GADGIL LAB
for Energy and Water Research

Five Select Current Projects on Water Technology Research

Ashok Gadgil, UC Berkeley and LBNL

With sincere thanks to multiple funding agencies and sponsors:

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CHED-PCARI

BLUM CENTER
FOR DEVELOPING ECONOMIES

Many more past key participants not shown (for lack of space)

Sara Glade

Siva Bandaru

Dana Hernandez

Gabriel Lobo

Dr. Mohit Nahata

Dr Arka Kumar

Shelby Witherby

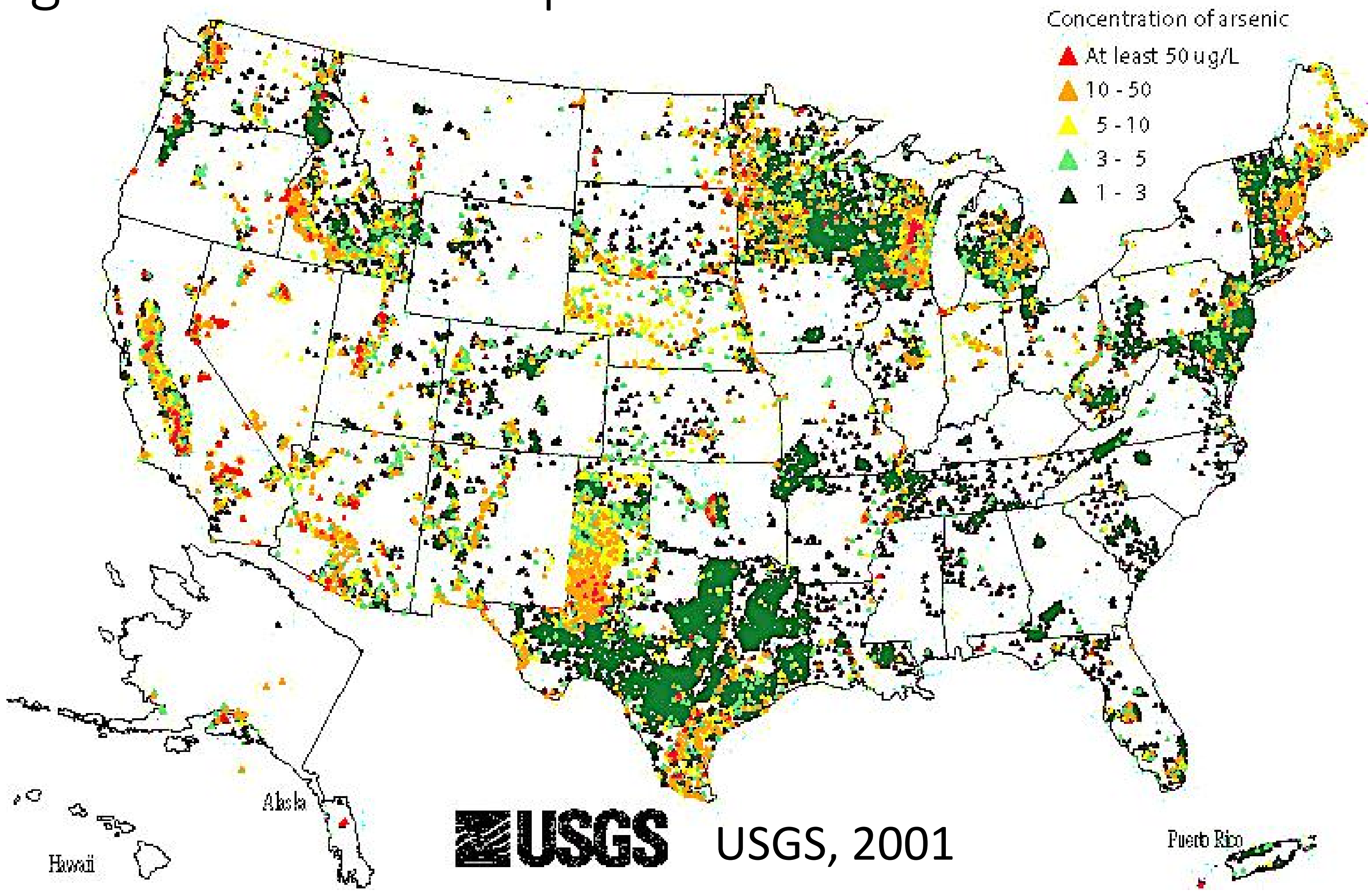
Dr. Sean PAN

1. Field Trial of ElectroChemical Arsenic Remediation in Alllensworth, California

Lead doctoral student researcher: Sara Glade
saraglade@berkeley.edu

Arsenic is a widespread, geogenic contaminant of drinking water with significant health impacts

- >50 µg/L
- 10-50 µg/L
- 5-10 µg/L
- 3-5 µg/L
- 1-3 µg/L



USGS, 2001

Existing treatment options for arsenic have limitations for small, low-income communities

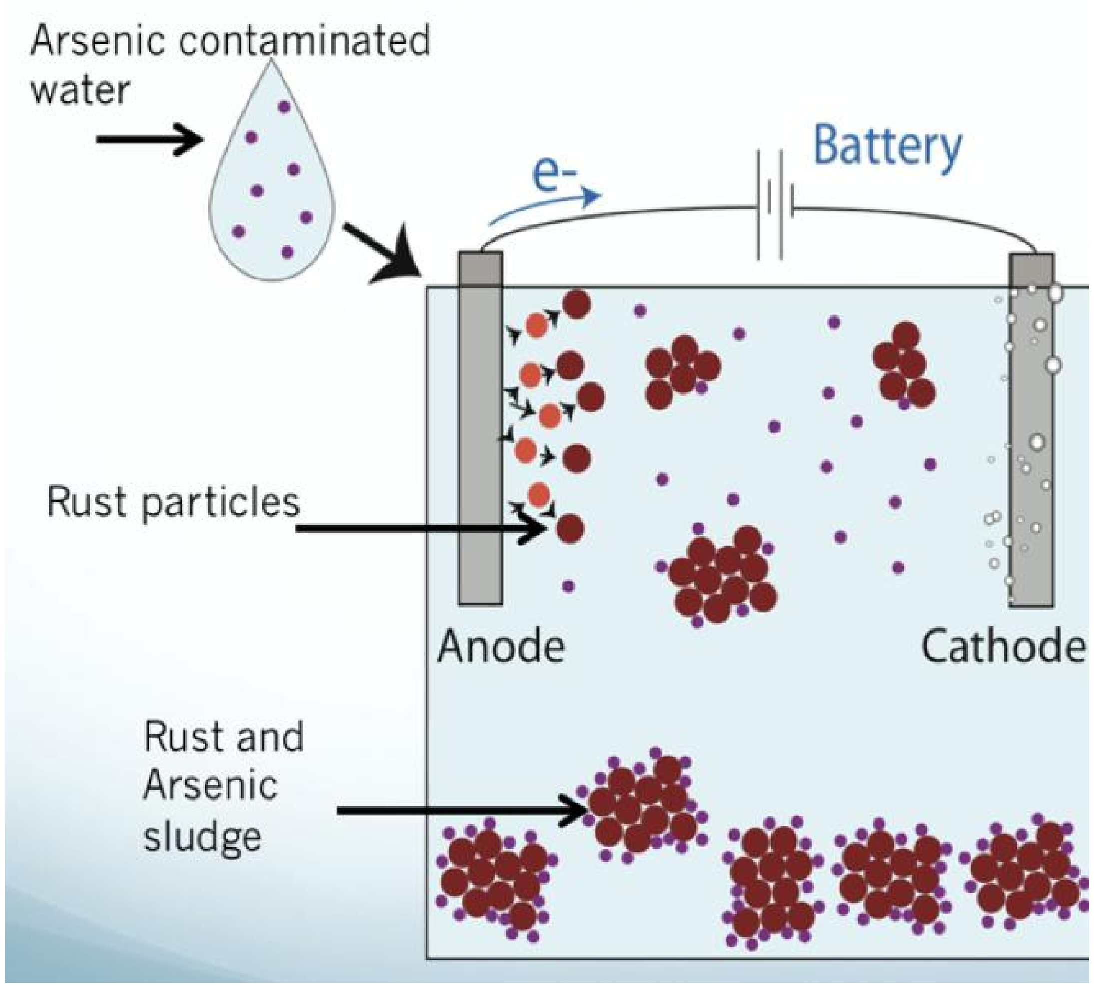
<u>Treatment options</u>

- Adsorption
- Coagulation-Filtration
- Ion Exchange
- Reverse Osmosis
- Oxidation-Filtration (requires pre-existing dissolved iron in the water)

<u>Limitations</u>

- High Capital Costs
- High Operating Costs
- High Operating Complexity (requires skilled labor)

A novel technology, Electrochemical Arsenic Remediation (ECAR), was developed in Gadgil group. Successfully operating in India since 2016.



Amrose et al., 2014

ECAR can overcome limitations of existing treatment options with its:

- Lower operating cost
- Low demand on operator skill
- Minimal supply chain

ECAR was designed to fit within a sustainable and scalable system

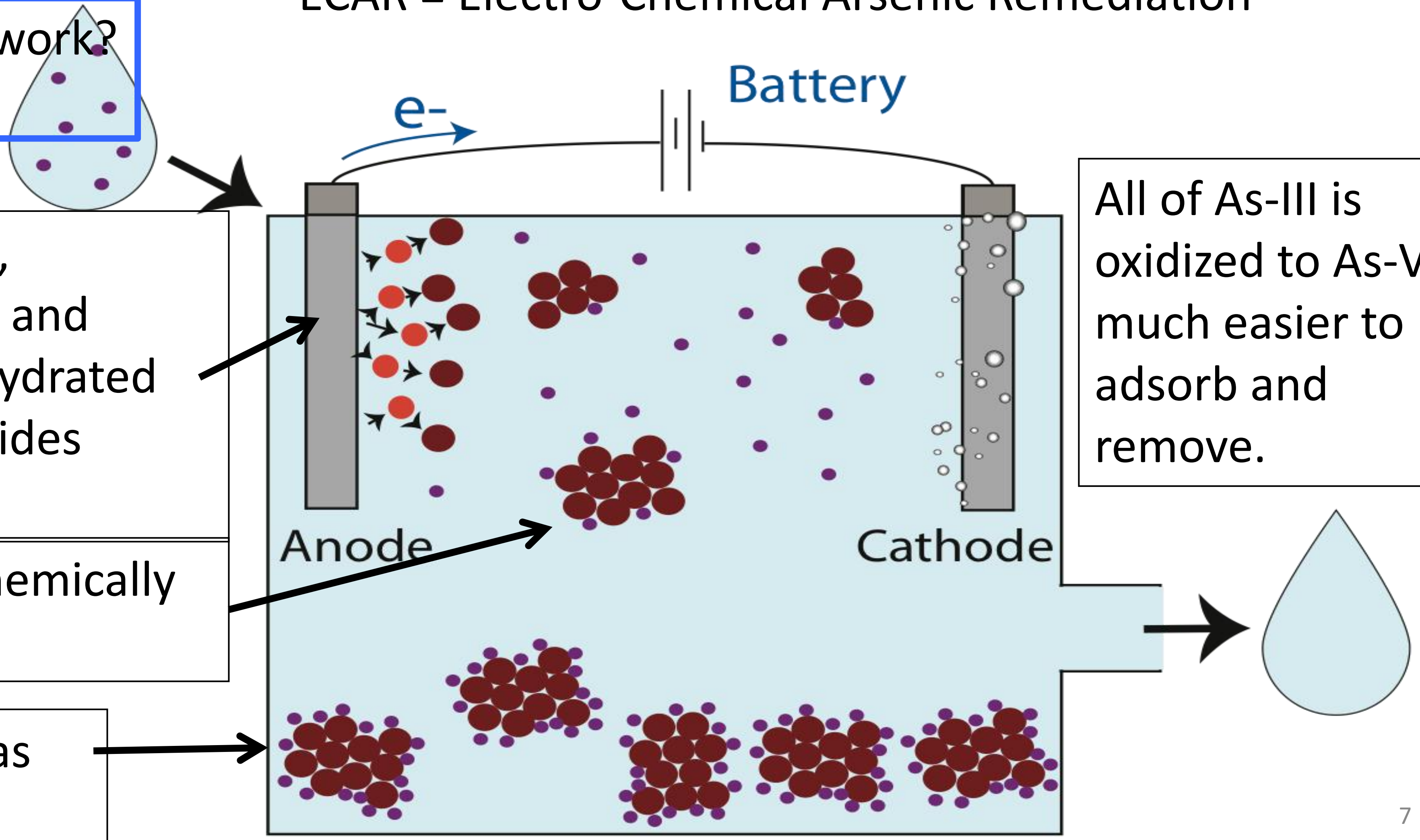
ECAR = Electro-Chemical Arsenic Remediation

How does ECAR work?
The Big Picture

Fe-II is produced, oxidizes to Fe-III, and precipitates as Hydrated Fe-III-OxyHydroxides (“HFO”)

P, Si, and As-V chemically sorb to HFO

Then settle out as sludge



All of As-III is oxidized to As-V; much easier to adsorb and remove.

To study ECAR in the US, we plan a field trial of ECAR on a farm in a small, low-income community: Allensworth, California. Farm has groundwater with $\sim$ 200 ppb arsenic

- **Will allow the opportunity to develop and test this novel technology for US conditions (of high labor costs)**

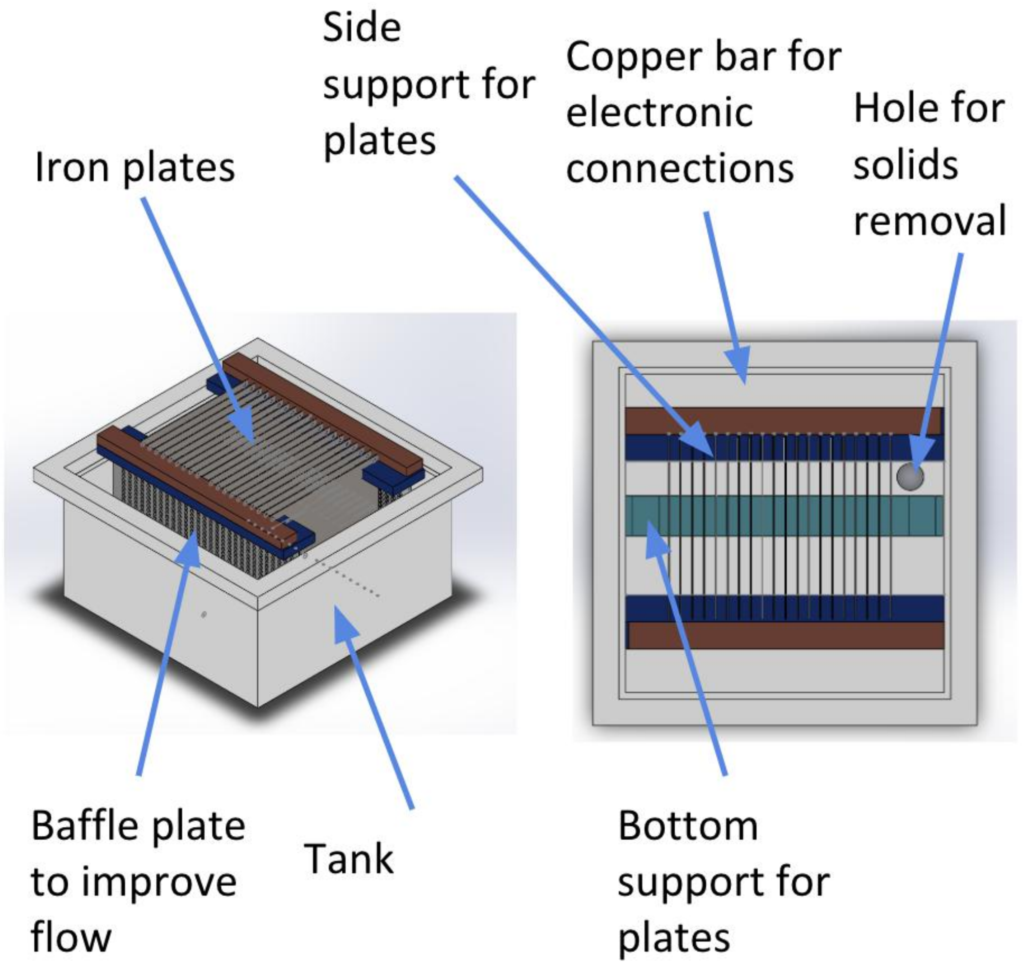
- **Community member-partners want arsenic-safe water on farm for a rabbitry project.** Their goals:
  - Economic opportunity
  - Local food production
  - Pride in community
  - Agency
  - Educational opportunity

Design criteria for the field trial

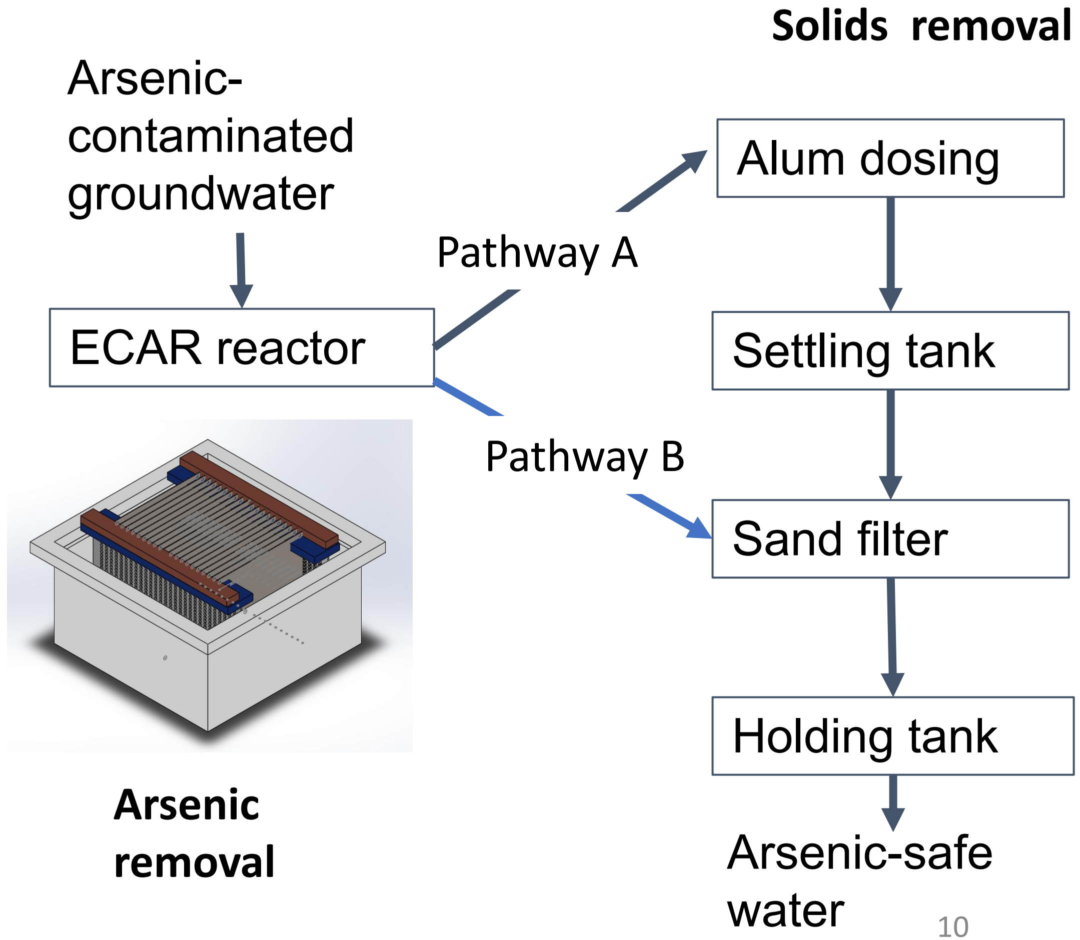
- 100 L water produced per batch
- Treat water with influent arsenic of ~ 200-300 ppb, to produce water below US-EPA MCL of 10 ppb
- <1 NTU turbidity
- Ensure all materials are food-grade (NSF-certified)

Design, implementation, and operation plans drafted for the field trial

Design of ECAR reactor



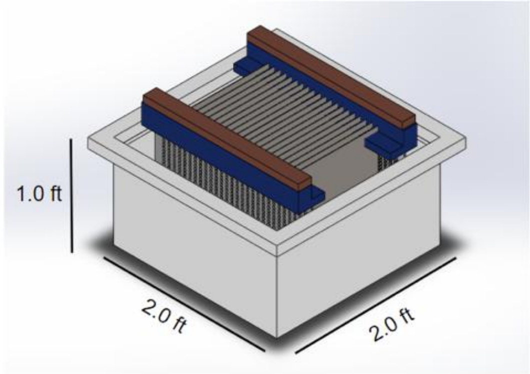
Process flow diagram for field trial

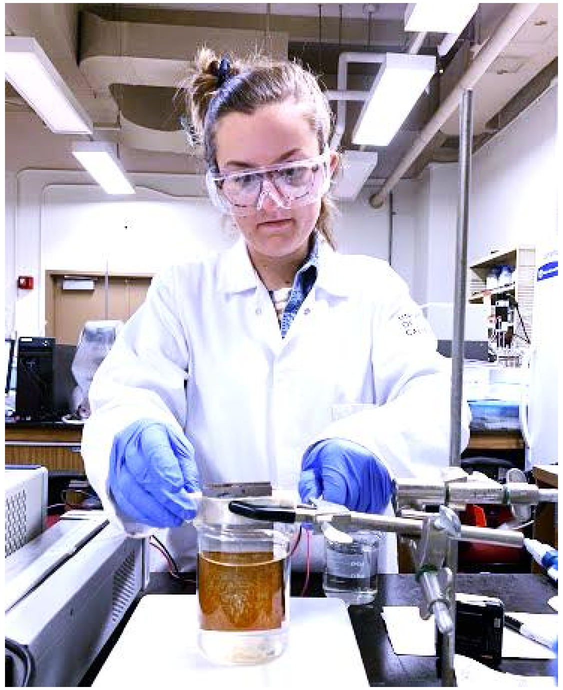


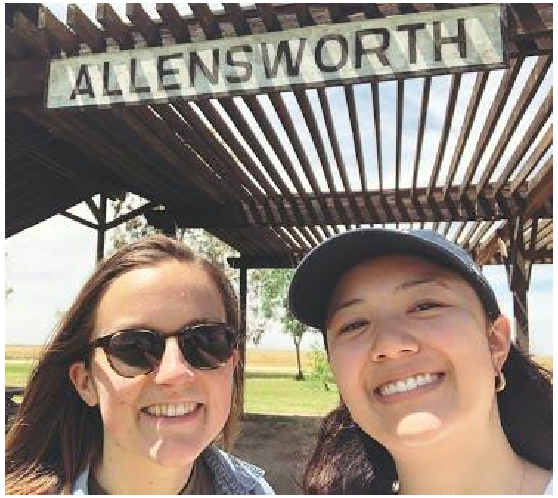
Field trial operation & maintenance plans

- 5 days operation per week & at least 1 batch/day
- 1 month of operation
- Measure Arsenic, iron, turbidity, conductivity, DO, and pH

The project is on track for a field trial this summer (2019)







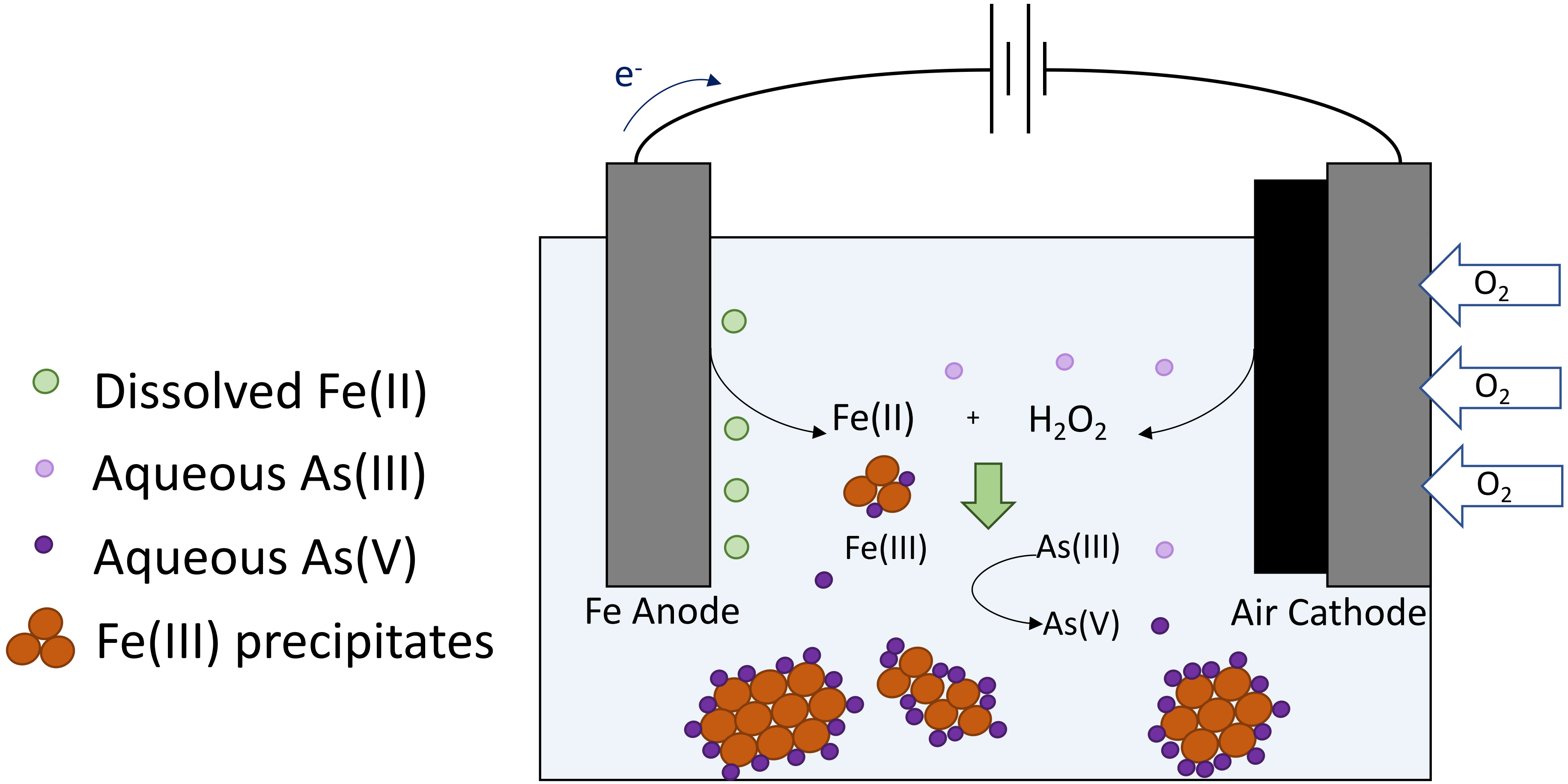
Learn more at EcarAllensworth.com!

2. Inventing and maturing a novel water treatment technology for arsenic removal in California

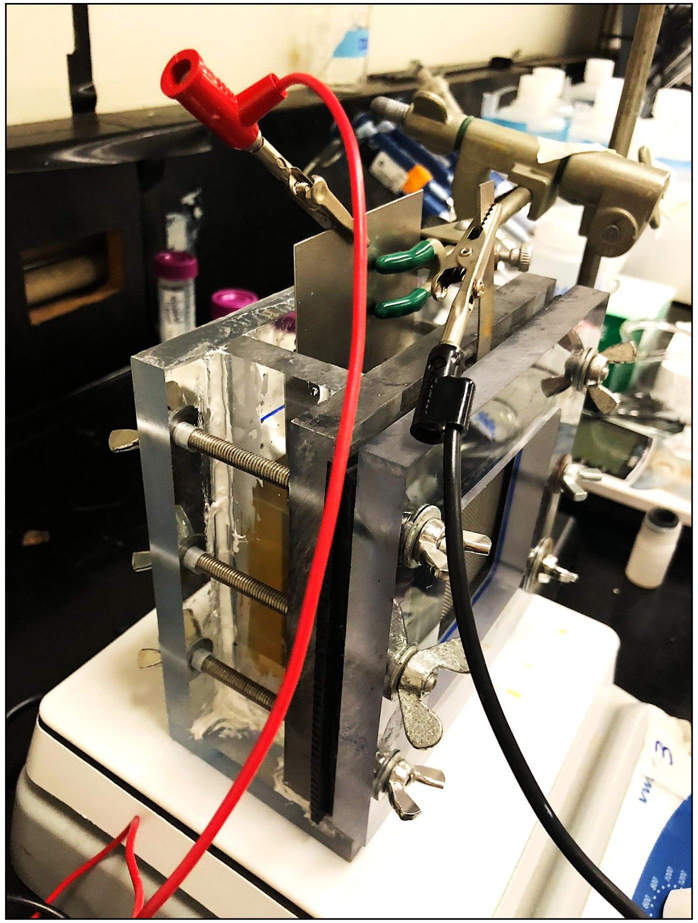
Lead doctoral student researcher: Dana Hernandez

danaah@berkeley.edu

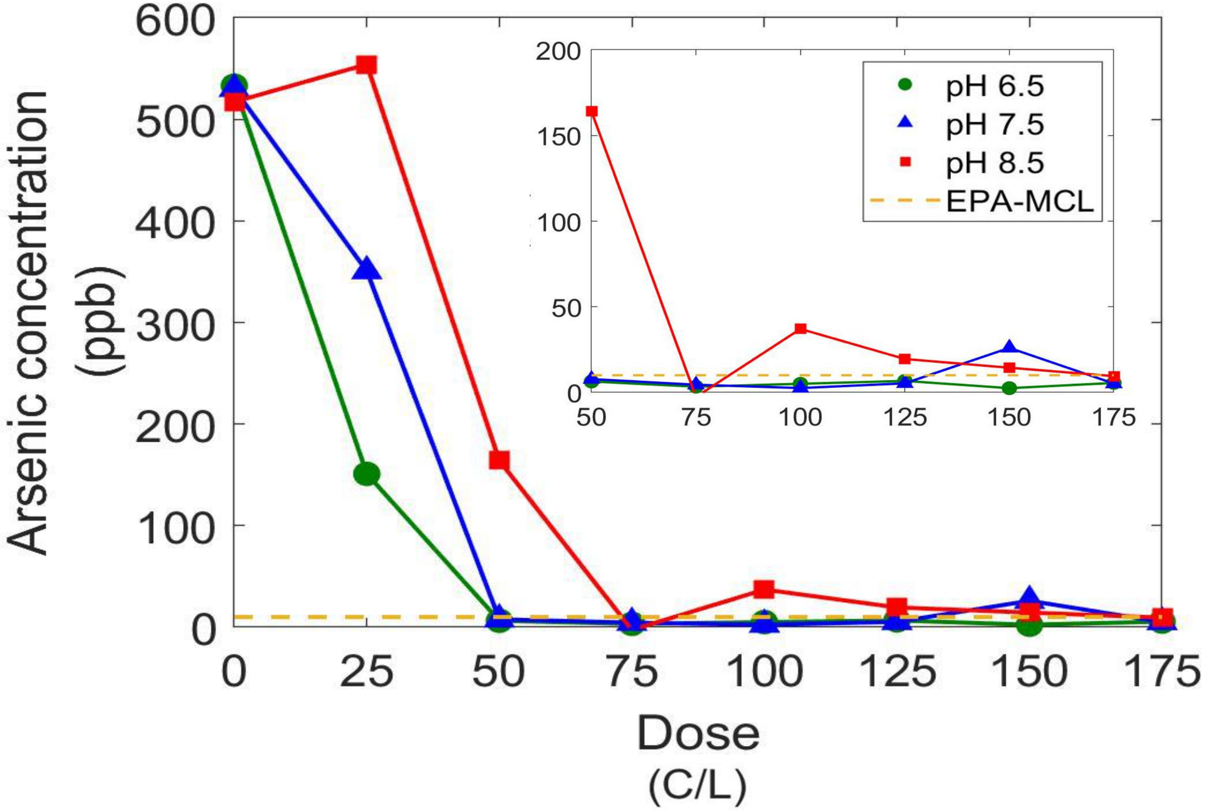
ACAIE (Air cathode assisted iron electrocoagulation)



ACAIE in the lab: A 500 mL batch reactor easily removes high concentrations of arsenic to below the EPA-MCL

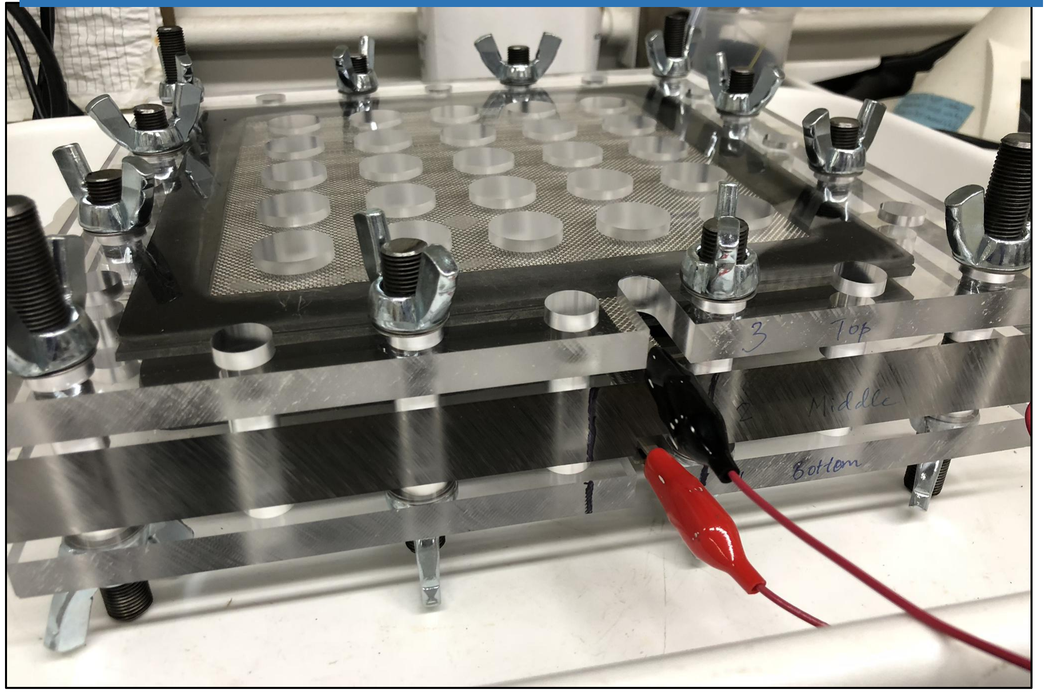


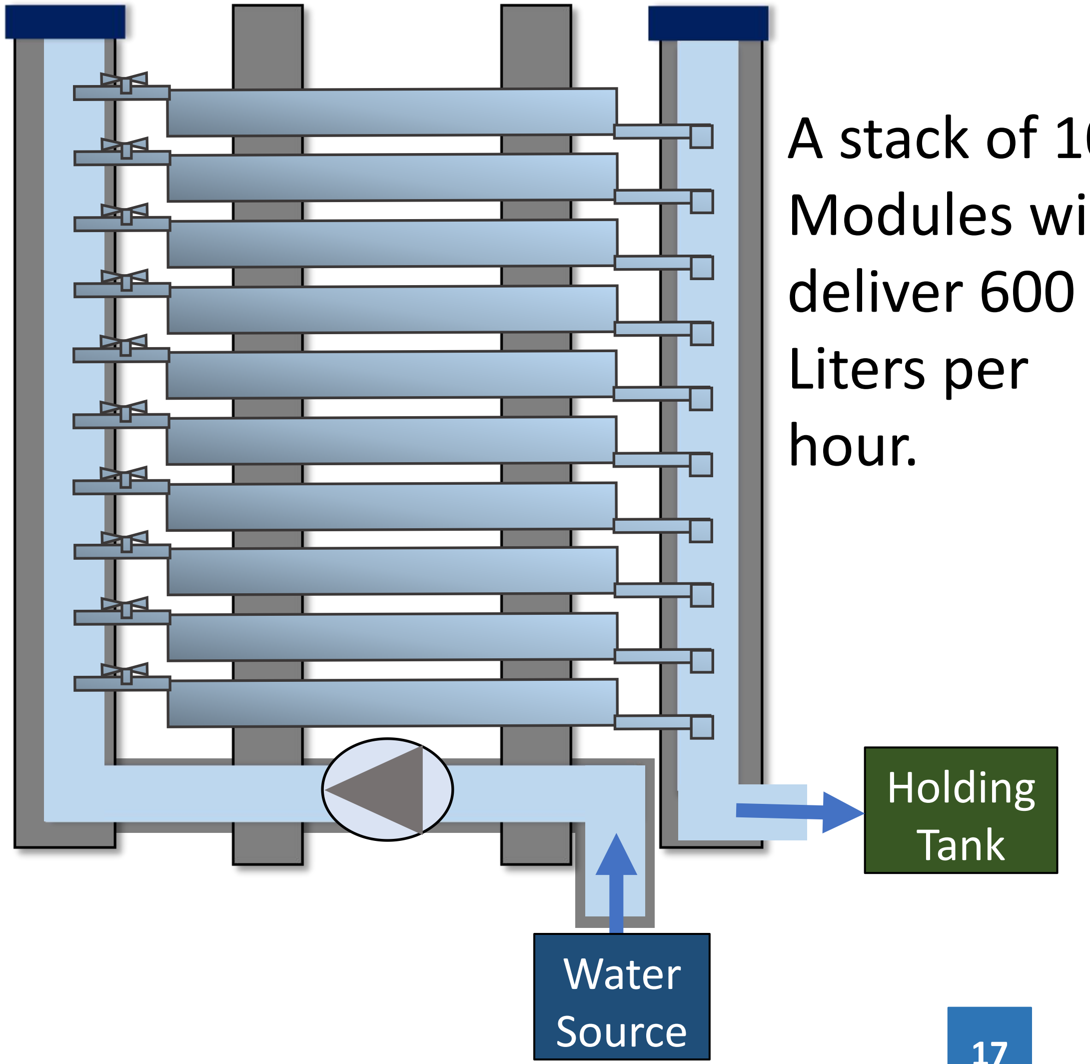
Experiments conducted in CEE lab at UC Berkeley



Progressing the lab prototype to a continuous flow process for eventual field test and demonstration

60 liters per hour Module





A stack of 10 Modules will deliver 600 Liters per hour.

Potential for ACAIE field trial at Central Union Elementary School, at a disadvantaged community in Kings County, California

THE DANGERS LURKING IN CALIFORNIA SCHOOL DRINKING FOUNTAINS

It has become too risky for tens of thousands of children in the San Joaquin Valley to drink water at their schools due to chronic contamination by chemicals, pesticides, and other toxins.

SASHA ABRAMSKY · JUL 7, 2017

CaliforniaHealthline

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Partnership Brings Clean Drinking Water to Central Valley Schools, Programs

by Alice Daniel, California Healthline Regional Correspondent

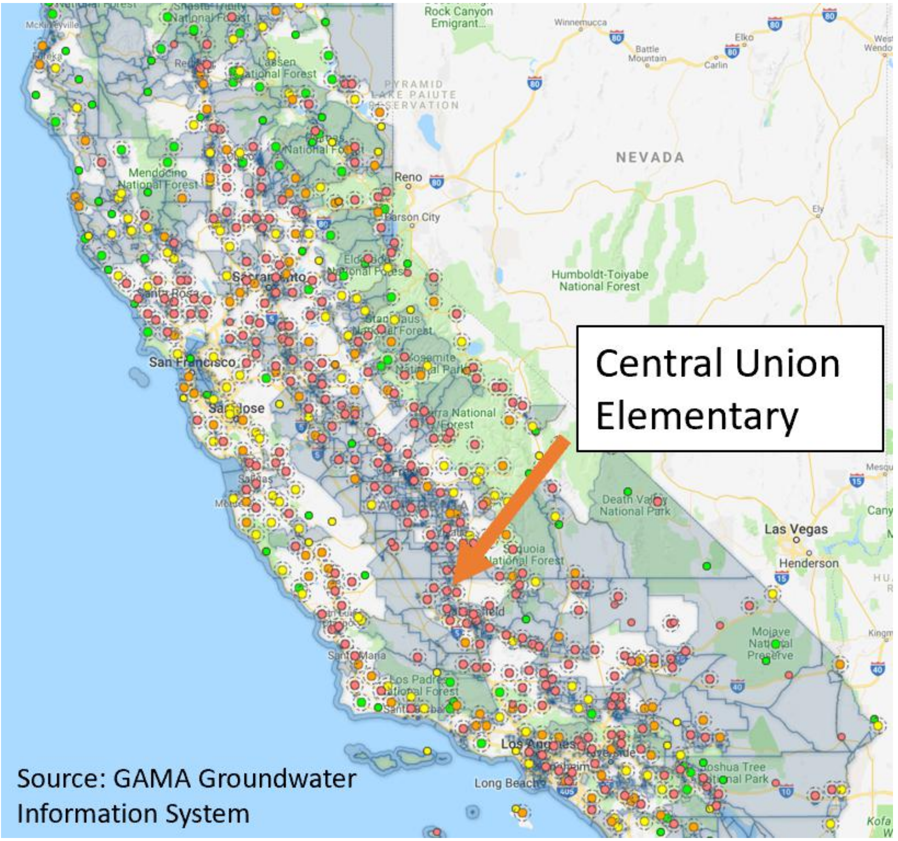
November 14, 2013

REPUBLISH THIS STORY

Public water systems (PWS) are regulated by the EPA, and data is available online

The 2014 median household income is $46,354 (below US median: $53,657)

Central Union must reach compliance by **July 1, 2019**



Source: GAMA Groundwater Information System

3. Air Cathode And Iron-Electrocoagulation (ACAIE) for removing emerging contaminants of concern

Lead doctoral student researcher: Siva Bandaru

sivaram.satyam@berkeley.edu

Emerging contaminants such as **pharmaceuticals**, **personal care products**, and **pesticides and insecticides** are of concern due to their persistence and toxicity in the environment

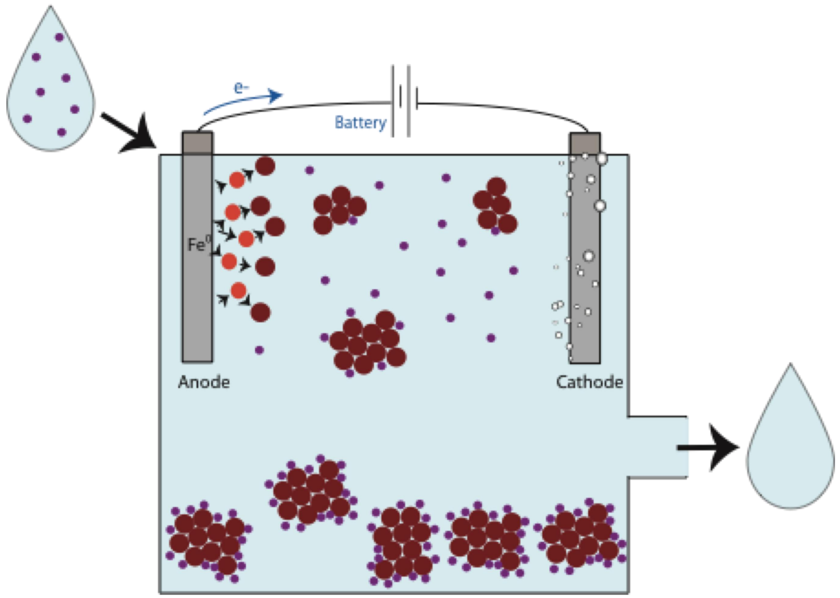
Emerging contaminants such as **pharmaceuticals, personal care by products** and **pesticides** are of concern due to their **persistence** and **toxicity** in the environment

Most of these compounds were detected in surface water and groundwater

- Recalcitrant to microbial degradation

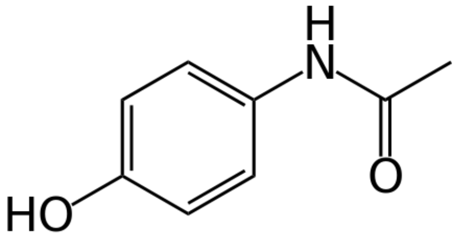
Iron (Fe) based electrochemical (EC) technology is a promising solution to address WASH challenge in resource poor settings: Emerging Contaminants

- ❑Low cost
- ❑Flexible operation
- ❑Easy to scale
- ❑Environmental friendly byproducts
  - ❑Known sorbents for multiple contaminants

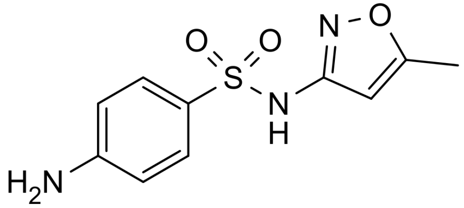


Schematic of Fe EC system. Fe anode and Fe cathode

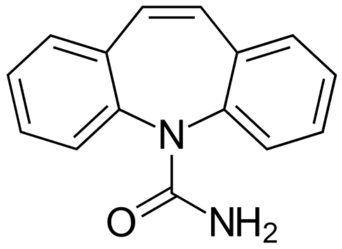
We are studying the removal of following compounds with FeEC and Air Cathode Assisted Iron EC (ACAIE) systems



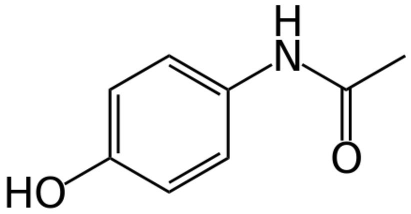
Acetominophen (ACT)



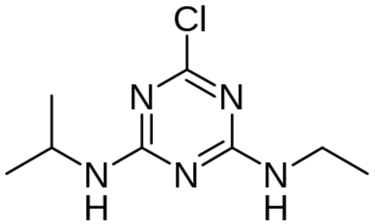
Sulfamethoxazole (SMX)



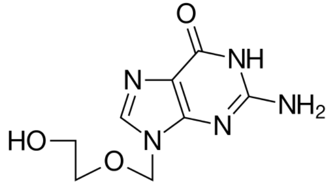
Carbamazepine (CBZ)



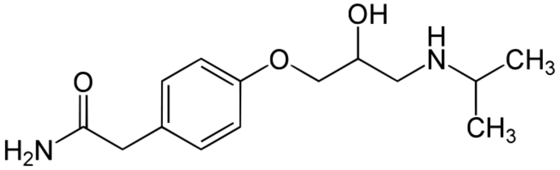
Isoproturon (ISO)



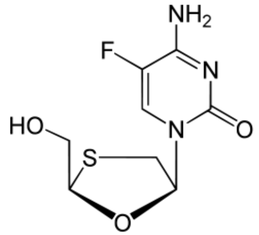
Atrazine (ATZ)



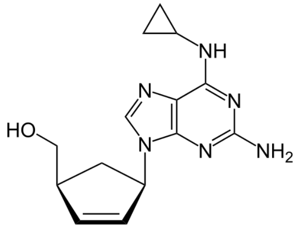
Acyclovir (ACY)



Atenolol (ATL)



Emtricitabine (EMT)



Abacavir (ABC)

Early Findings

- Emerging organic contaminants are already a problem in use of recycled water.

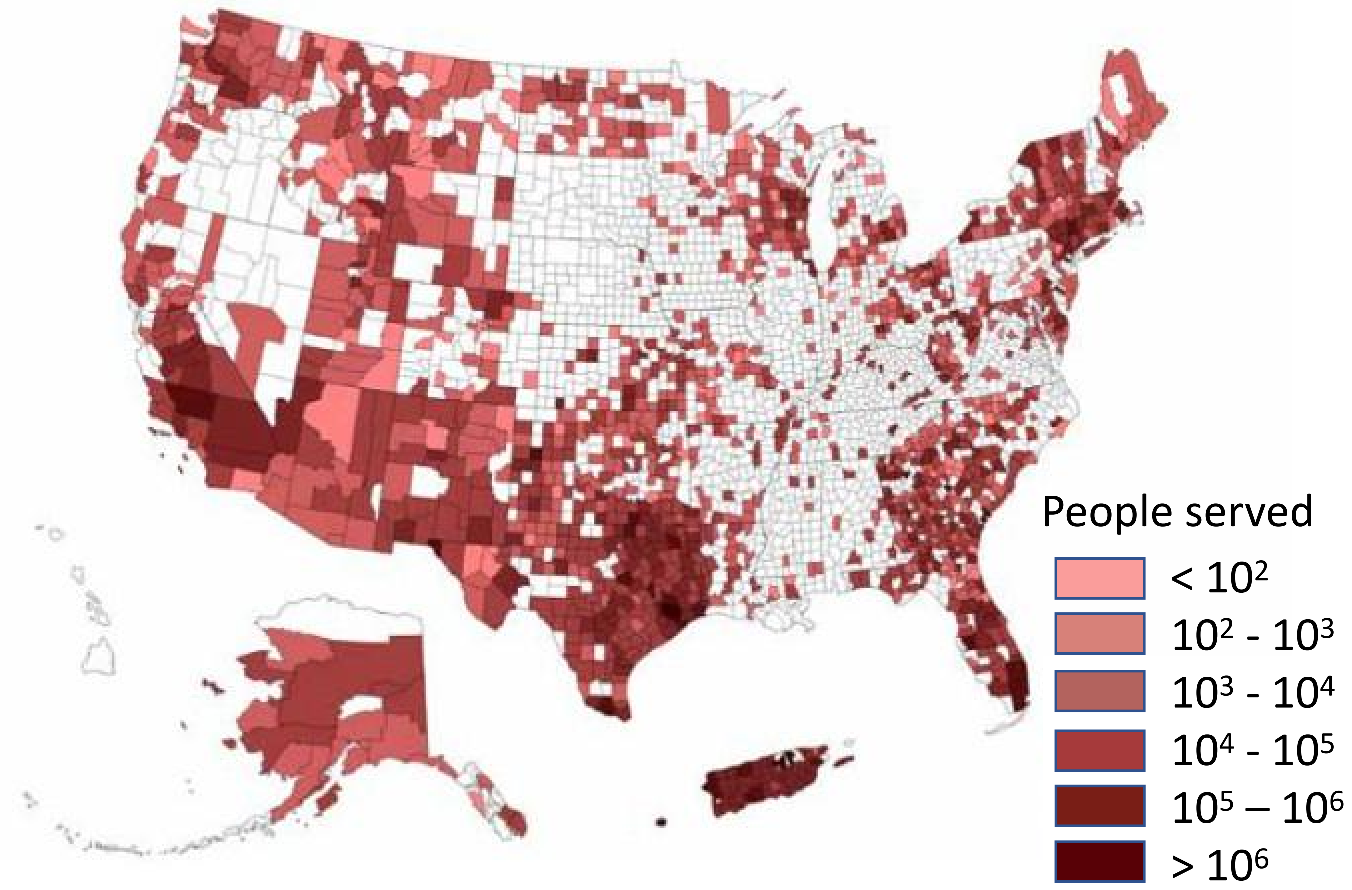
- This contamination will become only more serious as water recycling increases in response to increasing water demand and limited supply

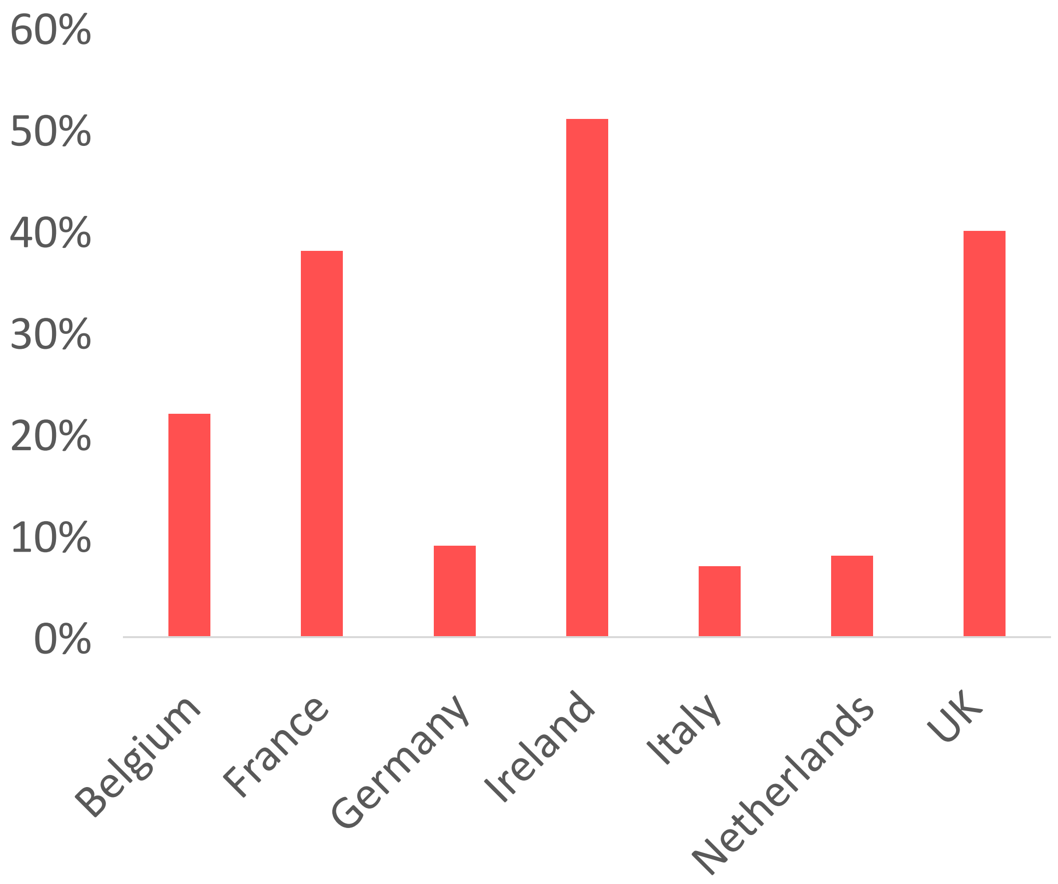
- Significant removal of emerging contaminants is desirable and may be possible with oxidative treatment with Iron EC and ACAIE

4. Making lead pipes safe for drinking water

Lead Doctoral Student Researcher: Gabriel Lobo
gplobo@berkeley.edu

Lead leaching from water pipes is widespread in industrialized countries





5,000 public US drinking water systems in violation of the lead and copper rule, exposing more than **17 M people**[1]

~25% of drinking water pipes in Europe are made of Pb, potentially affecting **180+ M people**[2]

1. *Olson and Fedinick, 2016*

2. Hayes & Skubala, 2009

Scale inside Pb pipes protects water from Pb leaching

Pb pipe with scale formation

Pb pipe with dissolved scale

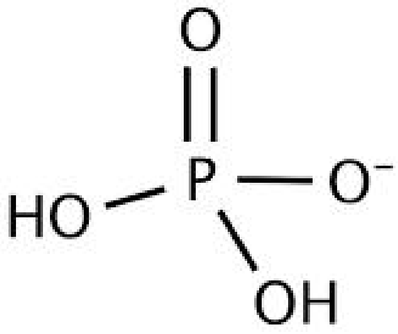
Image from: michiganradio.org

Existing solutions are either too expensive or too slow

1. Pipe replacement

Permanent solution
Expensive ($150 - 300 /m)

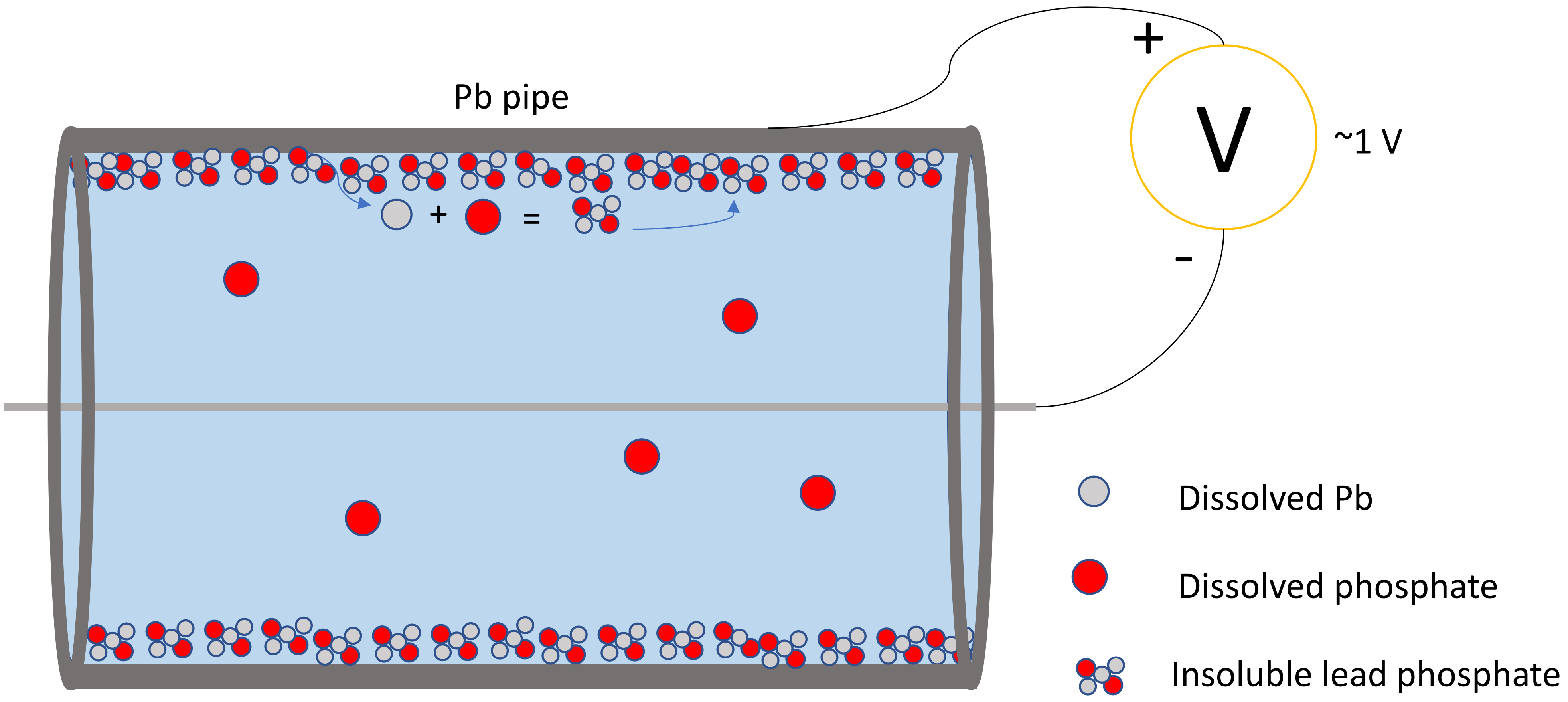
2. Chemical conditioning of water



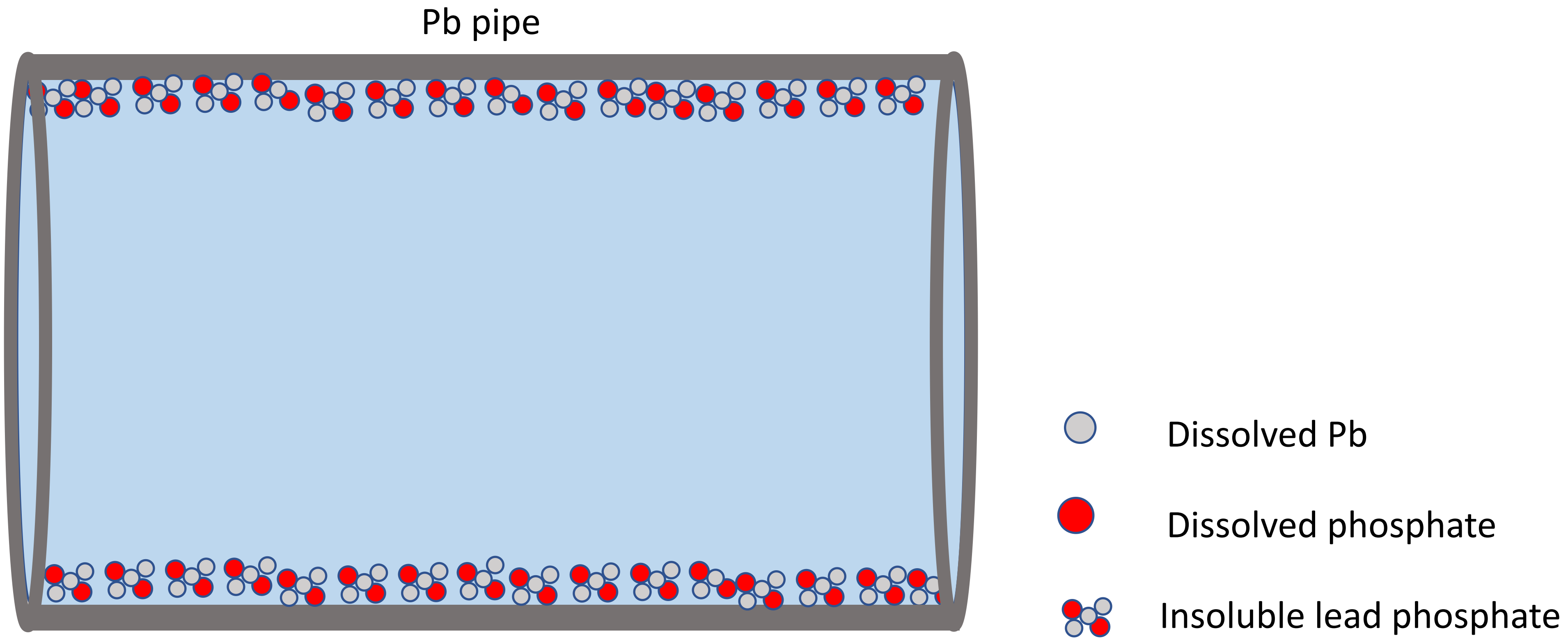
Cheap (~$0.000016 /L)
Good for maintaining existing scale
Too slow for developing new scales (years)

1. Boffardi & Sherbondy, 1991; 2. Boyd et al, 2001

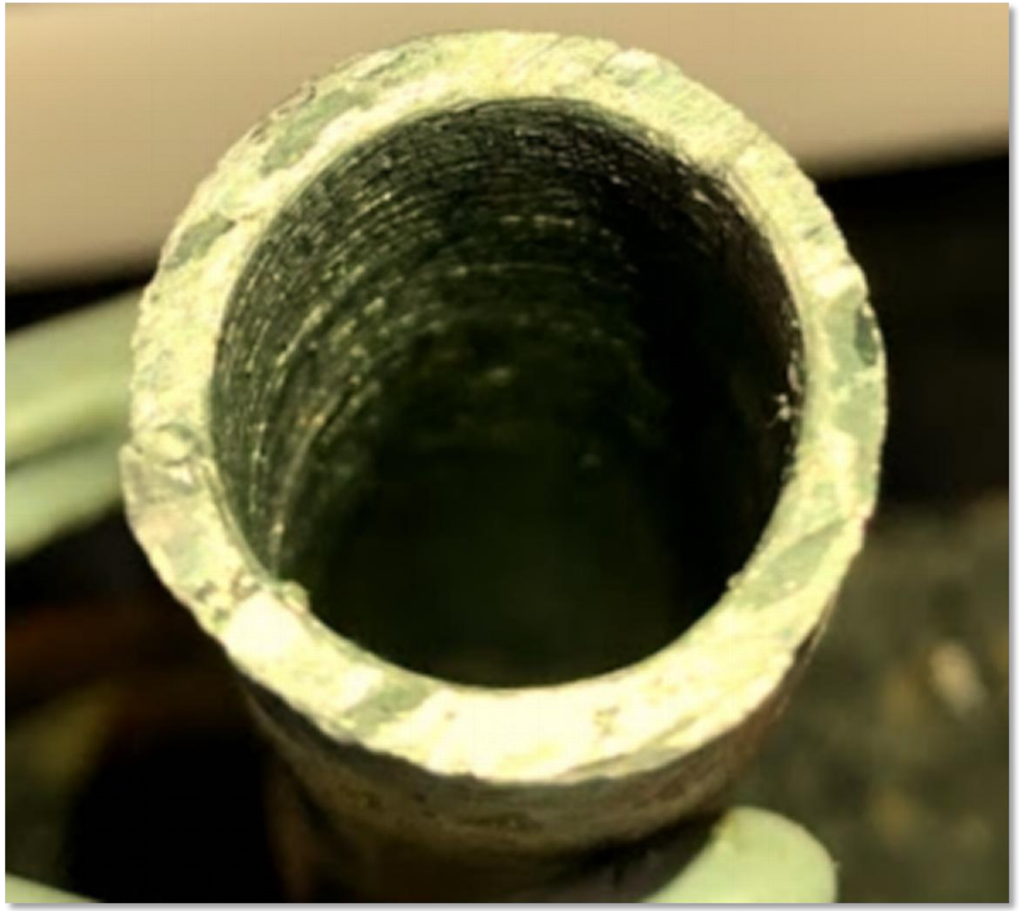
ALPS (Accelerated Lead Pipe Scale-buildup)

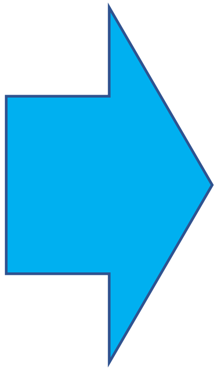


ALPS (Accelerated Lead Pipe Scale-buildup)



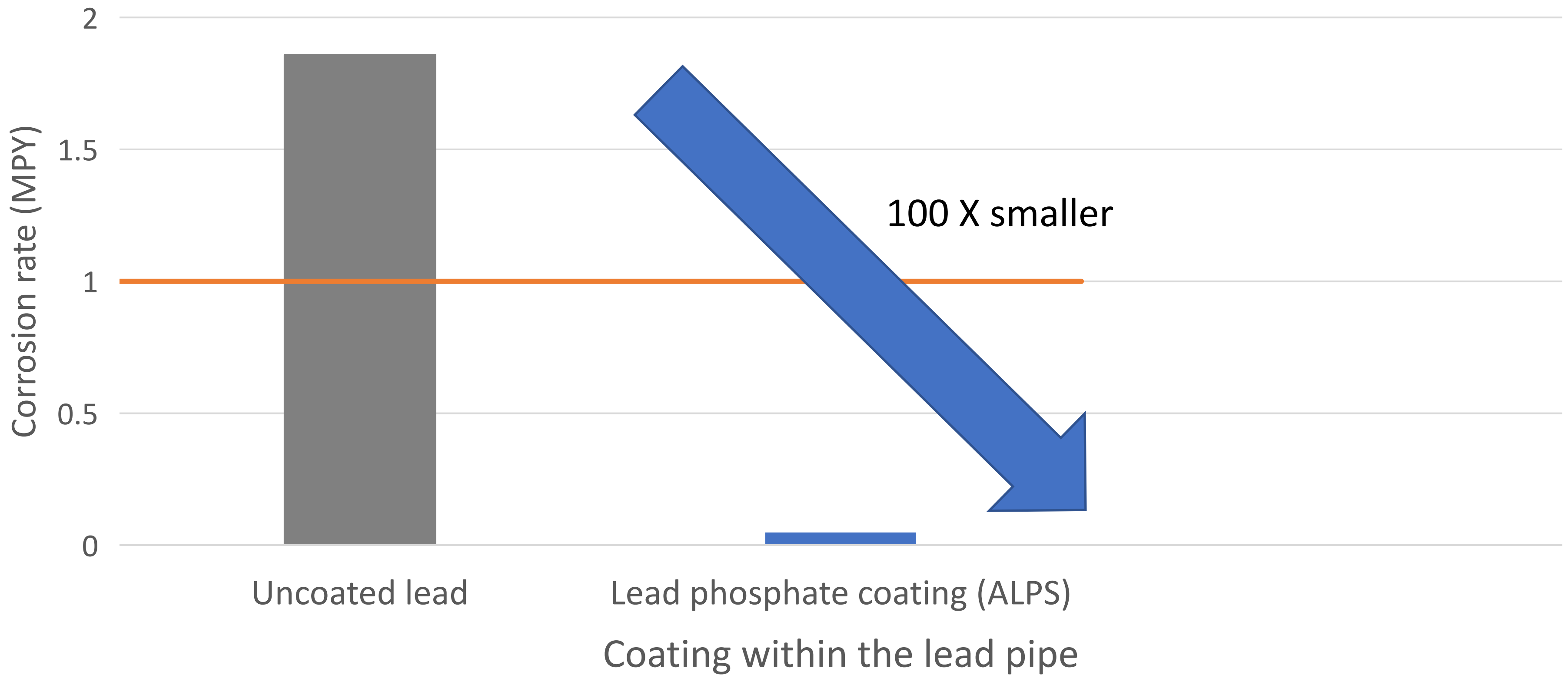
Using ALPS, a thin $Pb_3(PO_4)_2$ film develops within the pipe





ALPS dramatically decreases lead corrosion rates in Synthetic tap water

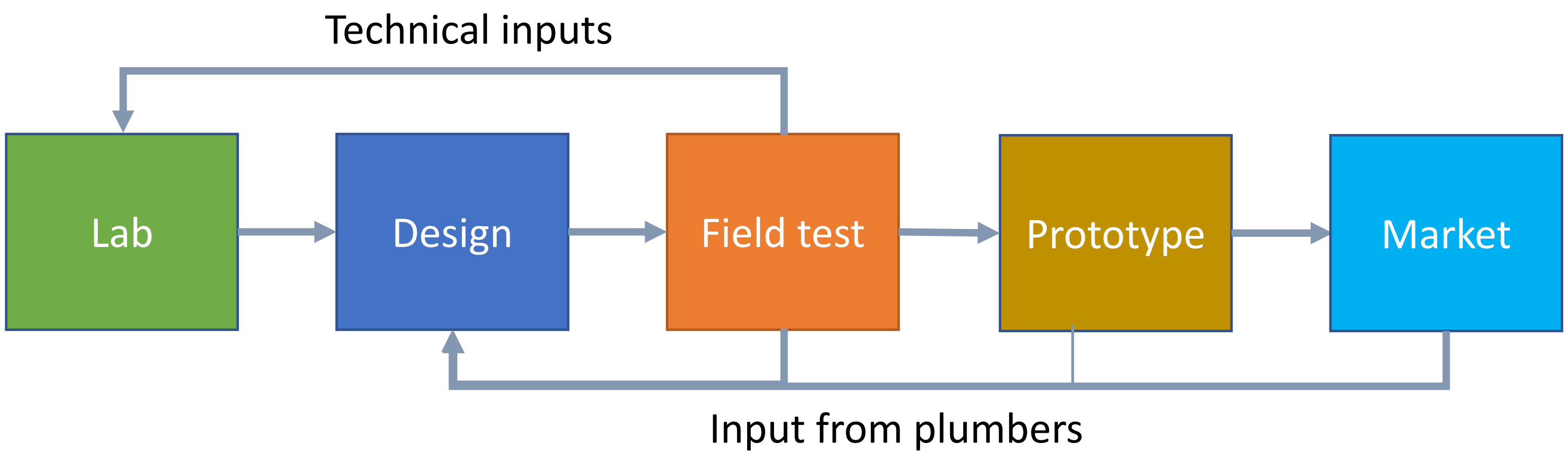
Synthetic tap water: 1mM NaCl, 0.7 mM $CaCO_3$, 0.02 mM Na_2HPO_4



1 MPY = 0.0254 mm per year, lead corrosion rate considered “acceptable” by water utilities and health authorities

ALPS will protect the health of tens of millions of people from toxic-level lead in their drinking water

Technology	Consumables cost per meter	Labor cost per meter	Total cost per meter
Pipe replacement	$30 - $50	$120- $250	$150 - $300
ALPS	**$1**	**$10 - $20**	**$11 - $21**



Making lead pipes safe for drinking water

Gabriel Lobo, Ashok Gadgil
University of California Berkeley
gplobo@berkeley.edu

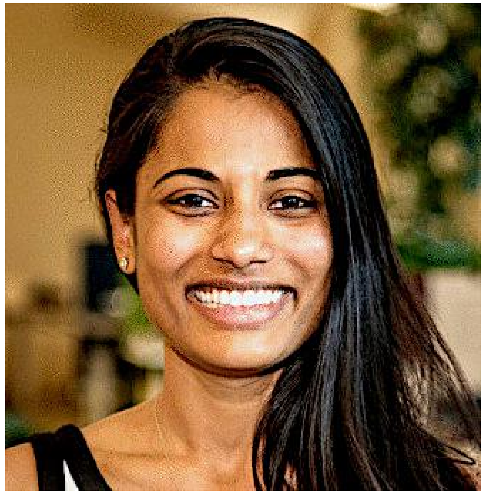
5. Removing Fluoride from groundwater used for drinking

Lead graduate student researcher: Shelby Witherby
Email: Shelby_Witherby@Berkeley.

Key Past Researchers

Dr. Andrew Haddad

Dr. Heather Buckley



Katya Churukumilli

Shelby Witherby



Fluorosis causes dental and skeletal deformities, anemia, other diseases

~200 Million people are affected by Fluorosis globally

The right to safe drinking water
remains a promise unfulfilled

Health effects of Fluoride in water vary with concentration of F^-

- World Health Organization Maximum limit: 1.5 ppm of F^-

Fluoride, ppm	Medium	Effect
< 1.5	Water	Reduction in Dental caries
>2	Water	Mottled enamel
10	Water	10% osteosclerosis, dental and skeletal Fluorosis

- Recommended concentration is between 0.5 – 1 ppm

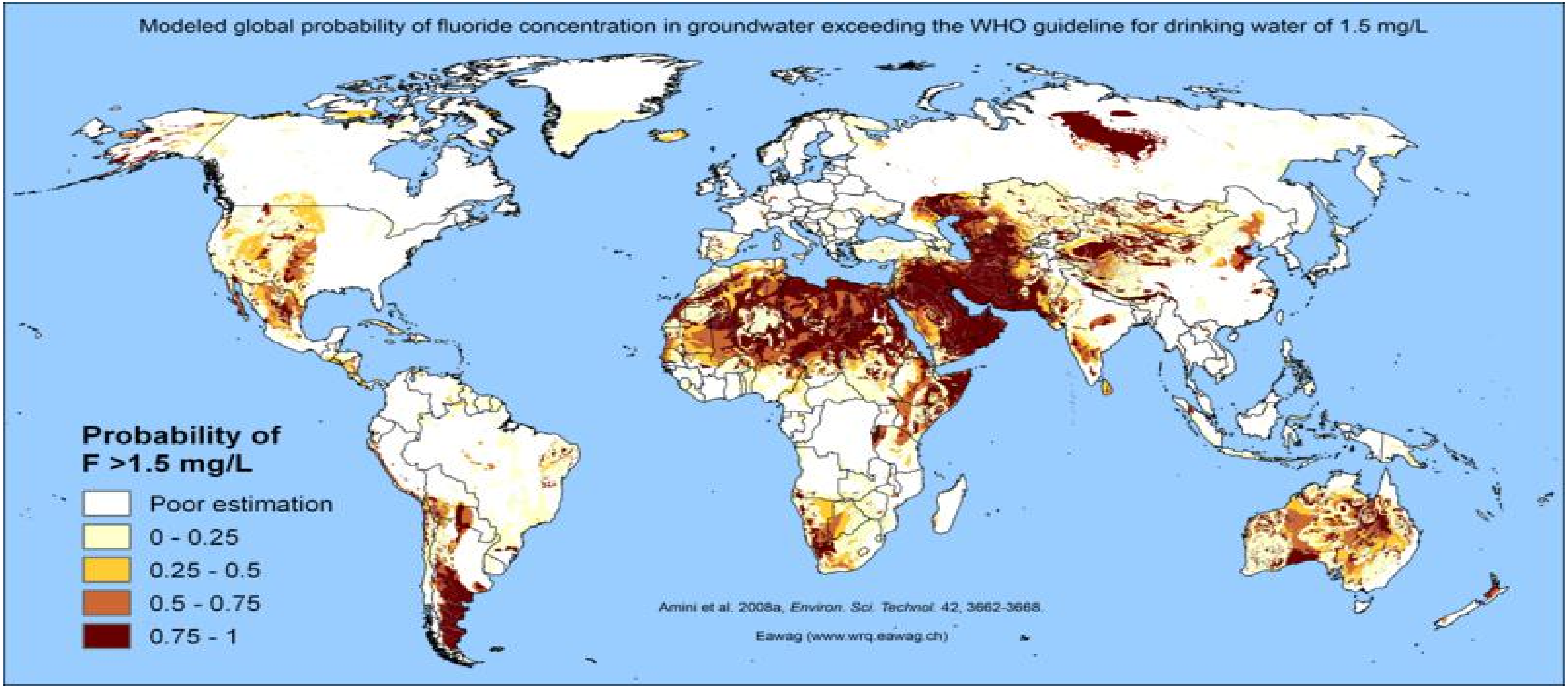
Primary Cause of Fluoride in Groundwater is Geological

- Fluoride in minerals is solubilized by alkaline groundwater conditions.

- $CaF_2 + 2[HCO_3]^- \rightarrow CaCO_3 + 2F^- + H_2O + CO_2$

Mineral	Chemical Formula
Sellaite	MgF_2
Fluorite	CaF_2
Cryolite	Na_3AlF_6
Fluorapatite	$Ca_3(PO_4)_3F$

Global Fluoride Distribution in Groundwater



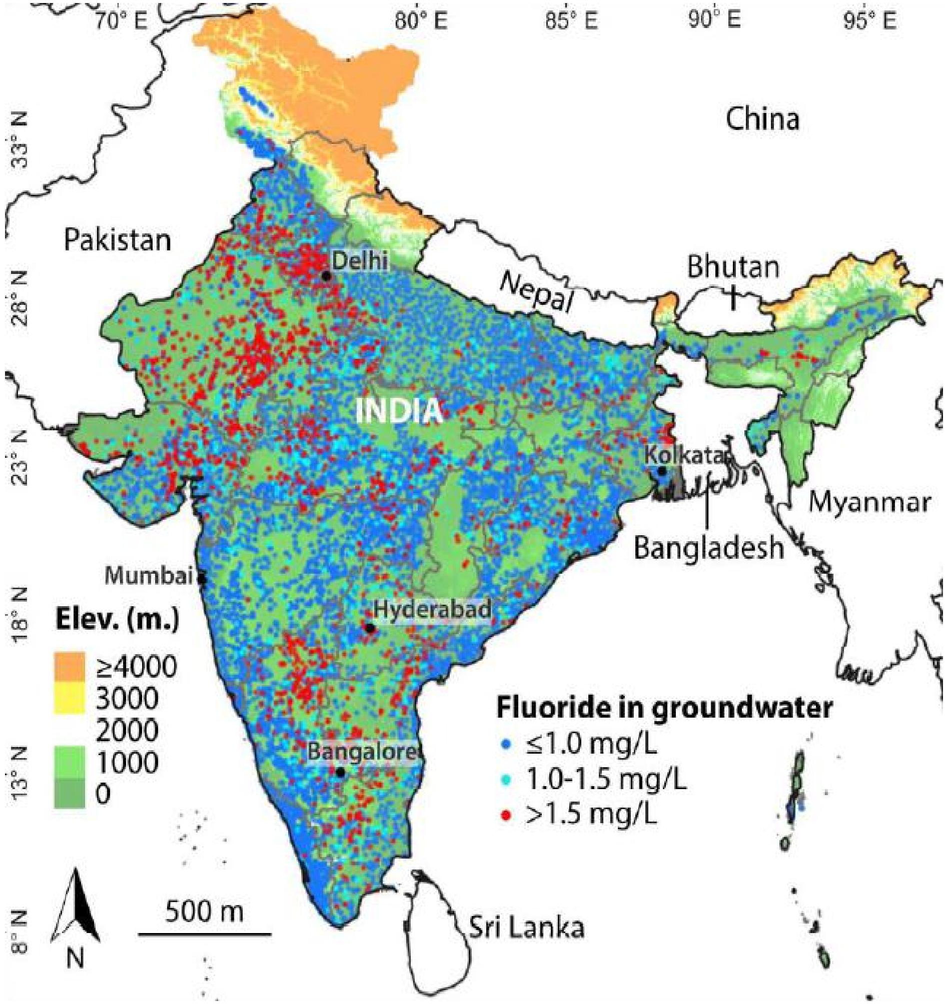
❖ Populations in ~23 countries globally suffer from fluoride contamination of groundwater

Amini et al. ES&T 42, 3662

Fluoride Distribution in Indian Groundwater

Berg et al. ES&T, 2018

Amini et al. ES&T 42, 3662



https://youtu.be/u2sv9e3bL6Q

Methods do exist for removing Fluoride from water, however…

Activated Alumina (AA)

- Effective but expensive
- Made from Bauxite
- AA filter media $2000/ton
- **Unaffordable** ($50 per capita per annum)

Reverse Osmosis & Electrodialysis

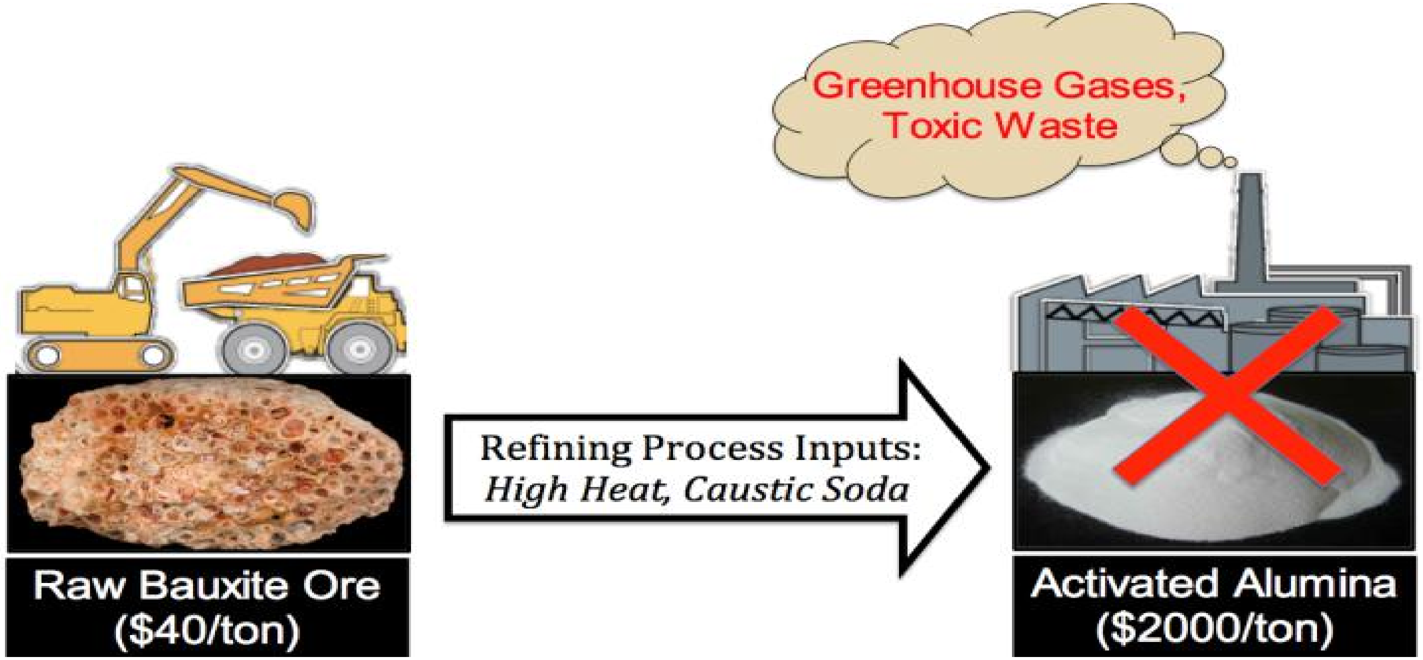
- Effective but expensive
- High maintenance costs
- Membrane Fouling issue
- **Needs highly skilled labor**

Carbon based materials

- Activated carbon coated with Fe or Al, Mn oxides
- Carbon coated clays
- **Only moderately effective**

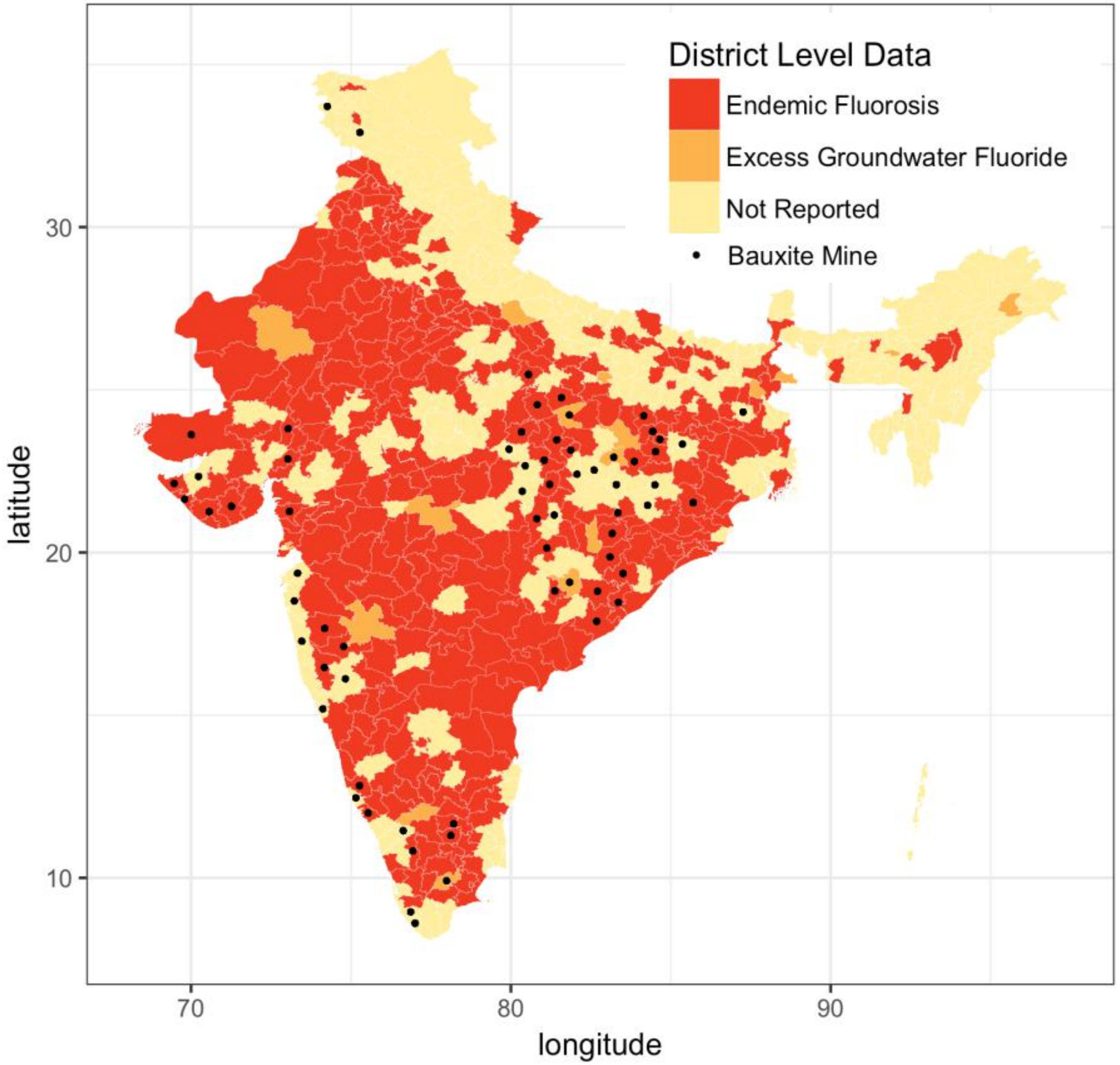
- Most of the available adsorption techniques are infeasible for rural areas of poor communities
- Need to find ***locally available defluoridation method at both small community and household scale***

Refining bauxite to make Activated Alumina (the recommended fluoride adsorbent) is costly, energy intensive, and polluting

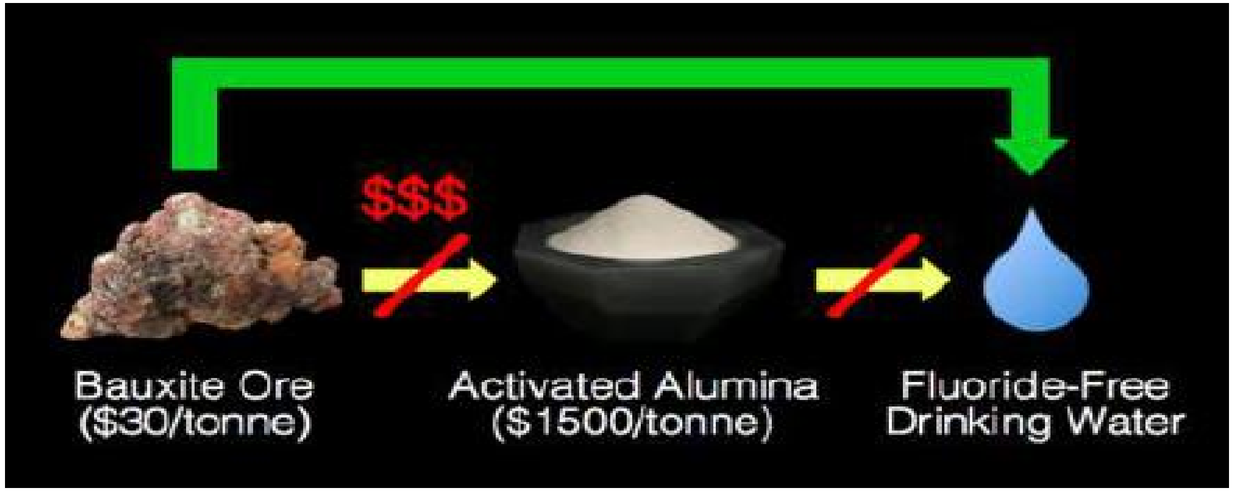


- ❖ Can't we directly activate bauxite? Yes, we can!!
- ❖ We discovered a way to avoid the refining process. This very substantially reduces the annual per capita material-cost.

Locally sourced Bauxite for Fluoride removal is an attractive alternative to AA



Cherukumilli et al. Environ. Sci. and Technol. ***2017****, 51, 2321*

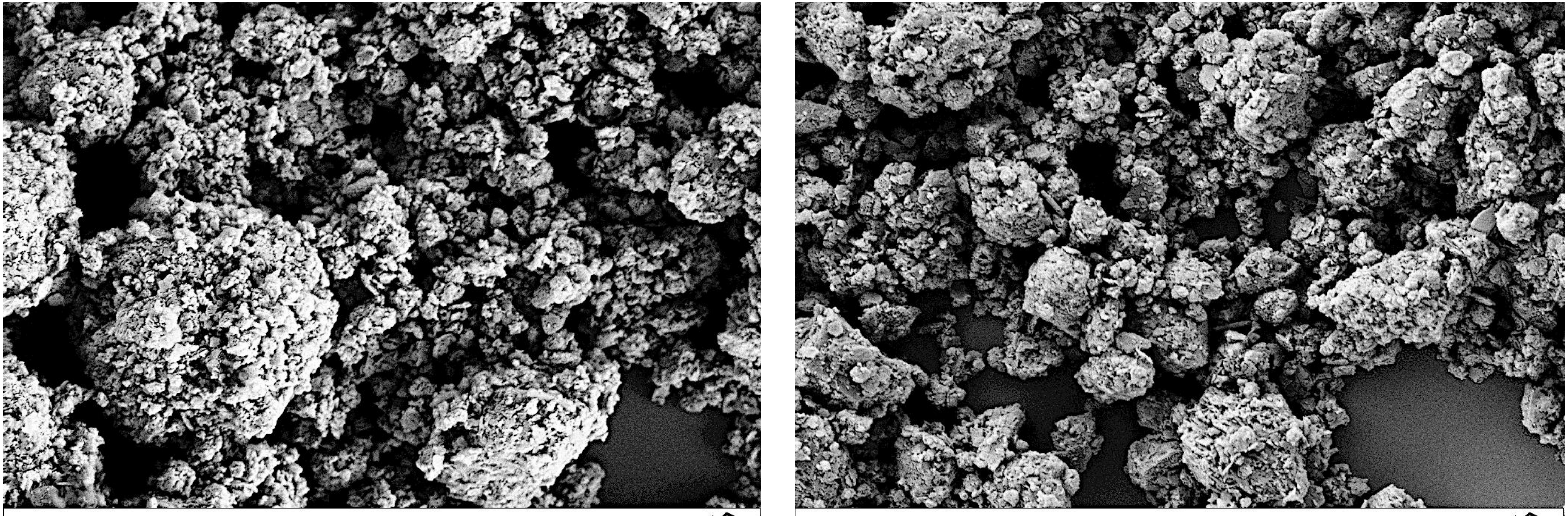


- Bauxite is abundant in most countries

- Can be sourced locally
- We estimate < US¢ 0.5 / L materials-cost to defluoridate water

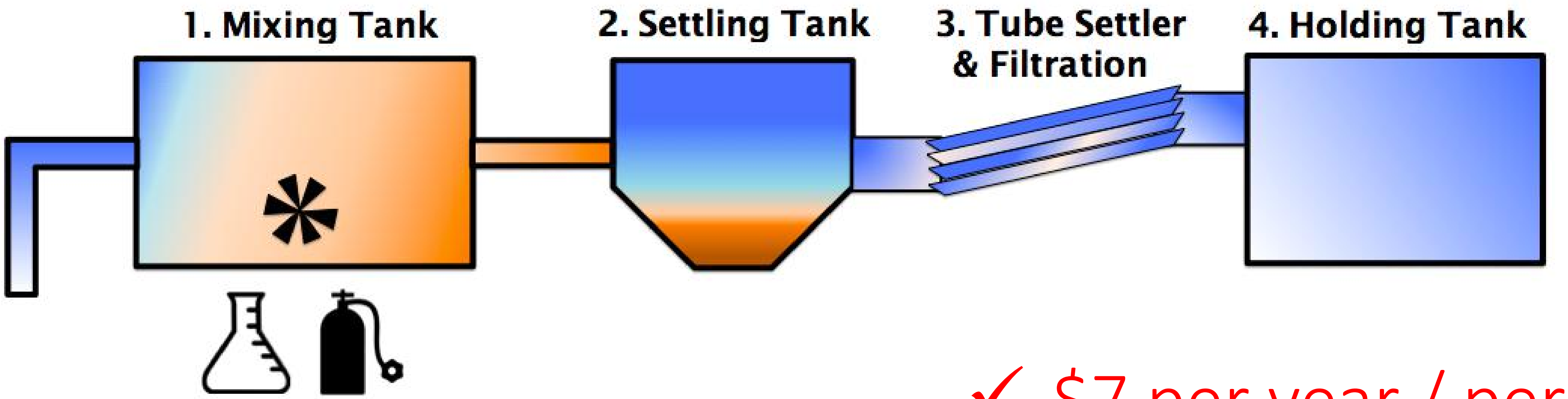
Toasting at 300 C increases surface area and improves performance

SEM Images of milled Indian bauxite ores heated at 100 C (left) and 300 C (right)



Cherukumilli et al. Environ. Sci. and Technol. ***2018***

Implementation vision: Community-scale water treatment centers



- ❖ Clean water sold on a per Liter basis
- ❖ 1000 L Tank, assuming 5L/day per person
- ❖ Aim to reach 2000 people (size of small village)

✓ $7 per year / person to provide 5 L per day (maximum cost estimate)

Currently working with partners in India

Institute of Chemical Technology	INREM Foundation	SATTVA
• Partnerships with two Professors (Rathod and Marathe) at ICT Mumbai • Reproducible results in India and Berkeley • Assist in pilot plant design	• Provide safe and clean water to all in a sustainable manner. • Leader in addressing fluorosis in India	• Consulting firm for CSR and coordination • Aid in implementation and finding start up funding

HARVARD
Global Health Institute

- Our bauxite-based technology has the potential to be locally available and affordable, culturally appropriate, and easily operated and maintained in a rural setting

Thank you