Multifunctional hydrogels to simultaneously absorb organic and inorganic micropollutants

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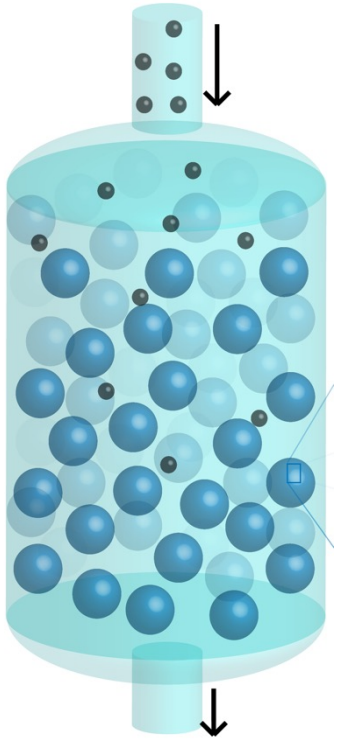


New England Water Environment Association

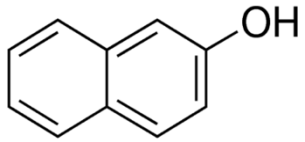
January 22, 2024

Micropollutants are chemically diverse

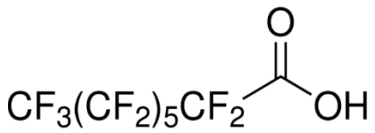
As

Pb

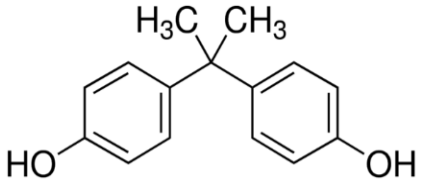
Heavy metals
mining, pipes



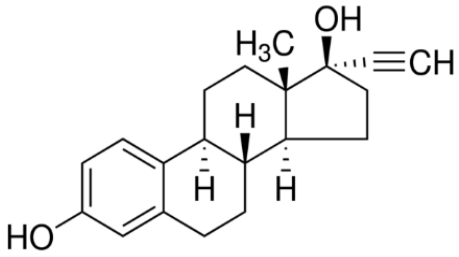
2-Naphthol
dyes



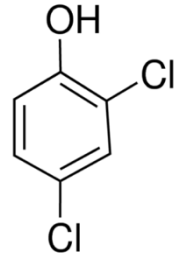
PFOA
surfactants



Bisphenol A (BPA)
plastics



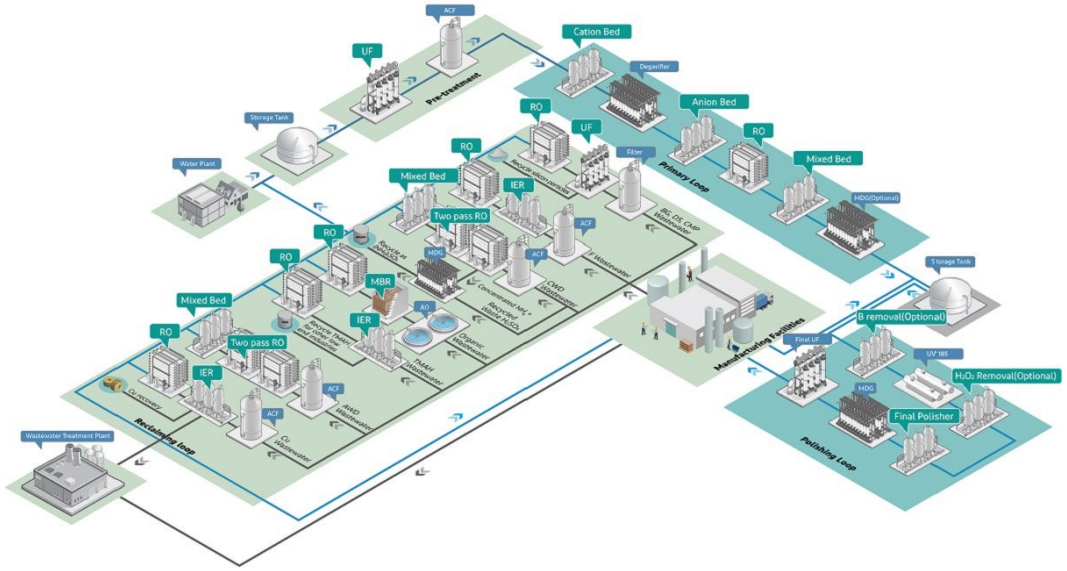
Ethinyl Estradiol
pharmaceuticals



2,4-Dichlorophenol
pesticides

Activated carbon

Ion-exchange resin



A typical UPW plant (duPont) has numerous unit operations

Membrane-based processes: 13
Adsorption processes: 16

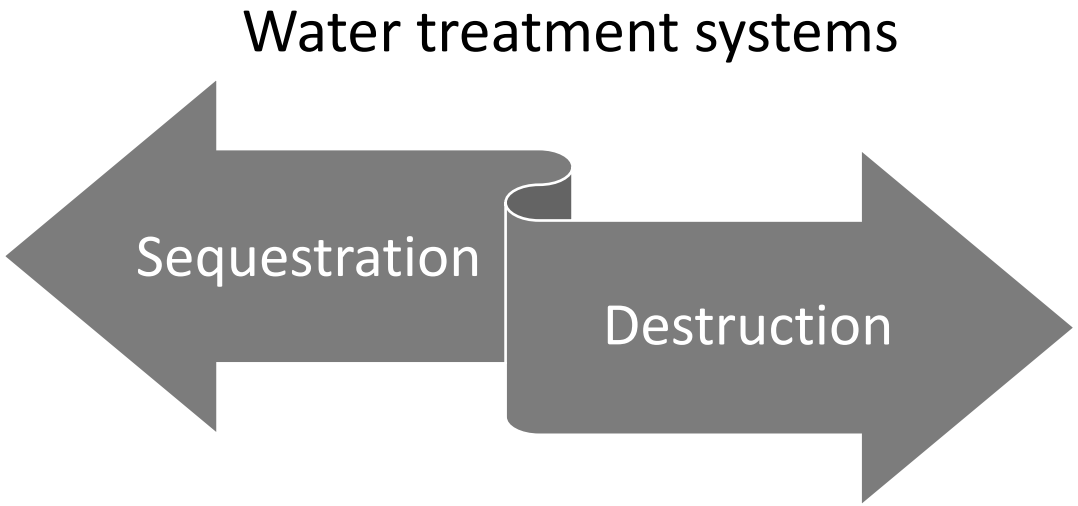
Total: 30+ processes

Very difficult to remove everything to ppt levels

Combining sequestration and destruction

- Produce toxic waste
- Or can be regenerated to upconcentrate for destruction

- Activated carbon
- Ion-exchange
- Various membranes
- Electrochemical methods



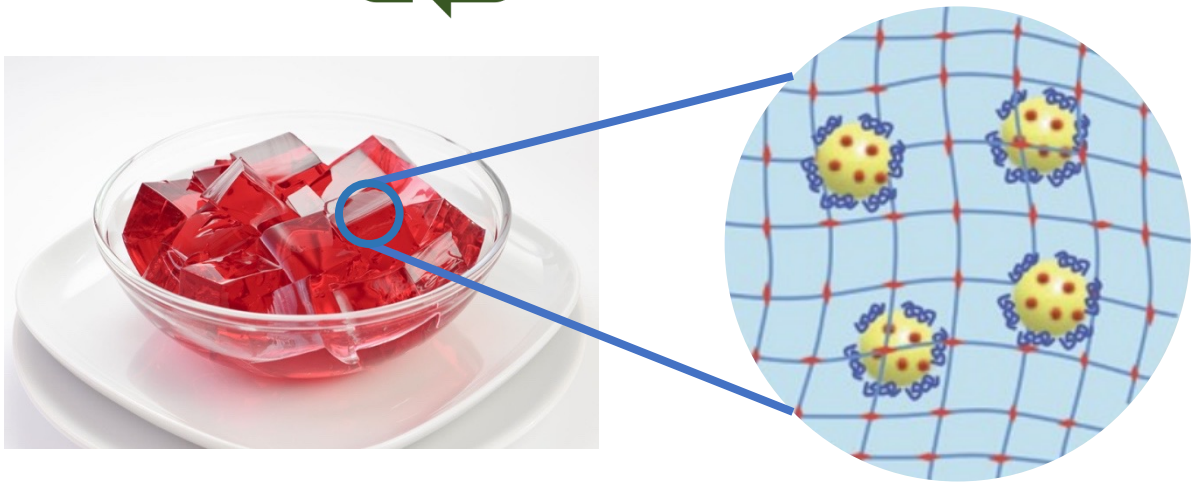
- Better end-of-life solution
- Requires high concentrations to be cost-effective

- Electrocatalysis
- Photocatalysis
- Advanced Oxidation Processes

Separation of units leads to larger footprint and costs, reduces design flexibility

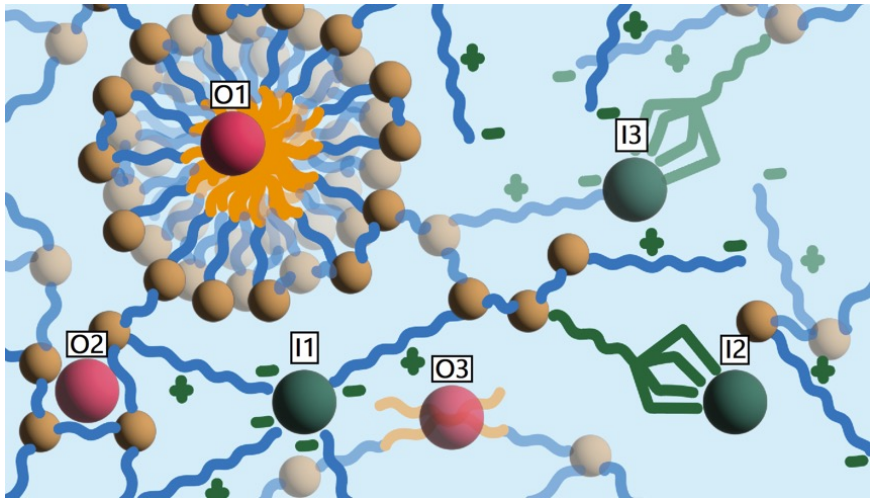
Hydrogels are ideal platforms for water treatment applications

Sustainable



Highly porous polymers with high water fraction (up to 90%)
- Rapid transport & safe degradation

Versatile



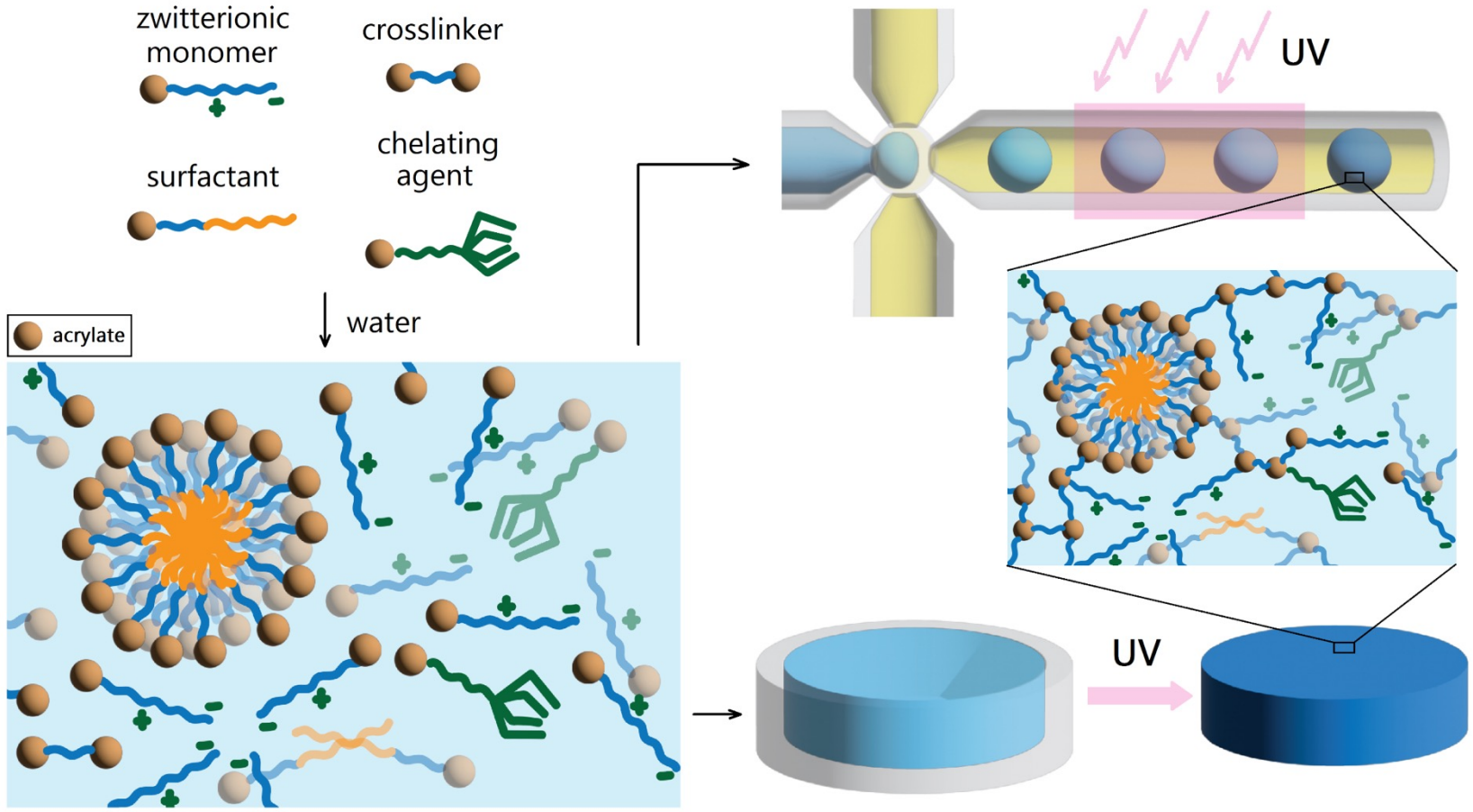
Easy and <u>bulk</u> functionalization with chemically bound micelles, chelating agents, charges, etc.

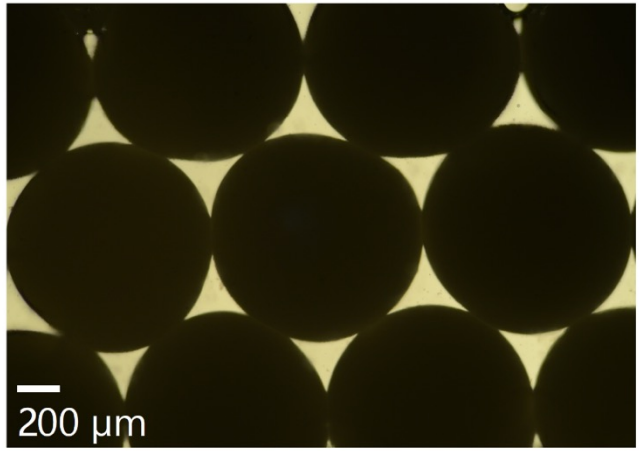
Extensively used in pharma – well-established supply chains & low cost

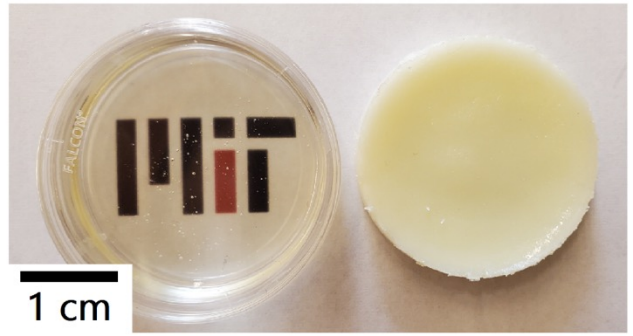
Scalable

***Gokhale**, Chen, and Doyle, ACS Appl. Polym. Mater. 2022*
***Gokhale**, Hamelberg, and Doyle, Nat. Water 2024*

Hydrogels can be made in facile processes



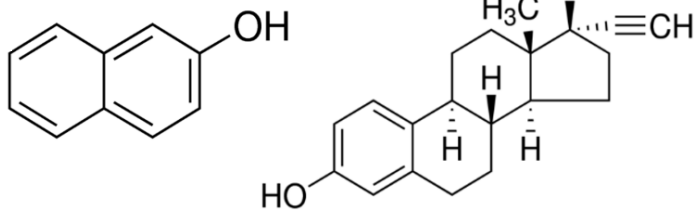




***Gokhale**, Chen, and Doyle, ACS Appl. Polym. Mater. 2022*
***Gokhale**, Hamelberg, and Doyle, Nat. Water 2024*

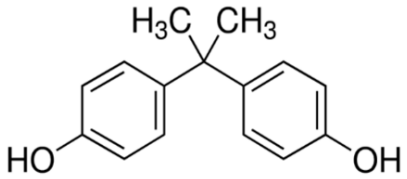
***Gokhale**, Chen, and Doyle, Soft Matter 2022*
*Doyle and **Gokhale**, WO/2023/086073 (International Publication)*

Zwitterionic hydrogels bind diverse micropollutants



2-naphthol
dyes
NOL

ethinylestradiol
drugs
EDOL

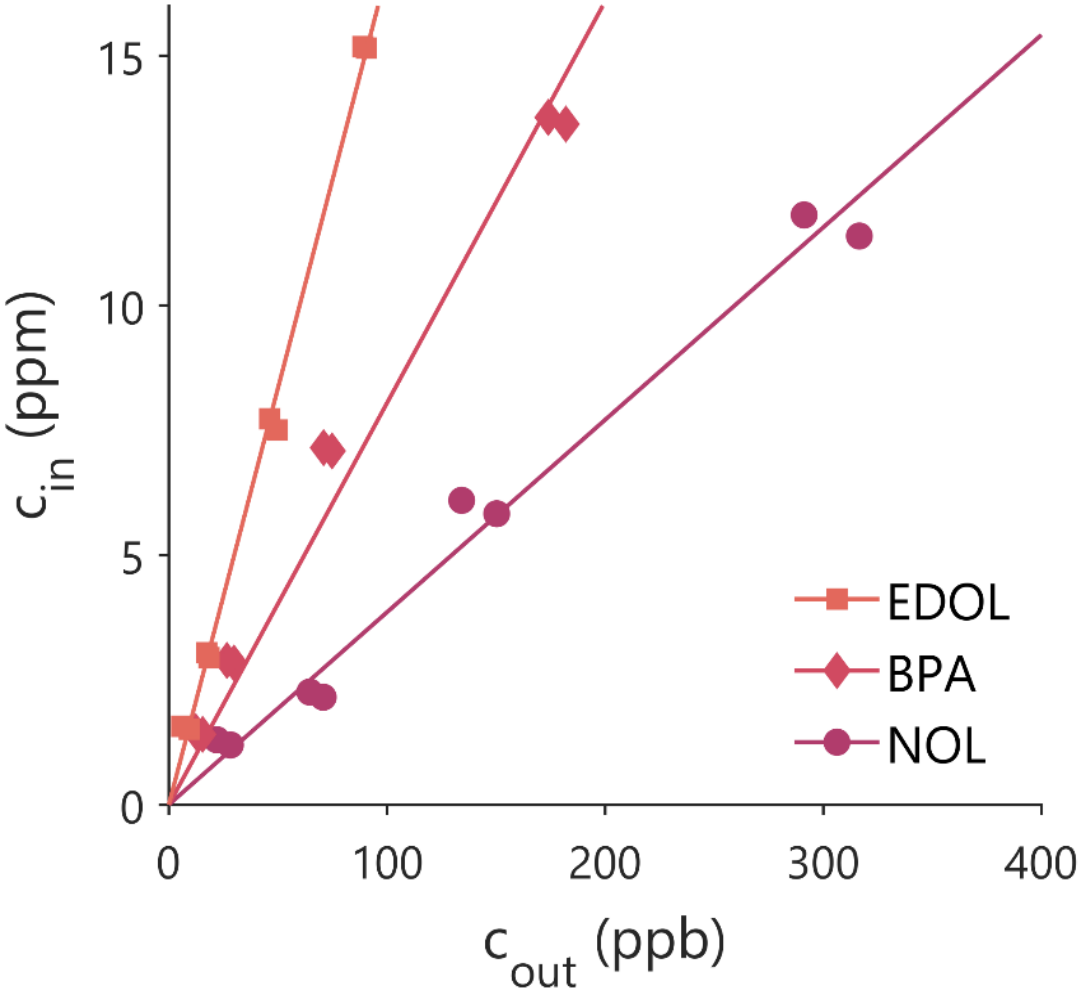


bisphenol A
plastics
BPA

Cu
copper

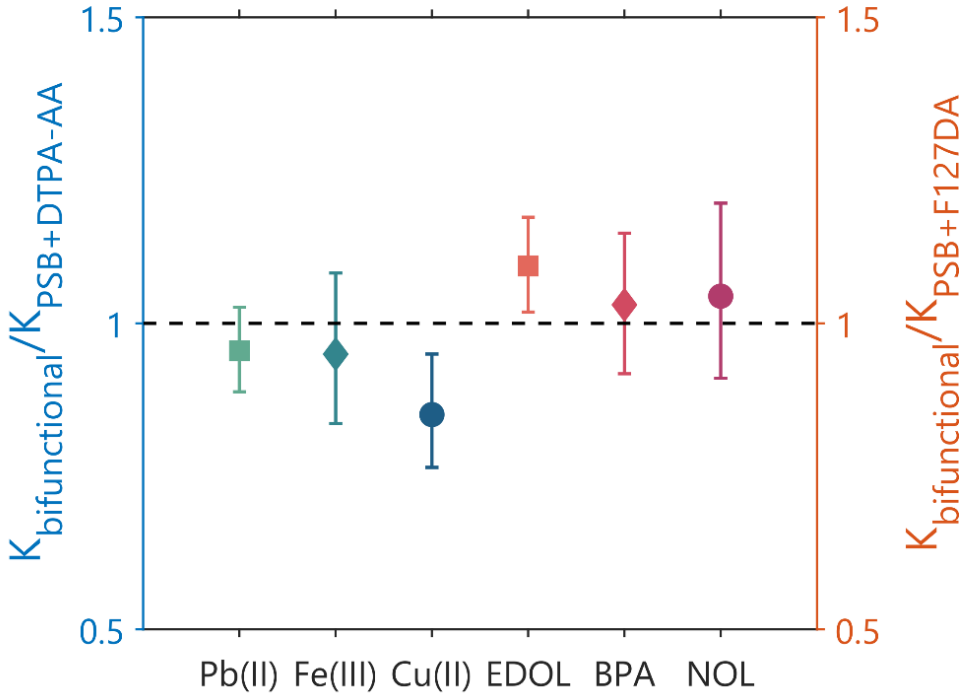
Pb
lead

Fe
iron

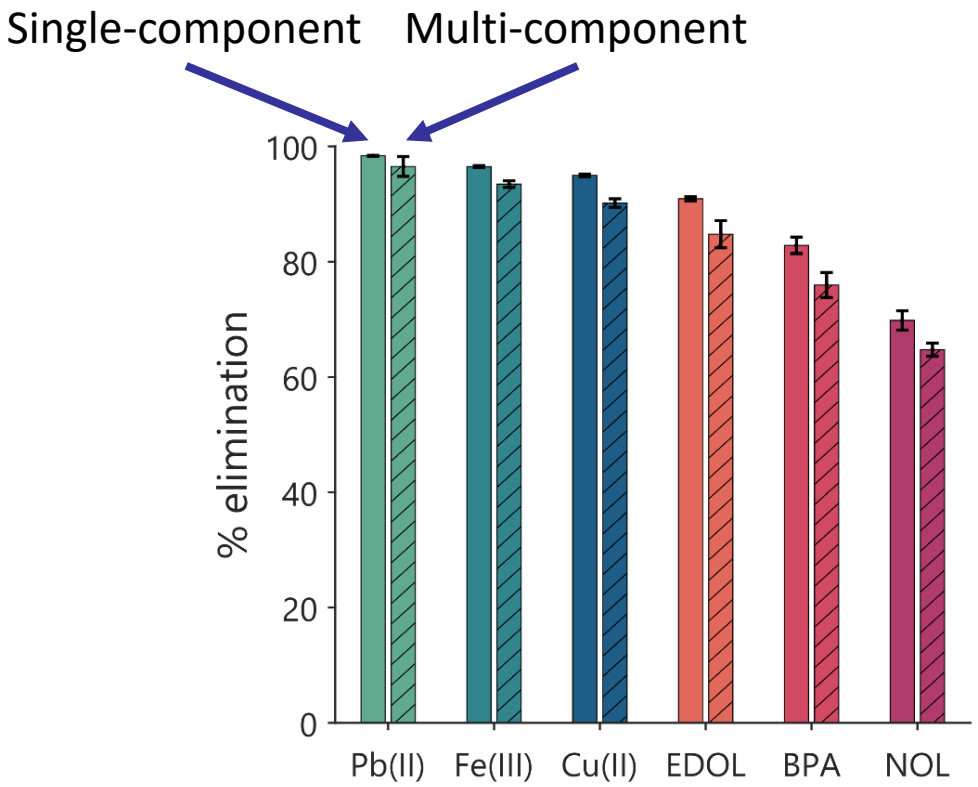


Equilibrium measurements (24h) in batch experiments

Hydrogel absorbents can be made using plug-and-play design

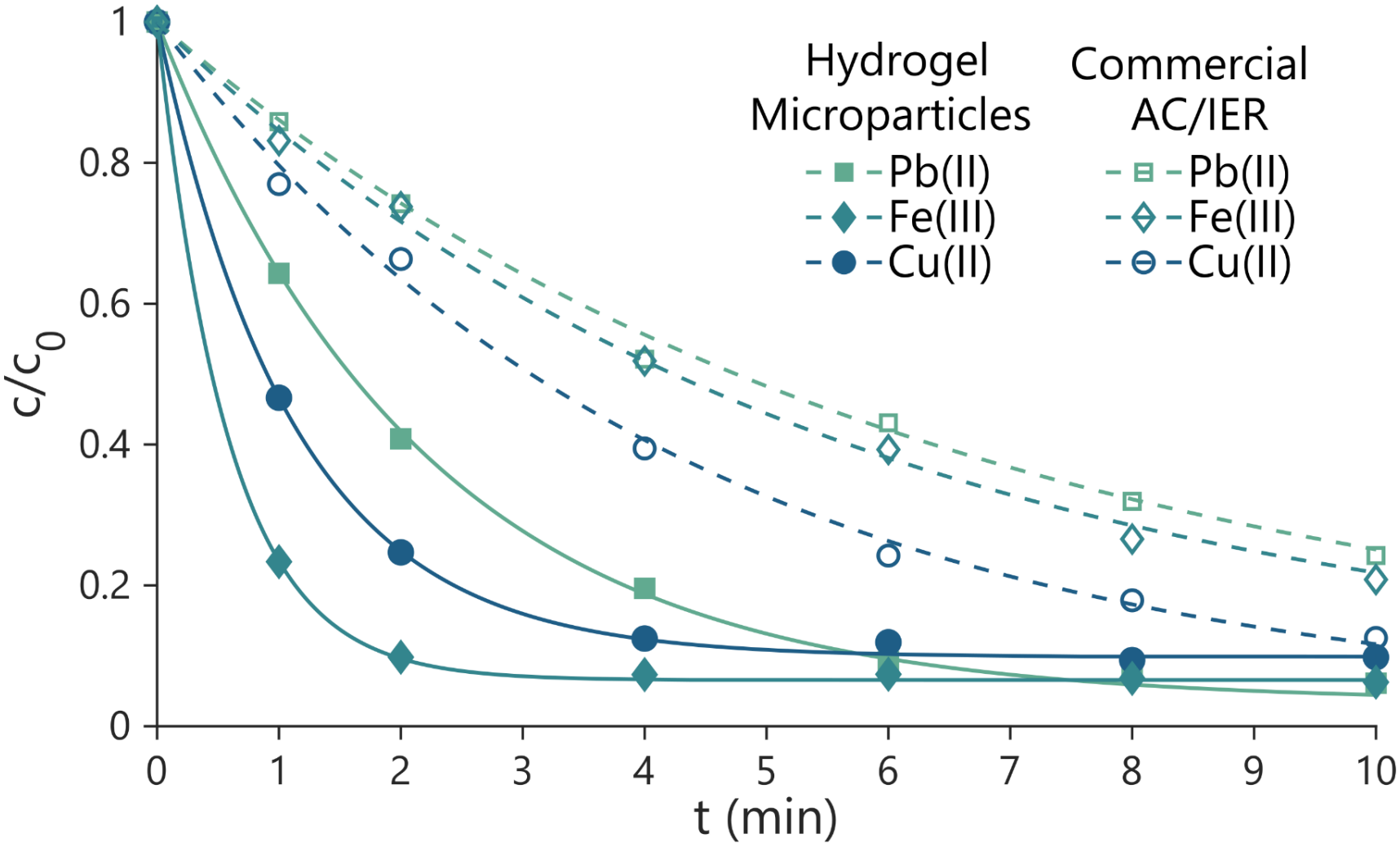


Functional groups do not affect each other's performance



Micropollutants do not affect each other's uptake

Multifunctional hydrogels rapidly sequester contaminants

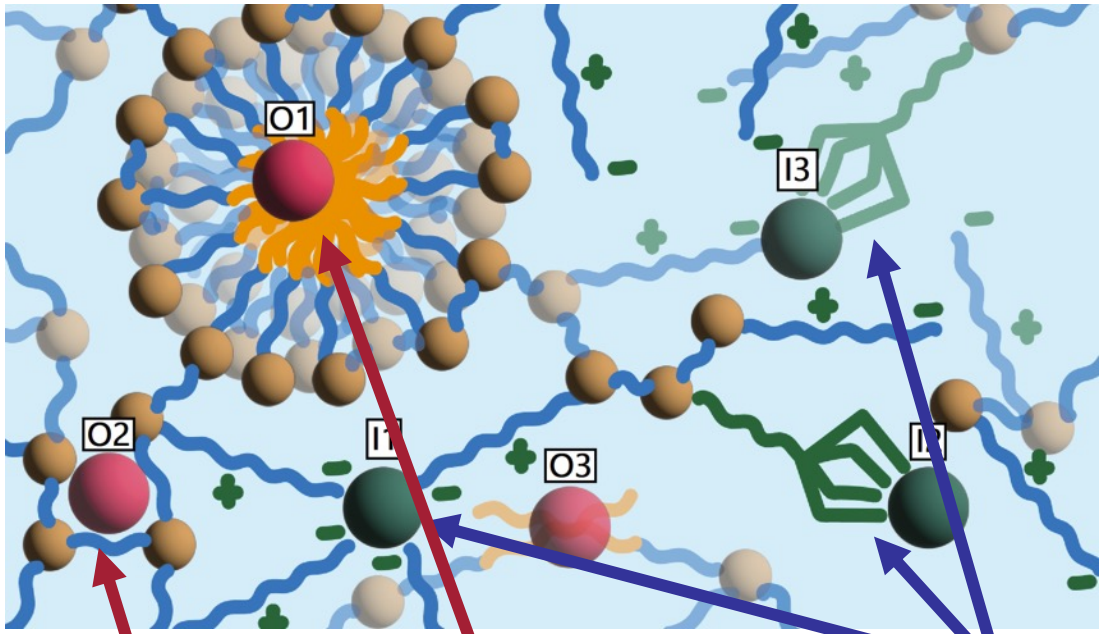


200 ppb each of:

- ethinylestradiol
- bisphenol A (BPA)
- 2-naphthol
- lead
- iron
- copper

Can reduce footprint or increase throughput

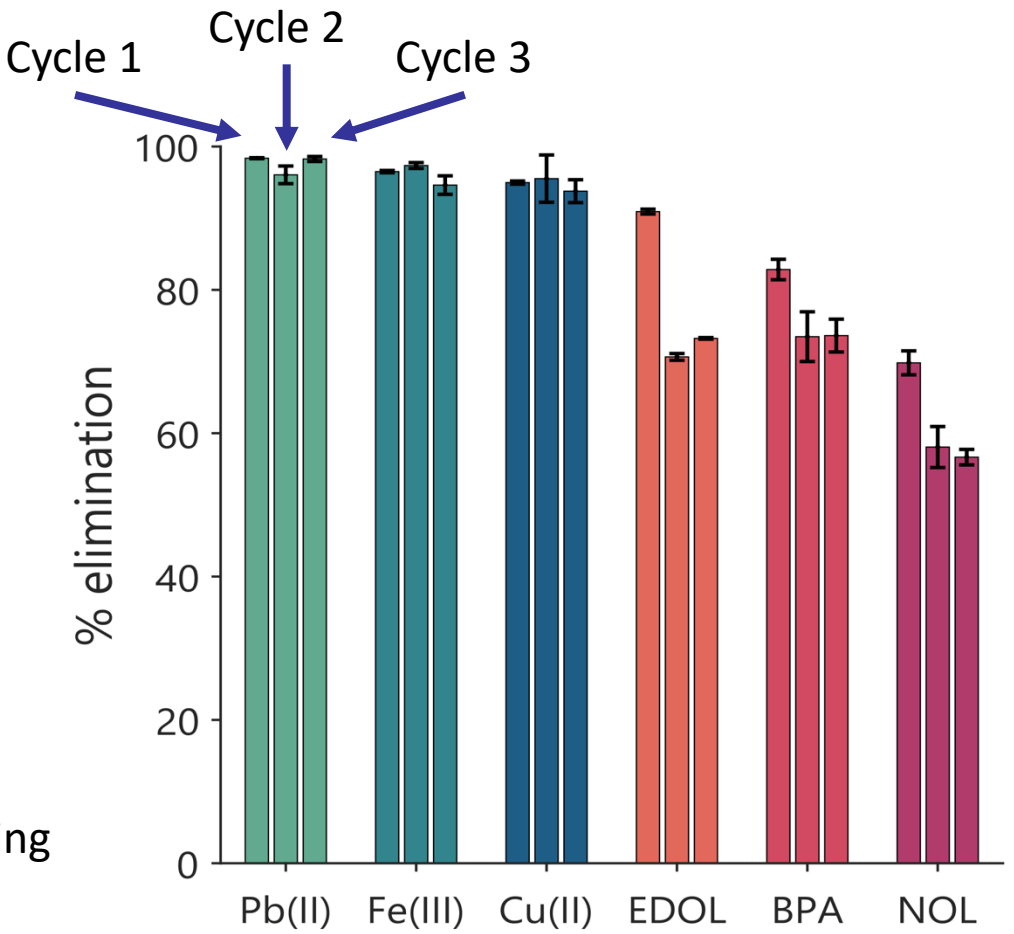
Hydrogels absorbents are versatile and reusable



Ethanol shrinks micelles
Stronger affinity for organics

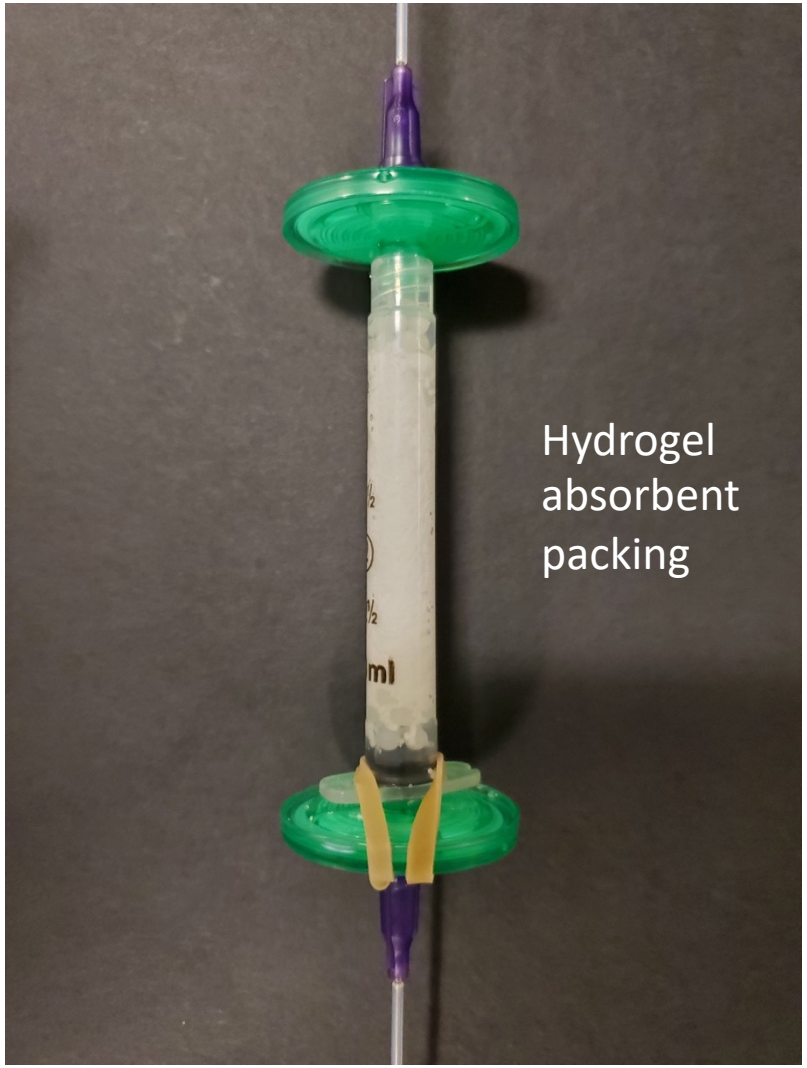
Brine reverses binding

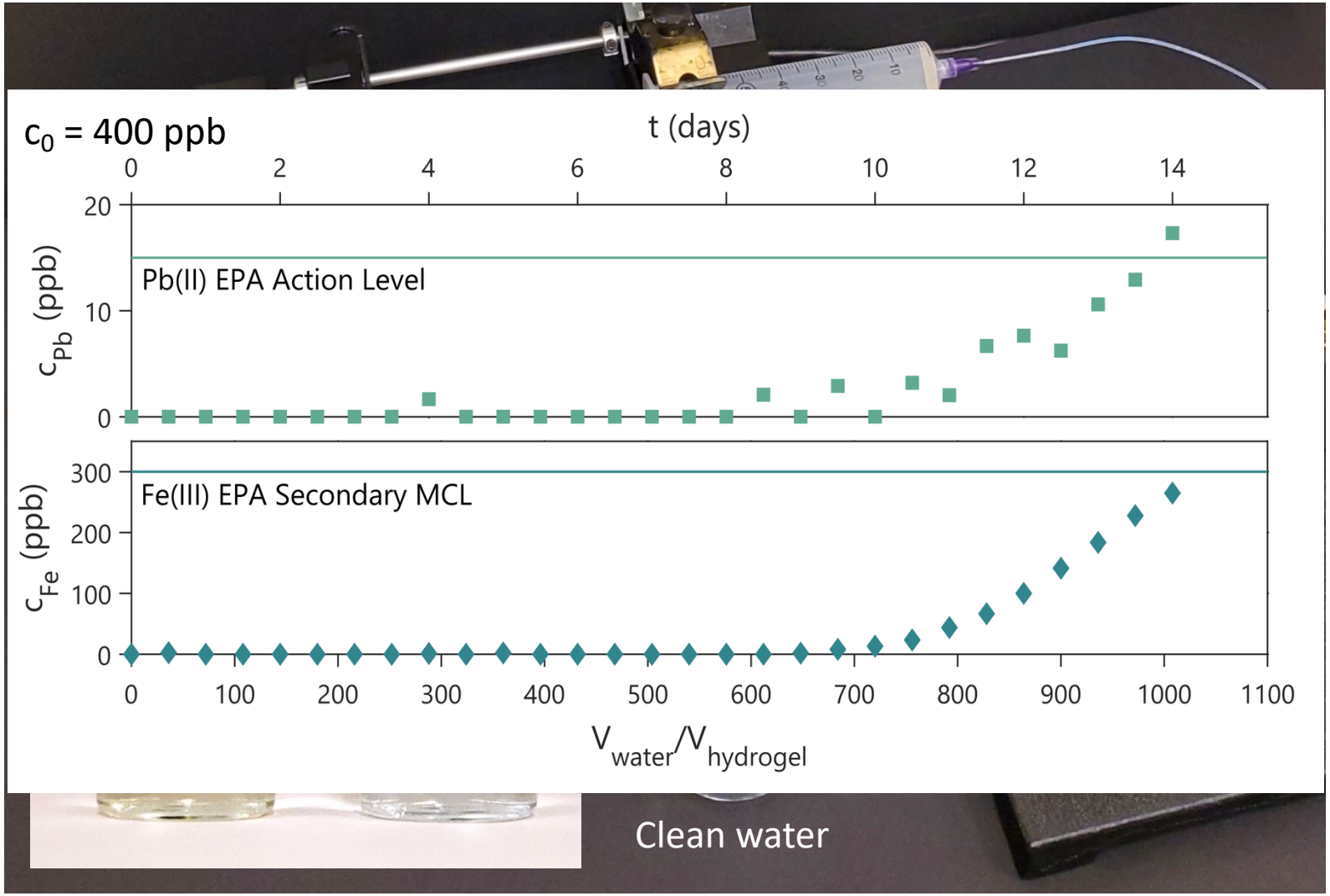
Irreversible using ethanol



Hydrogels retain performance after regeneration by washing with ethanol & brine

Hydrogel-based filters are easy to scale





***Gokhale**, Hamelberg, and Doyle, Nat. Water 2024*
***Gokhale**, Chen, Wu, and Doyle, in review*
*Doyle and **Gokhale**, WO/2023/086073 (International Publication)*
***Gokhale**, Stathatou, Athanasiou, and Doyle, in review*

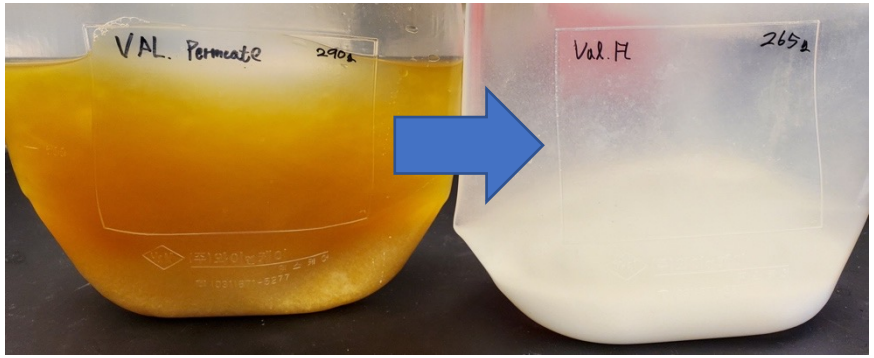
Industrial applications in selective separations

CJ CheilJedang is a ~$21 billion food and beverage company in South Korea

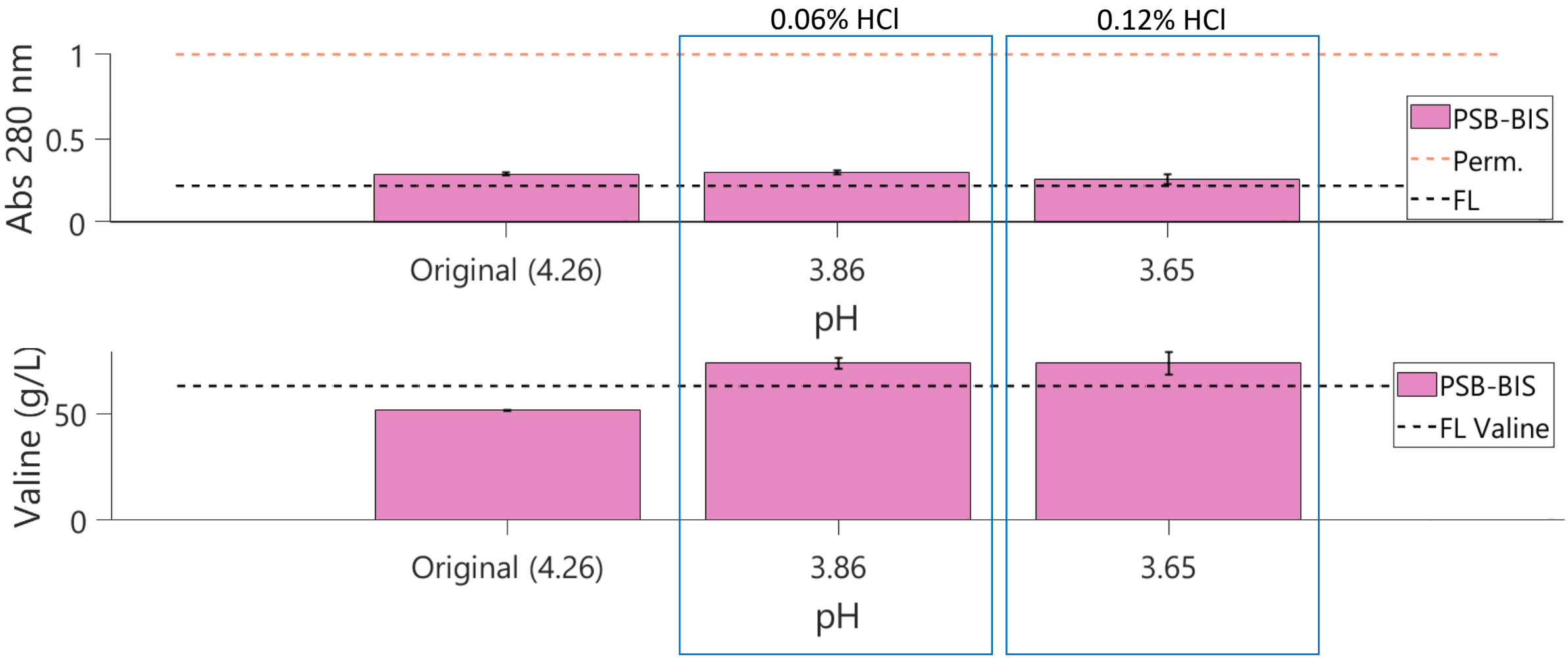
- Fermentation process to produce amino acids
- Final product needs to be polished to remove color, micropollutants
- Currently use about 10,000 tons of activated carbon per year
- No regeneration/reuse – 110,000 metric tons of indirect CO_2 emissions annually

~ 50,000 – 100,000 ppm salt & organics background
~ 100 – 10,000 ppm contaminants

Objective: preserve valine while removing contaminants

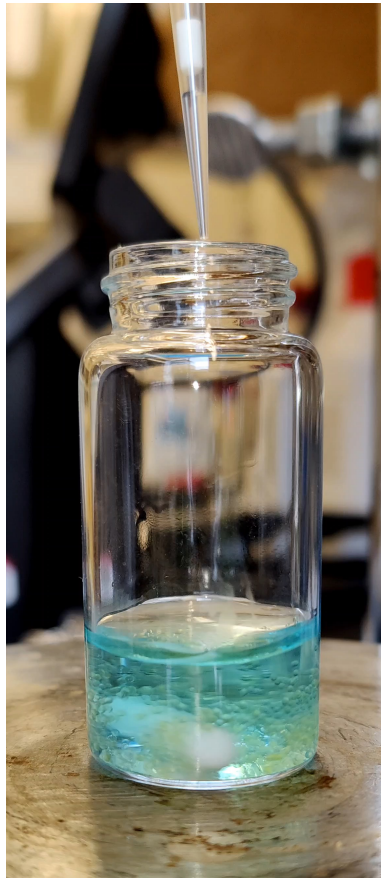


Processes are highly tunable

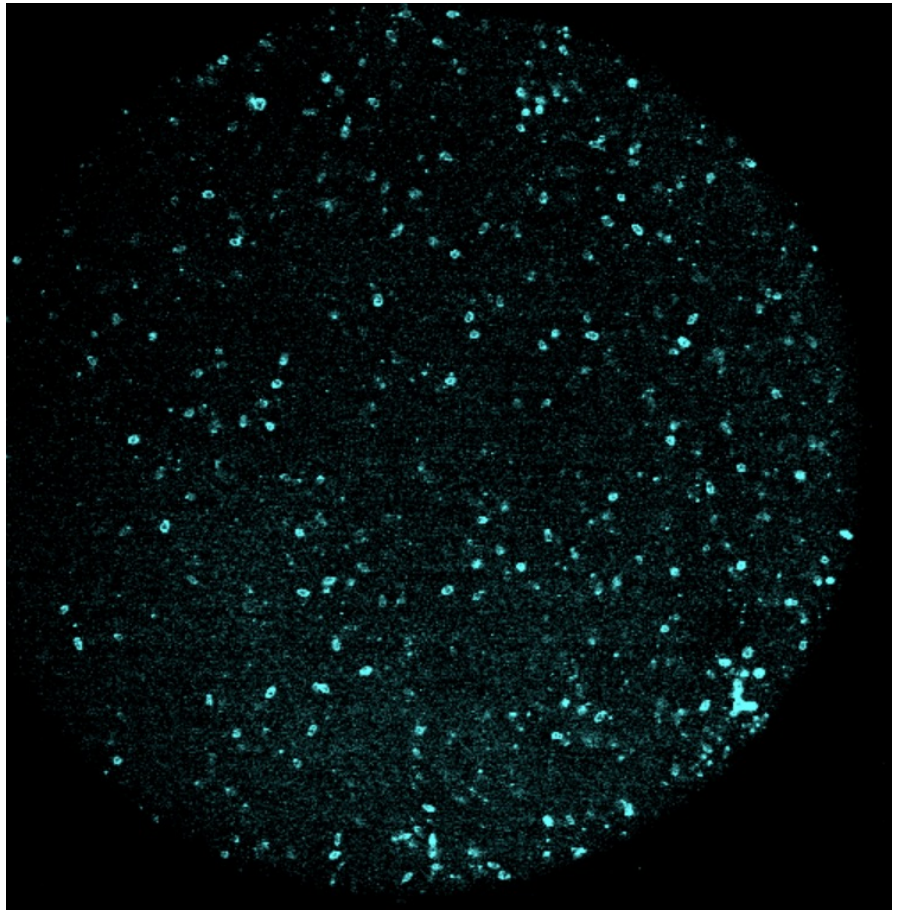


No significant effect on contaminant removal, but optimized valine retention

Hydrogels are a platform technology for water treatment



Catalytic hydrogels
to drive AOPs



Yeast encapsulation in hydrogels for
heavy metal remediation

***Gokhale**, Chen, and Doyle, in review*
***Gokhale**, Stathatou, Athanasiou, and Doyle, in review*

*Doyle, **Gokhale**, and Chen, 63/600,591 (US Provisional Application)*

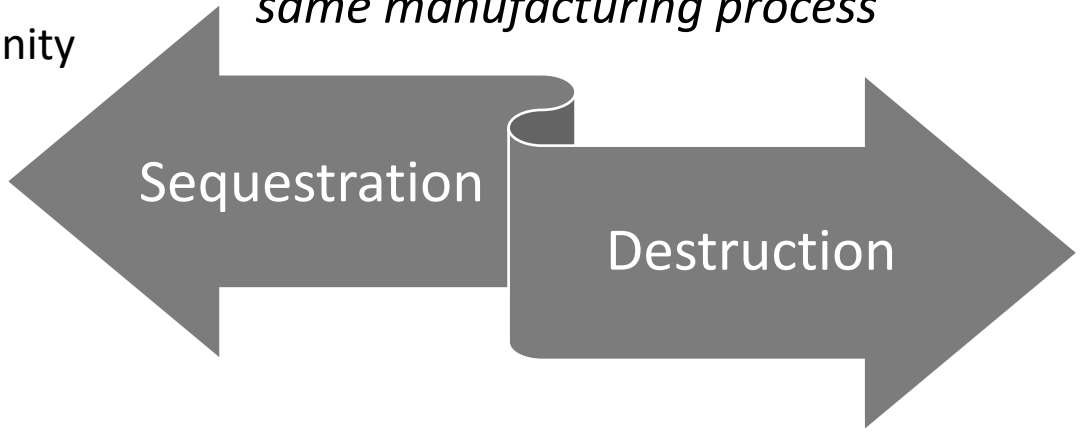
Combining sequestration and destruction

- Ideal for complex contaminant mixtures
- Tolerates background TDS/salinity

- Industrial water treatment applications
- Wastewater treatment
- Off-grid applications

Hydrogel microparticles

same manufacturing process



- Ideal for organic contaminants
- Minimal background TDS/salinity

- Drinking water treatment
  - PFAS elimination for cities
- Disaster-relief applications

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***Gokhale**, Hamelberg, and Doyle, Nat. Water 2024*
*Doyle and **Gokhale**, WO/2023/086073 (International Publication)*
*Doyle, **Gokhale**, and Chen, 63/600,591 (US Provisional Application)*

Our ask

- Do you think this technology would fit your process needs and would you be interested in a pilot together?
- Are you looking to fund a technology in this space?
- If you are a regulator, do you see upcoming regulations that our technology could help meet?
- If you are in the EPCM business, would you be interested in productizing this or offering this as a part of your portfolio?

Looking to hire a technical person at the postdoctoral level now!

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