Bioremediation

Prof. Tiffany Abitbol

2025

General announcements

- **December 2: Lab Activity** with Buse Tatli and final short assignment due (see announcement)

- **December 9: Poster session**
  - Make sure to hand in your poster and teaser slide
  - The afternoon will begin with teaser slide presentation, followed by poster presentations and evaluations
  - No written report
  - We will provide a printed evaluation sheet for you to grade your peers – this is mandatory
  - Snacks will be served, and a best poster prize will be awarded on Dec 16 (last class)
  - Final course evaluations in paper form – please fill in

- **December 16: Last class**
  - Presentations from SML post doc and PhDs
  - Your chance to ask fellow students what its like in graduate school and why they decided on this path

ACS NANO

www.acsnano.org

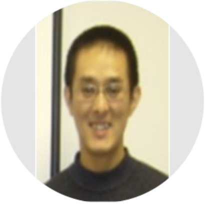
ARTICLE

Engineered Cyanobacteria-Based Living Materials for Bioremediation of Heavy Metals Both In Vitro and In Vivo

Tao Sun,[▽] Huaishu Huo,[▽] Yingying Zhang,[▽] Yaru Xie, Yize Li, Kungang Pan, Fenfang Zhang, Jing Liu, Yindong Tong, Weiwen Zhang,[*] and Lei Chen[*]

Cite This: *ACS Nano* 2024, 18, 17694–17706

- 2023 IF = 15.8
- # of citations = 23



Lei Chen

FOLLOW

Associate Professor of Chemical Engineering, Tianjin University, China
Verified email at tju.edu.cn

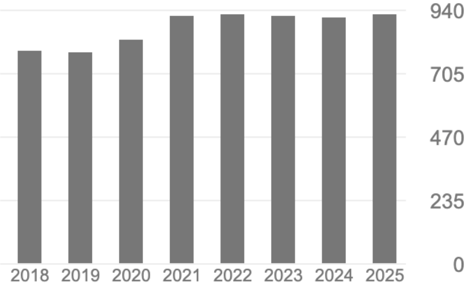
synthetic biology   systems biology   genetic engineering

TITLE	CITED BY	YEAR
Mapping and sequencing of structural variation from eight human genomes JM Kidd, GM Cooper, WF Donahue, HS Hayden, N Sampas, T Graves, ... Nature 453 (7191), 56-64	1471	2008
The genome sequence of taurine cattle: a window to ruminant biology and evolution Bovine Genome Sequencing and Analysis Consortium, CG Elsik, ... Science 324 (5926), 522-528	1233	2009
The genome of a songbird WC Warren, DF Clayton, H Ellegren, AP Arnold, LDW Hillier, A Künstner, ... Nature 464 (7289), 757-762	997	2010
Genome analysis of the platypus reveals unique signatures of evolution Nature 453 (7192), 175-183	798	2008

GET MY OWN PROFILE

Cited by   VIEW ALL

	All	Since 2020
Citations	12799	5443
h-index	51	38
i10-index	129	110



Lei Chen

Doctorate

Professor
Tianjin University
Tianjin, China

University rankings

BCUR National[15]	Domestic	20
Wu Shulian National[16]	Domestic	17
CUAA National[17]	Alumni	22
QS National[18]	General	12
THE National[19]	General	14–19
QS Asia (Asia version)[20]	General	57
THE Asia (Asia version)[21]	General	=32
ARWU World[22]	Research	101–150
QS World[23]	General	=257
THE World[24]	General	201–250
USNWR World[25]	General	=182

FOLLOW

Overview | Bio | 56 Network | 39 Publications | 26 Editorial Contributions | Impact

Brief Bio

My current research interest is mainly focused on the design and construction of photosynthetic cyanobacteria chassis. Photosynthetic cyanobacteria have emerged as an important chassis for producing biofuels and chemicals, due to their capability to utilize sunlight and CO2 as the sole energy and carbon sources. However, current productivity in the engineered cyanobacterial systems is still very low, partially due to the relatively low tolerance to end-products and various environment stresses. Our major academic achievements in recent years include:

(i) Development and optimization of genetic toolboxes for a fast-growing cyanobacterium *Synechococcus elongatus* UTEX 2973: However, the limited genetic tools currently restrict its further research and application efforts using synthetic biology approaches.

Expertise

Genetic Engineering · Synthetic Biology · Systems Biology · two component systems · Biofuels · Synechocystis · network · tolerance · WGCNA · Growth · Microalgae · chemicals · bioproducts · Accumulation · Metabolomics · ...

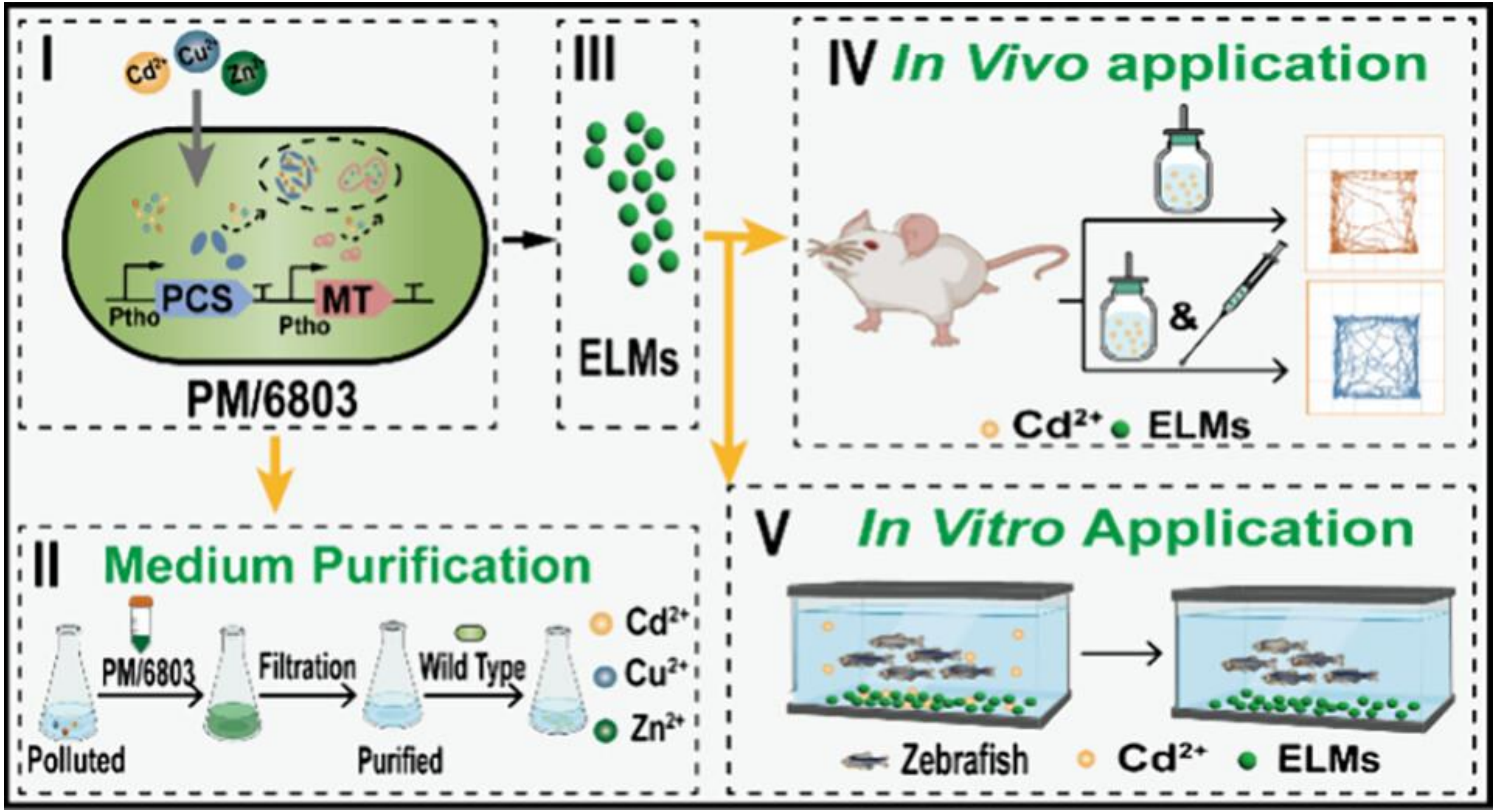
Abstract

- Heavy metal (HM) pollution is a serious threat
- Photosynthetic cyanobacteria can remediate HMs like cadmium
- But their practical use is complicated by a low tolerance to HMs and recycling issues
- In response, this study develops and evaluates engineered cyanobacteria for HM bioremediation
- How? Introduce genes encoding phytochelatins (PCSs) and metallothioneins (MTs) into the model cyanobacterium *Synechocystis* sp. PCC 6803, creating PM/6803
- The strain had better tolerance to HMs and effectively removed a combination of Cd^{2+}, Zn^{2+}, and Cu^{2+}

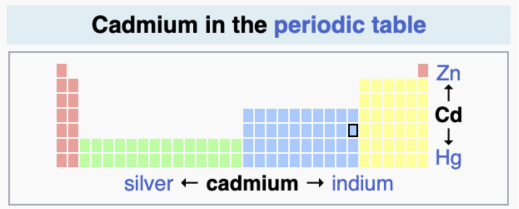
Abstract

- Using Cd^{2+} as a representative, PM/6803 achieved a bioremediation rate of approximately 21 µg of Cd^{2+}/OD_{750} under the given test conditions
- To facilitate its controllable application, PM/6803 was encapsulated using sodium alginate-based hydrogels (PM/6803@SA) to create "living materials" with different shapes
- This system was feasible, biocompatible, and effective for removing Cd^{2+} under simulated conditions of zebrafish and mice models
- Briefly, in vitro application of PM/6803@SA efficiently rescued zebrafish from polluted water containing Cd^{2+}, while in vivo use of PM/6803@SA significantly decreased the Cd^{2+} content in mice bodies and restored their active behavior.
- The study offers feasible strategies for HMs bioremediation using the interesting biomaterials of engineered cyanobacteria both in vitro and in vivo.

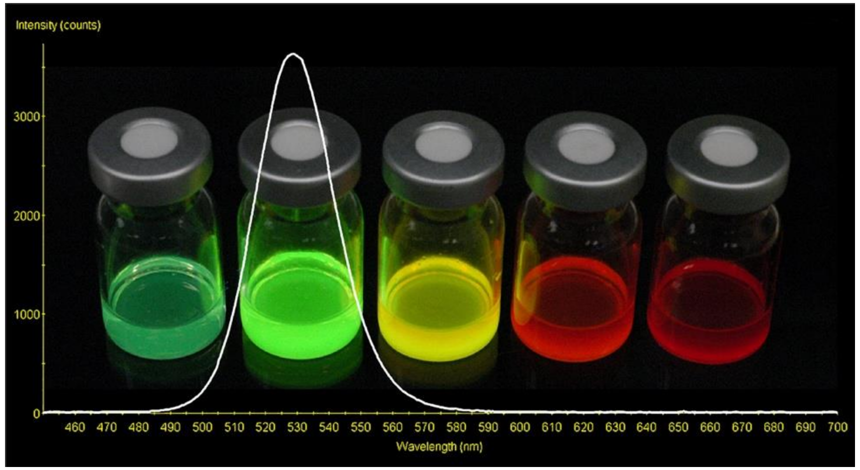
Graphical abstract



Cadmium



Atomic number (*Z*)	48
Group	group 12
Period	period 5
Block	d-block
Electron configuration	[Kr] $4d^{10}\ 5s^2$
Electrons per shell	2, 8, 18, 18, 2



"Human exposure is primarily from fossil fuel combustion, phosphate fertilizers, natural sources, iron and steel production, cement production and related activities, nonferrous metals production, and municipal solid waste incineration.[20] Other sources of cadmium include bread, root crops, and vegetables.[81]"

Lethal dose[106]	Organism	Route	Time
LD_{50}: 225 mg/kg	rat	oral	n/a
LD_{50}: 890 mg/kg	mouse	oral	n/a
LC_{50}: 25 mg/m^3	rat	airborne	30 min

https://en.wikipedia.org/wiki/Cadmium

Introduction – What's the problem with HMs?

- Although naturally occurring, rapid industrialization and urbanization have led to serious environmental pollution

- Specifically implicated are chemicals containing cadmium (Cd), copper (Cu), lead (Pb), zinc (Zn), mercury (Hg), and chromium (Cr) are released into the soil and hydrosphere

- HMs like Cd have no physiological function but act as toxicants and carcinogens that affect the kidneys and skeleton; originates from copper and nickel smelting and refining, fossil fuel combustion, and the use of phosphate fertilizers; widely employed as a stabilizer in plastics, color pigments, and Ni–Cd batteries, whose wastes worsen environmental pollution

Etymology [edit]

The term *itai-itai disease* (in Japanese イタイイタイ病 *itai-itai byō*, "it hurts-it hurts disease" or "ouch-ouch disease") was coined by the affected locals for the severe pains that people with itai-itai disease felt in the spine and joints.[6] In Japanese 痛い *itai* is used as an adjective meaning "painful" or as an interjection equivalent to "ouch".

Causes [edit]

Itai-itai disease was caused by cadmium poisoning due to mining in Toyama Prefecture. Regular mining for silver started in 1589, and soon thereafter, mining for lead, copper, and zinc began. The earliest records of mining for gold in the area date back to 1710. Cadmium is a metal byproduct of mining that is toxic to most organisms.

Animal studies have shown that cadmium poisoning alone is not enough to elicit all of the symptoms of itai-itai disease.[7] These studies point to damage of the mitochondria of kidney cells by cadmium as a key factor of the disease.

https://en.wikipedia.org/wiki/Itai-itai_disease

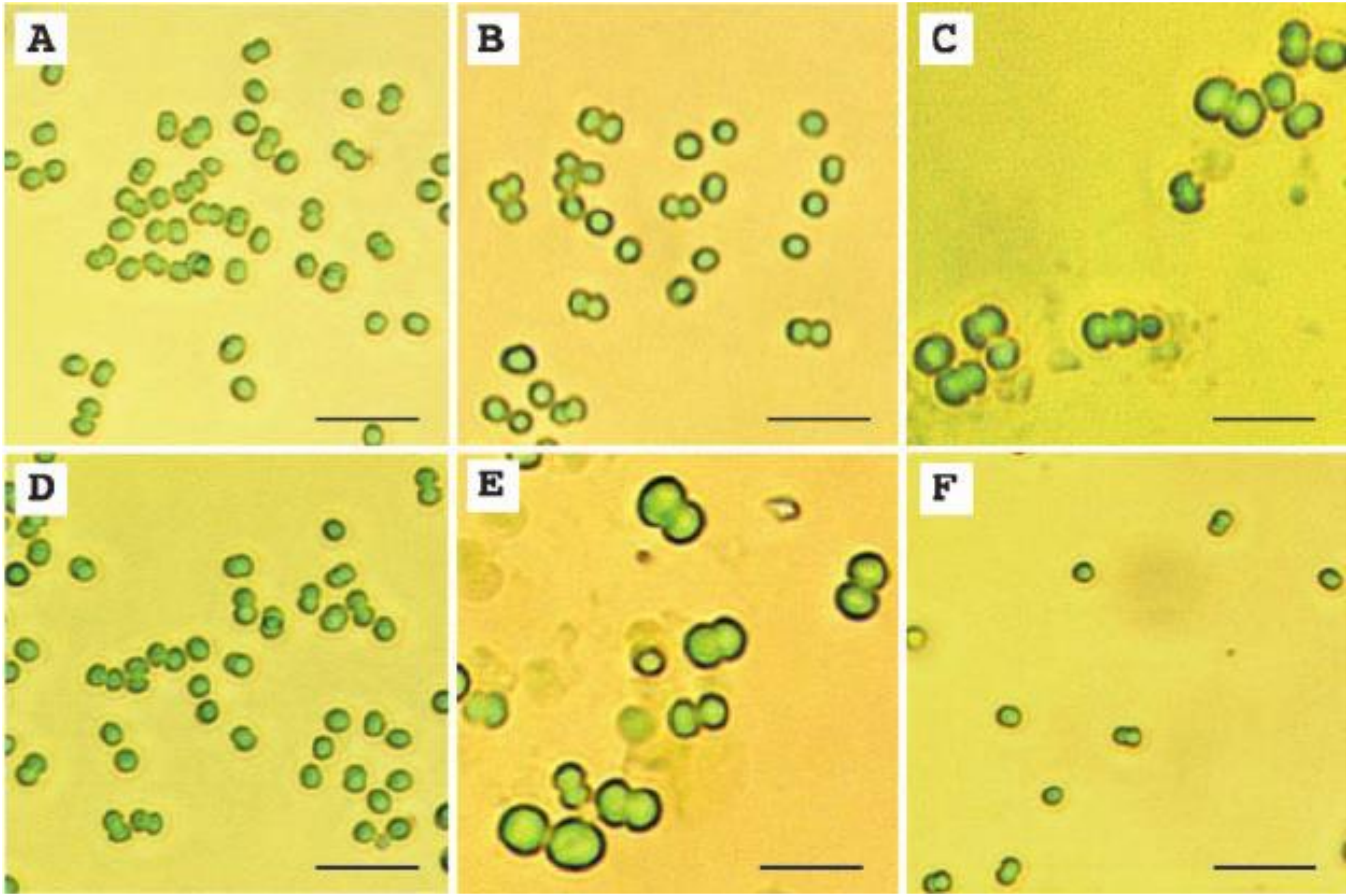
Introduction - Background

- Traditionally, chemical and physical methods for heavy metal removal are often costly and less efficient, generating large quantities of toxic sludge.
- In contrast, bioremediation using microorganisms such as bacteria, microalgae, and yeast is a promising, eco-friendly, and cost-effective alternative.
- Among them, **autotrophic** cyanobacteria are the only **prokaryotes** capable of **oxygenic photosynthesis**, thereby occupying an important ecological niche and accounting for approximately 25% of the annual carbon fixation on earth
- Cyanobacteria have great potential for bioremediation due to their naturally high binding affinity and rich binding sites for HMs.

Introduction - biopart

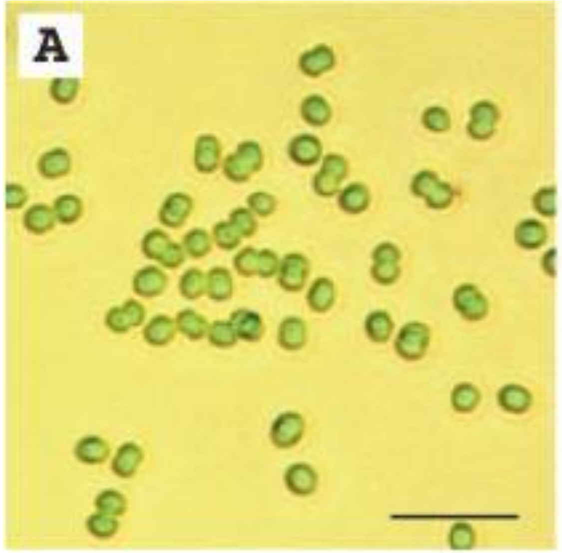
Synechocystis sp. PCC 6803

https://doi.org/10.1104/pp.102.017277



- These cyanobacteria can remove HMs
- But they have a limited tolerance to HMs, as evidenced by their arrested growth
- Strain is fully sequenced but has low tolerance to HMs

Introduction - biopart



Synechocystis sp. PCC 6803

https://doi.org/10.1104/pp.102.017277

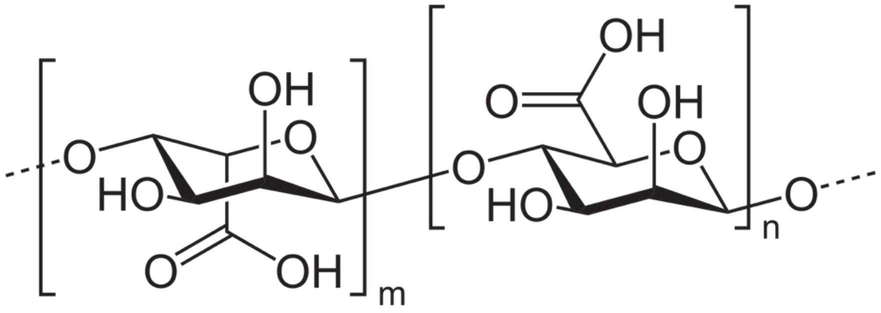
- Phytochelatins (PCSs) and metallothioneins (MTs) are the most important types of metal chelators, capable of withstanding high concentrations of HMs and chelating them

- PCS and MT respectively from *Arabidopsis thaliana* (25) and *Pseudomonas* (26) were selected in this study due to their chelating ability specifically for heavy metals like Cd^{2+}, Zn^{2+}, etc.

- We integrated genes encoding PCS and MT into the model cyanobacterium *Synechocystis* sp. PCC 6803 and explored their roles in tolerance and bioremediation of HMs, particularly Cd^{2+}, through several compelling examples in this study

- A significant resistance to Cd^{2+}, Cu^{2+}, and Zn^{2+} was achieved in the engineered strain along with the improved bioremediation ability…

Materialw part



Group 1:

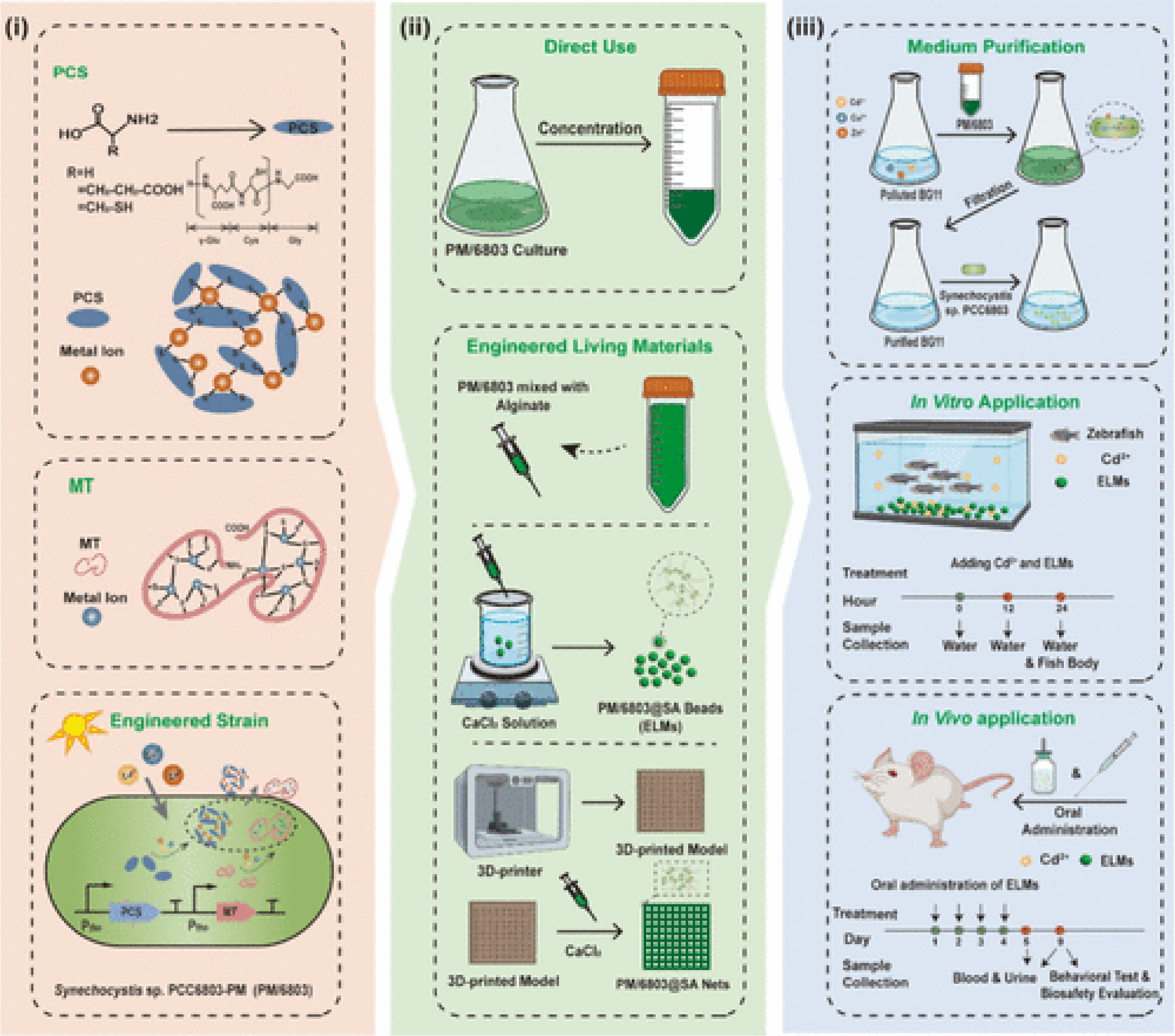
Genetic engineering

Group 2:

Materials part

Group 3:

Applications part



Today, we will try something different!

3 groups, 30 min to read and extract the key information from each part

10 min to explain to the class/discuss

Group 1: **Group 2:** **Group 3:**

Genetic engineering | Materials part | Applications part

Questions you might consider: (not limited)

- `What HMs were evaluated?
- Were the engineered strains more resistant to heavy metals? How was this shown?
- How did they evaluate whether the construct worked in bioremediation?
- How did the engineered bacteria perform compared to the controls? Were both PCS and MTS needed? Why not one?
- Why is the photosynthetic nature of cyanobacteria important?

Group 1: Genetic engineering

Group 2: Materials part

Group 3: Applications part

Questions you might consider: (not limited)

- Why did they select alginates? What are its beneficial properties in this context?
- How did they introduce the bacteria into the alginate? What architectures did they design and why?
- How did they test that the bacteria was still able to bind HMs when encapsulated?

Group 1:	Group 2:	Group 3:
Genetic engineering	Materials part	Applications part

Questions you might consider: (not limited)

- What different applications and contexts were tested?
- Did the materials perform as expected? Why or why not?
- Were adequate controls tested?
- Would you have done anything differently? Can you imagine a different application?
- What do we do with the HM-loaded materials/cells? Did the authors address this?

Was this activity useful?