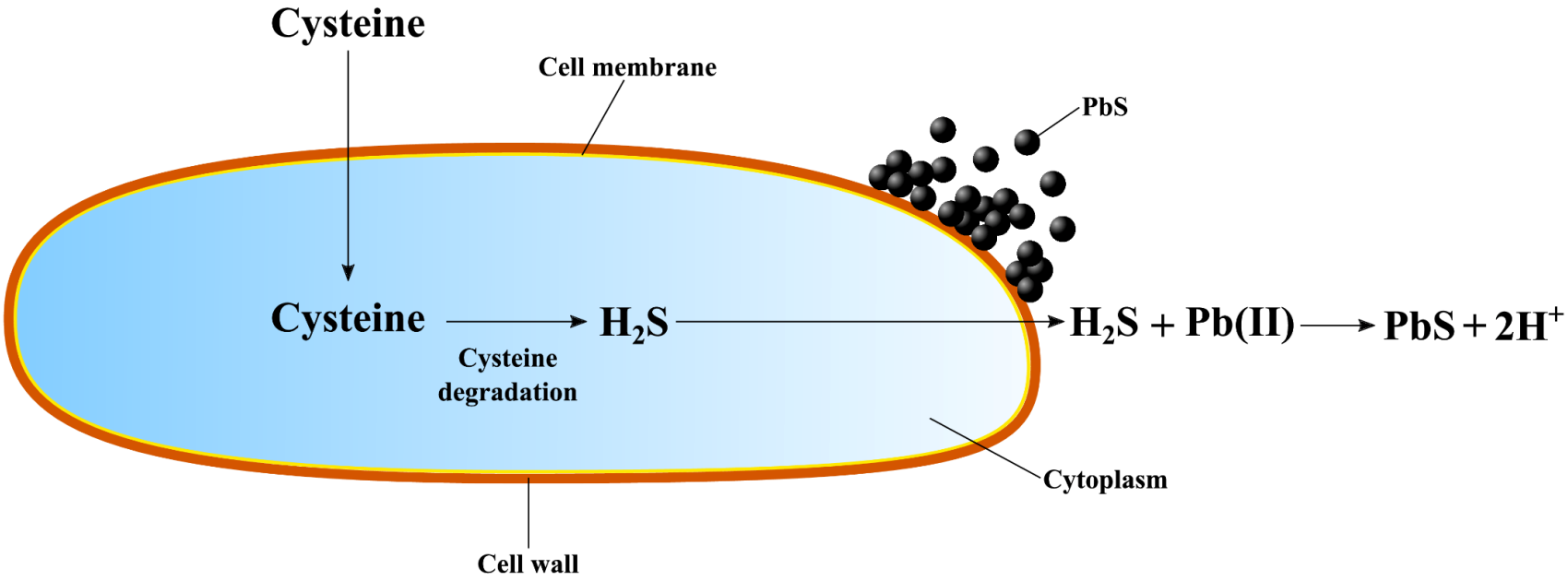


Ctrl PbS

Growth: LB, aerobic, 30 °C, 150 rpm, pH=5.0, 1 mM cysteine and Pb(II)acetate.

*Staicu LC et al. (2020) PbS biomineralization using cysteine: *Bacillus cereus* and the sulfur rush. FEMS Microbiology Ecology 96 (9).

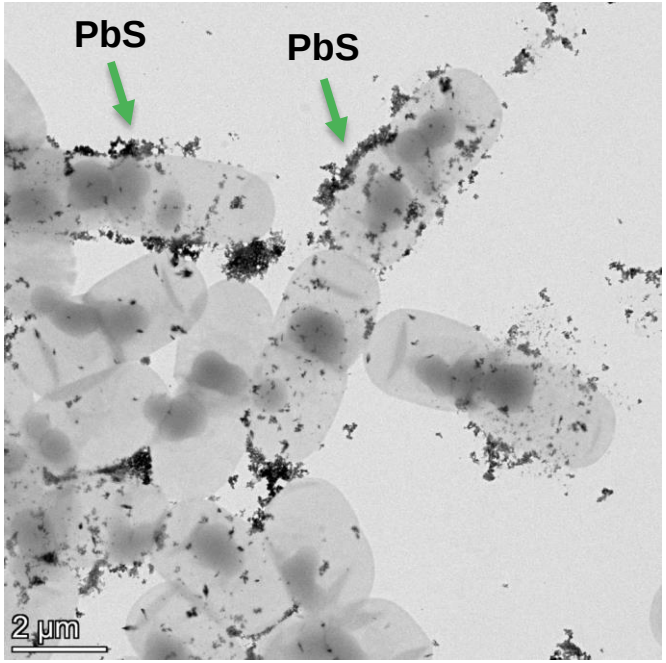
PbS biomineralization



*Staicu LC et al. (2020) PbS biomineralization using cysteine: *Bacillus cereus* and the sulfur rush. FEMS Microbiology Ecology 96 (9).

PbS biomineralization

- Pb(II) removal is time dependent and biotic
- Cysteine degradation occurs intracellularly
- PbS formation is extracellular
- PbS: crystalline, 4-10 nm



*Staicu LC et al. (2020) PbS biomineralization using cysteine: *Bacillus cereus* and the sulfur rush. FEMS Microbiology Ecology 96 (9).

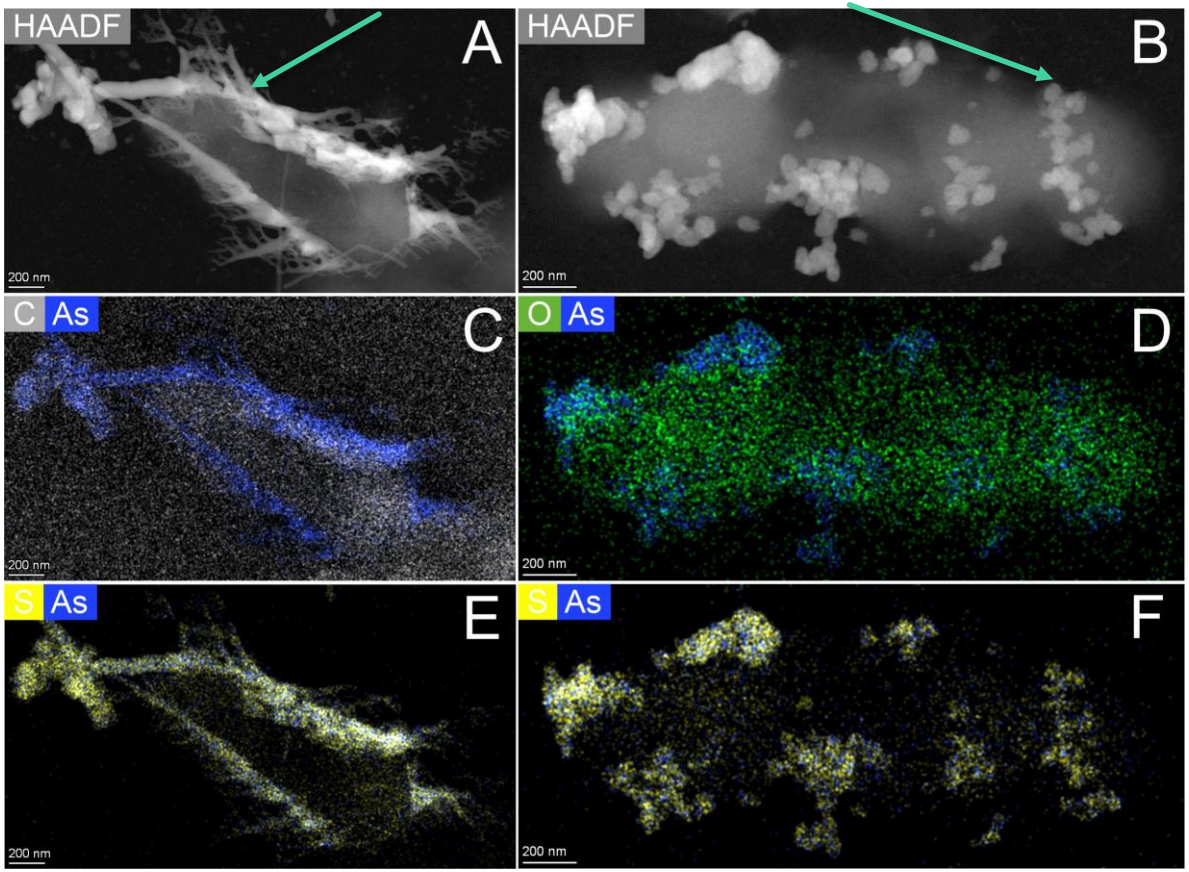
Arsenic and selenium biomineralization

- ***Shewanella* sp. O23S** (related to ***Shewanella baltica***) isolated from a former gold mine (SW Poland)
- **Tolerance to toxic metals** (Cd, Co, Cr, Cu, Mn, Mo, V and Zn)
- **Arsenic resistance** (*ars* operon) and **respiration** determinants (*arr*)
- Reduces **Se oxyanions** under **oxic** and **anoxic** conditions to **red Se^0**

***Shewanella sp.* O23S**

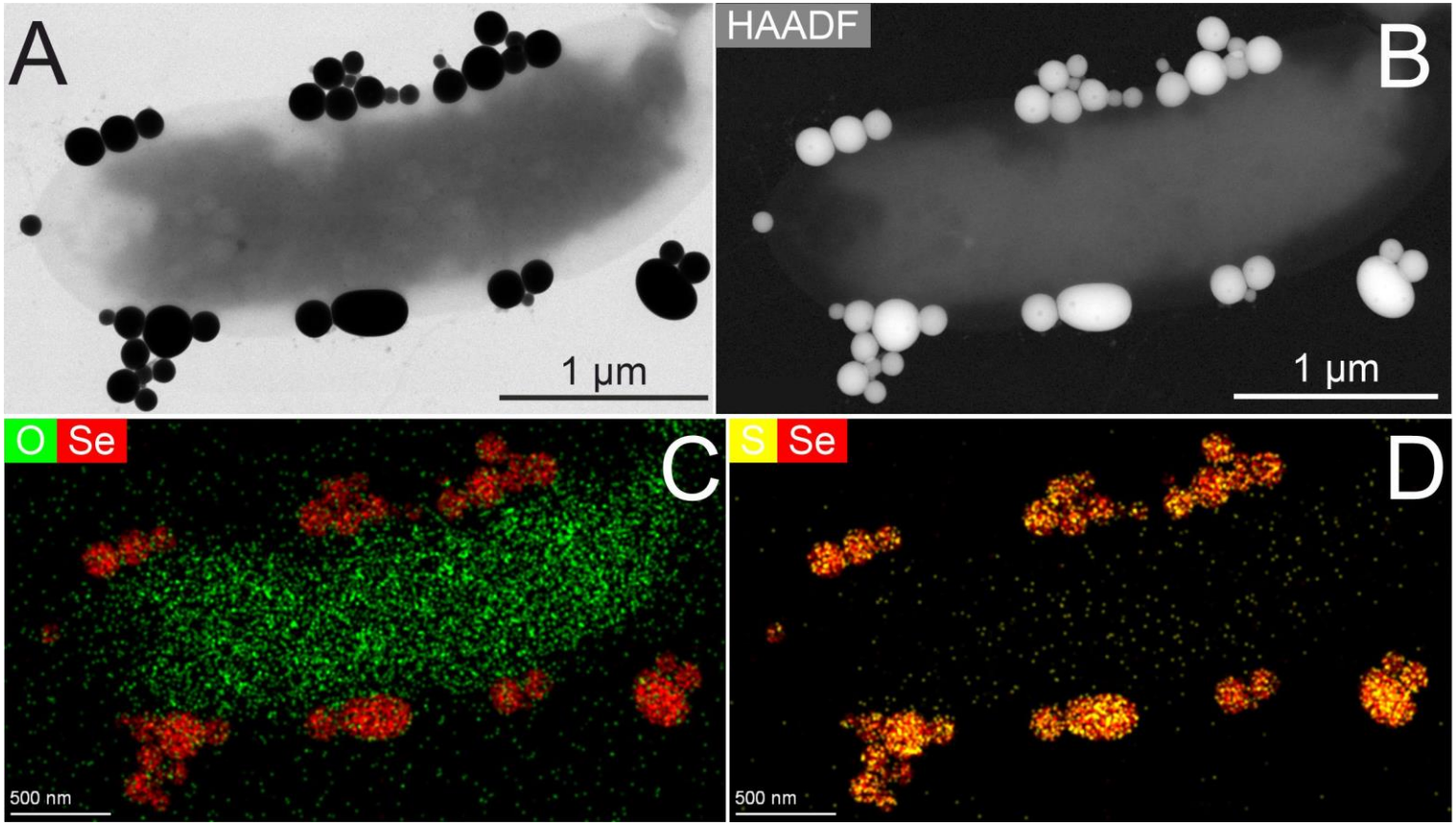
Shewanella sp. O23S: Biogenic AsS

AsS (realgar) As_2S_3 (orpiment)



Staicu et al. (2022) Environ Pollut 306, 119451

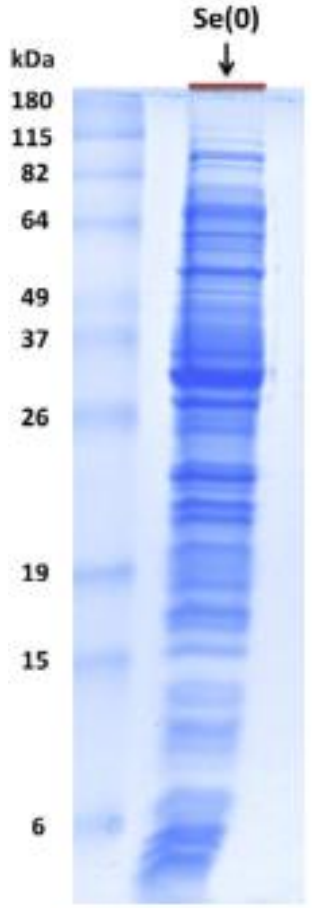
Shewanella sp. O23S: Biogenic Se^0



Staicu et al. (2022) Environ Pollut 306,119451

Challenges for resource recovery

- Upscale from lab to full-scale
- Biominerals are not pure (biological matrix)
- Difficult recovery and purification:
  - Cell lysis
  - Density-gradient centrifugation
  - Electrophoresis etc …



Biominerals – towards resource recovery using microorganisms

- Most **metals** are present in **soluble** forms in **industrial effluents** and could be **recovered** as insoluble **biominerals**
- Bacteria:
  - **High growth rates**
  - Amenable to **genetic engineering** (e.g. *Cupriavidus metallidurans* CH34*)
  - **Growth** can be **optimized** using bioreactors (controlled pH, t°, ORP, O_2)
  - Certain **enzymes** are **selective** for **metals/metalloids** (SeO_4^{2-} reductase from *Thauera selenatis*)

*van Houdt et al. (2018) Genes 9(10), 507

Perspectives

Received: 16 March 2023 | Accepted: 6 June 2023

DOI: 10.1111/1751-7915.14298

MICROBIAL BIOTECHNOLOGY Applied Microbiology International

OPINION

Burning Questions in Microbial Biotechnology

Will tomorrow's mineral materials be grown?

Julie Cosmidis

Department of Earth Sciences, University of Oxford, Oxford, UK

Correspondence
Julie Cosmidis, Department of Earth Sciences, University of Oxford, South Parks Road, Oxford OX1 3AN, UK.
Email: julie.cosmidis@earth.ox.ac.uk

Funding information
UK Research an Innovation (UKRI) Biotechnology and Biological Sciences Research Council, Grant/Award Number: BB/W010976/1

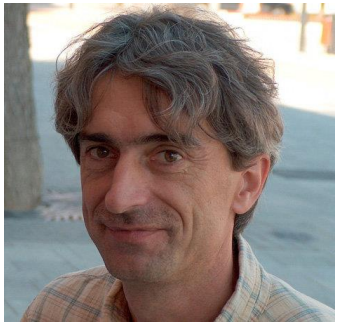
Abstract

Biomineralization, the capacity to form minerals, has evolved in a great diversity of bacterial lineages as an adaptation to different environmental conditions and biological functions. Microbial biominerals often display original properties (morphology, composition, structure, association with organics) that significantly differ from those of abiotically formed counterparts, altogether defining the 'mineral phenotype'. In principle, it should be possible to take advantage of microbial biomineralization processes to design and biomanufacture advanced mineral materials for a range of technological applications. In practice, this has rarely been done so far and only for a very limited number of biomineral types. This is mainly due to our poor understanding of the underlying molecular mechanisms controlling microbial biomineralization pathways, preventing us from developing bioengineering strategies aiming at improving biomineral properties for different applications. Another important challenge is the difficulty to upscale microbial biomineralization from the lab to industrial production. Addressing these challenges will require combining expertise from environmental microbiologists and geomicrobiologists, who have historically been working at the

Acknowledgements

Paulina Wójtowicz

Adrian Górecki



Mihály Pósfai

Larry Barton

- Encarnacion Ruiz-Agudo
- Mohamed Merroun
- José Luis Gallego
- Diego Baragaño
- Barbara Schoepp-Cothenet
- Laurent Charlet
- Zsombor Molnar
- Liane Benning
- Andreas Kappler

National Science Centre Poland

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Thank you for your attention!

- Questions …
- Comments …
- Suggestions …

https://staiculab.com/

staiculucian@gmail.com