Gadgil acceptance speech at Zuckerberg Water Prize May 2022. (Cleaned-up transcript)

First, I just want to say how greatly honored I am to be selected by the Jury for this highly prestigious prize, from among the hundreds of outstanding international scientists and activists in the field of water. It is a tremendous honor. Thank you so much!

I would also like to thank the University of California at Berkeley and Lawrence Berkeley National Laboratory for giving me the freedom to do what I enjoy doing.

This prize in some way honors everyone with whom I have worked, because it honors and validates the spirit of improving the human condition, using technology innovation that is disruptive. Rather than making small incremental improvements in a mature approach, if we can completely change the parameters we work within, we can allow human beings to have a much better life than they would have with the old way of doing things.

I must also mention my lifelong mentor and my role model, Professor Arthur Rosenfeld, who was also my thesis advisor, and to whom I owe a great intellectual debt as I stand in front of you.

And lastly, I thank my wife, for her steady support, encouragement, and understanding, as I spend my time on the computer day and night.

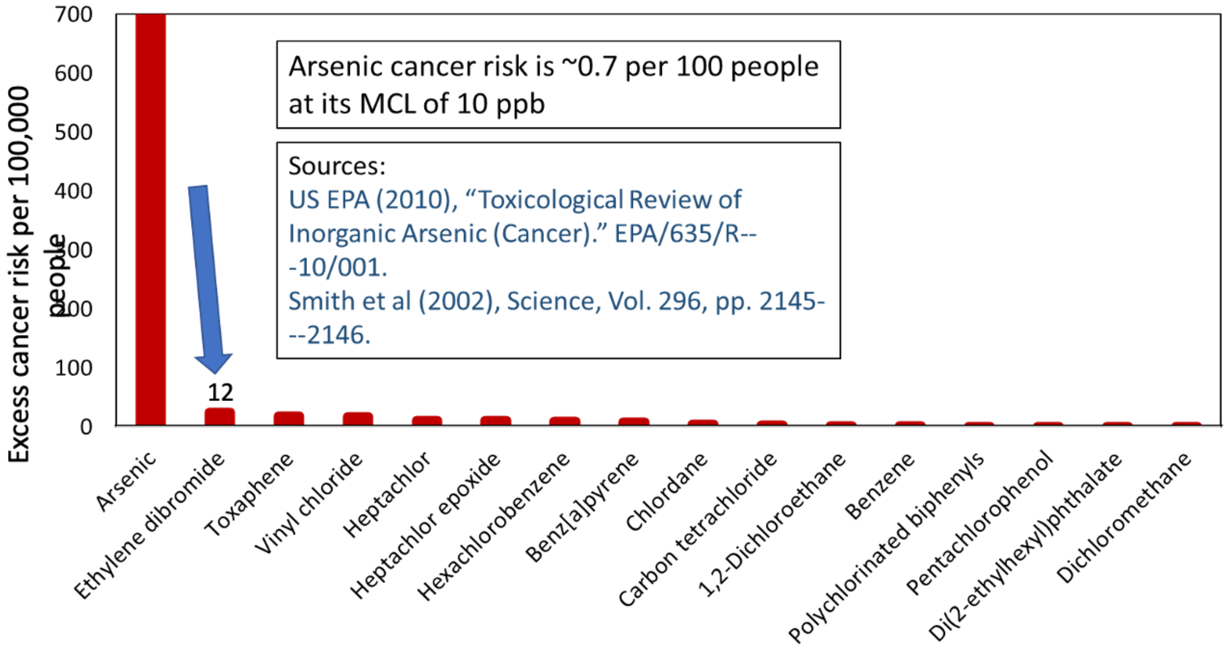
Since all of you gathered here know the field of water so well and I have only 15 minutes, I am going to give you an illustrative example, so you see one single project go from start to finish, and that is also compressed greatly, giving you about 15 years of work in about 15 minutes. That is not perfect, but that's how it goes.

And we all know that Water Is Life! Right? But what if sometimes the same water also brings death?

I am going to speak about solving the arsenic problem in small rural communities in India and the United States. And as some of you know, when the community is small, what is affordable elsewhere becomes unaffordable locally; the economics simply do not work. The unit cost of treating water for fewer and fewer people increases almost like 1/X, as X (the number of people served) gets smaller. So, if you have a community of 10,000 people, the cost is not a big deal; they can afford it. But if you have a small community of 100 people, they get left behind. Worse, if the small community is also poor, then there is no chance they are going to get water that is safe to drink. That is the problem I am trying to tackle and that is what this presentation is about.

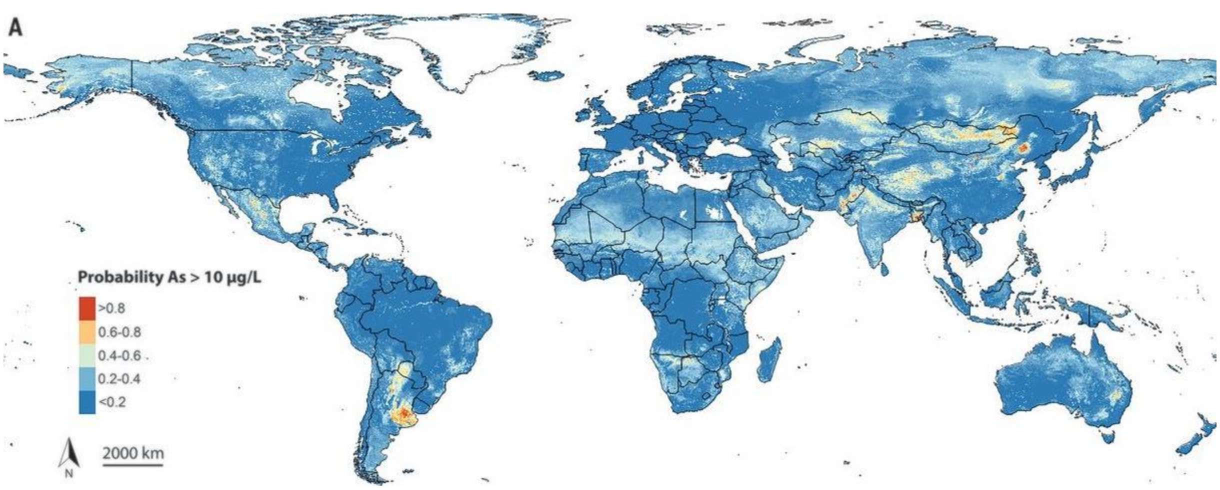
I gratefully acknowledge support from many organizations, and the contributions from lots of talented, hardworking people with whom I work – and that includes applied economists, social scientists, experts in public health – not just those in engineering science.

To start with, the lifetime risk of developing excess cancer from ingesting arsenic via drinking water at its maximum allowed concentration, its MCL (of 10 ppb), hugely exceeds the corresponding risk from the next most potent carcinogen at its MCL. The second most potent carcinogen is responsible for only 12 excess cancers per 100,000 people. In contrast, arsenic produces about 720 excess cancers per 100,000 people, and that is at their MCLs! Tens of millions of rural people routinely drink water that has 10, or even 20, times higher arsenic than its MCL.



That gives you an idea of why I am talking about water bringing death to some people.

Arsenic is unevenly but widely found in the Earth's crust, and the map shows the predicted likelihood of arsenic exceeding its MCL in groundwater. (Podgorski and Berg, (2020) Science; 368:845-850)



About 220 Million people around the world drink water with arsenic about the MCL, most of them relying on contaminated groundwater for drinking because they don't have access to any other source of water. And most of them are people in small, rural communities who commonly access that groundwater through handpumps.

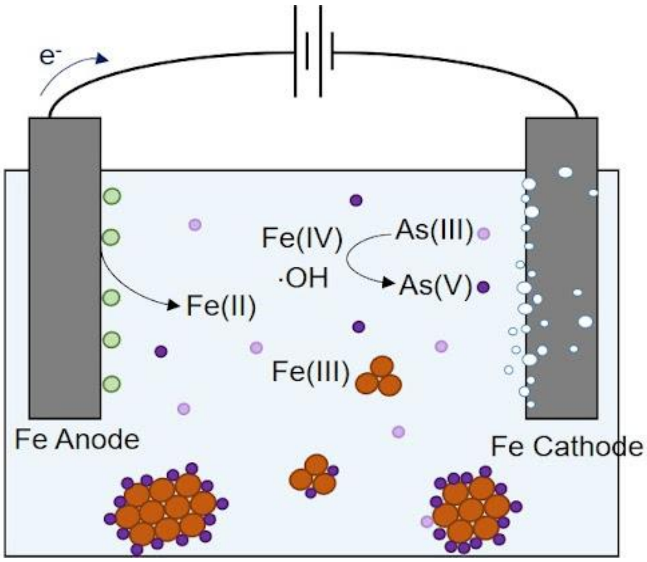
Internal cancer is not the only negative health outcome from chronic arsenic consumption. People suffer disfiguration, skin abnormalities, lower IQ in children, cardiovascular disease, gangrenes, and many other problems. A couple of men in the pictures below have lost their fingers or hands to gangrene, many are showing the hyperkeratosis on their hands (an early sign of arsenicosis), and the woman on the bottom right was abandoned by her husband because she is dying of internal cancers. Others are showing black spots and/or ulcers on their hands – one of the earlier signs of arsenicosis.






So, there is a lot of grief resulting from arsenic consumption via drinking water, and while technologies do exist to remove arsenic from water, they are not affordable on a small scale to small communities of the rural poor.

Over 2005-2015, we invented and developed a technology named ECAR (ElectroChemical Arsenic Remediation), capable of removing arsenic in water from 1000 ppb to levels below its MCL. ECAR was designed to fit into an effective, sustainable, scalable system that would be affordable to people in small rural communities in Bangladesh and nearby parts of India.



ECAR Reaction

ECAR uses two steel plates as electrodes immersed in water, with a small amount of current passing through. The current dissolves the anode and releases Fe(II) ions in the water. A small amount of hydrogen evolves at the cathode. The two key reactions are:

$Fe(0) \rightarrow Fe(II) + 2e^-$ and

$Fe\ (II) + O_{2(diss)} \rightarrow$ Complex Iron Oxides

(More chemistry details in Delaire et al (2017) Water Research, V. 112, pp.185-194)

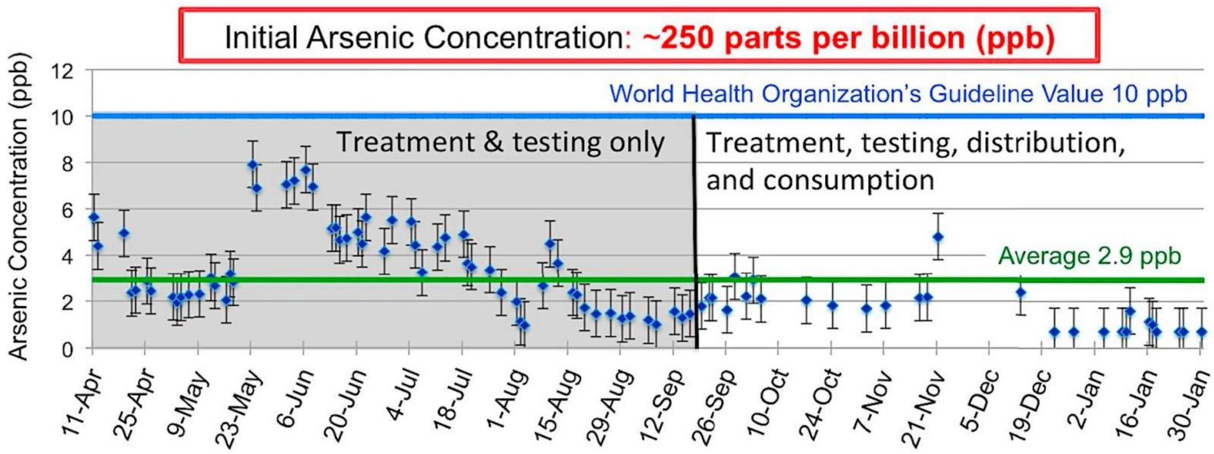
The Fe(II) ions react with the dissolved oxygen in the water to create iron-hydroxides (essentially, a kind of iron rust) which captures arsenic(V), and precipitates out. Along the way, the chemistry also oxidizes any As(III) into As(V), so As(III) is also captured and removed. The benefits of this system are many: there is no prior water treatment required; there is no pH adjustment needed; groundwater can be treated directly as is, so long as it has dissolved oxygen which you can ensure by aerating the groundwater with a pump. So, it is a single-step treatment process, simple to operate, and also has zero liquid discharge.

This process worked beautifully in a beaker in the lab. We scaled it up in stages, and in 2016 had built a pilot plant in a small town in West Bengal, India, about 2 hours outside of Calcutta, that was able to treat 10,000 Liters of water per day of groundwater with 250 ppb initial arsenic.

On the left you see two electrochemical reactor tanks, and on the right you see inter-digited steel plates that form the anode and cathode inside each reactor tank.

In exchange for locating the plant in two school classrooms, we offered to give arsenic-free water to the students and school staff, with the excess being sold to the community at a price of $0.01 per Liter, which covered all operating costs including operator salaries.

From the school's perspective our offer was fail-safe; if the pilot plant didn't work, we committed to take away the equipment, clean up the classrooms, and give them back. As it turned out, it worked! We transformed water with initial arsenic levels at 250 ppb into water that measured 2.9ppb.

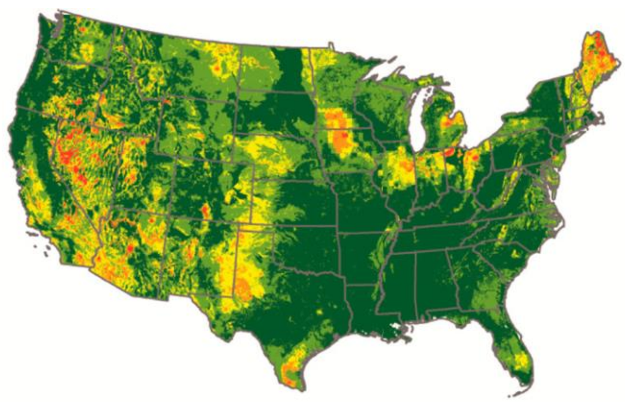


Performance of ECAR plant at Dhapdhapi, from April 2016 to January 2017. (Hernandez et al, (2019) Development Engineering Journal, vol. 4,100045.)

Electronic debit-cards dispense safe drinking water to students and staff at Dhapdhapi High School (2016)

The industrial licensee, Livpure, not only has continued to operate that plant at Dhapdhapi, but also built a new plant operating since early 2021 in another small town, Bahraich, in the State of Uttar Pradesh, India.

Now that this worked fine, in 2018 we turned our attention to the United States.
In the United States, an estimated 2 million rural people drink arsenic contaminated groundwater. Here is a map of coterminous US for arsenic in groundwater above its MCL.



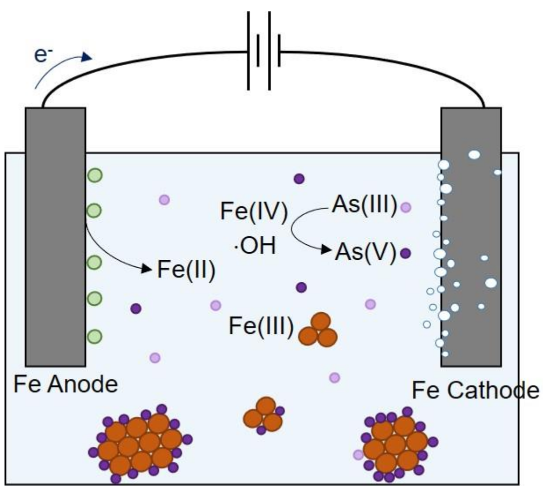
Probability of arsenic > 10 ppb in domestic wells

Above map from Ayotte et al (2017) Environ. Sci. Technol., V. 51, No. 21, pp. 12443-12454

However, the ECAR technology system developed for India won't work in the US because the US labor rates are high relative to those in India, and we had designed the technology for high labor content and low labor rates. The technology will remove arsenic just fine, but the overall system will be uneconomical and the water unaffordable for rural US. So we adapted. With labor, cost, and space constraints in the front of our minds, in 2018-2019 we developed the ACAIE (Air Cathode Assisted Iron Electrocoagulation) technology.

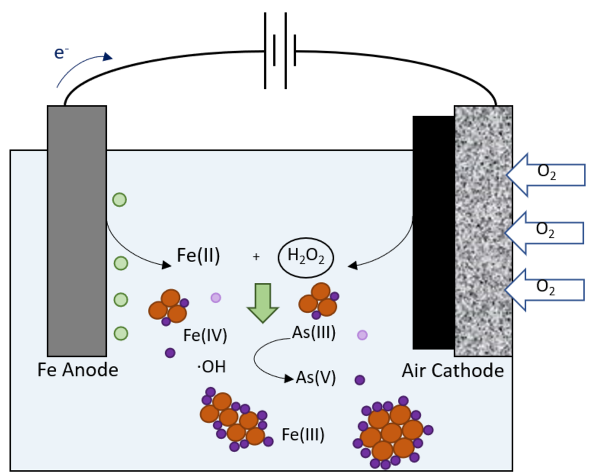
In 2018 we also started working with a small community in the Central Valley of California, Allensworth. In this community, 85% of the people live below the median California income, and 40% live below the poverty line. It is 5% Black, and 95% Hispanic. Allensworth is rural, poor, and politically weak, making it difficult for its members to advocate successfully for their needs.

Berkeley Researchers visiting Allensworth in 2018.



$$2H_2O + 2e^- \longrightarrow 2OH^- + H_{2(g)}$$

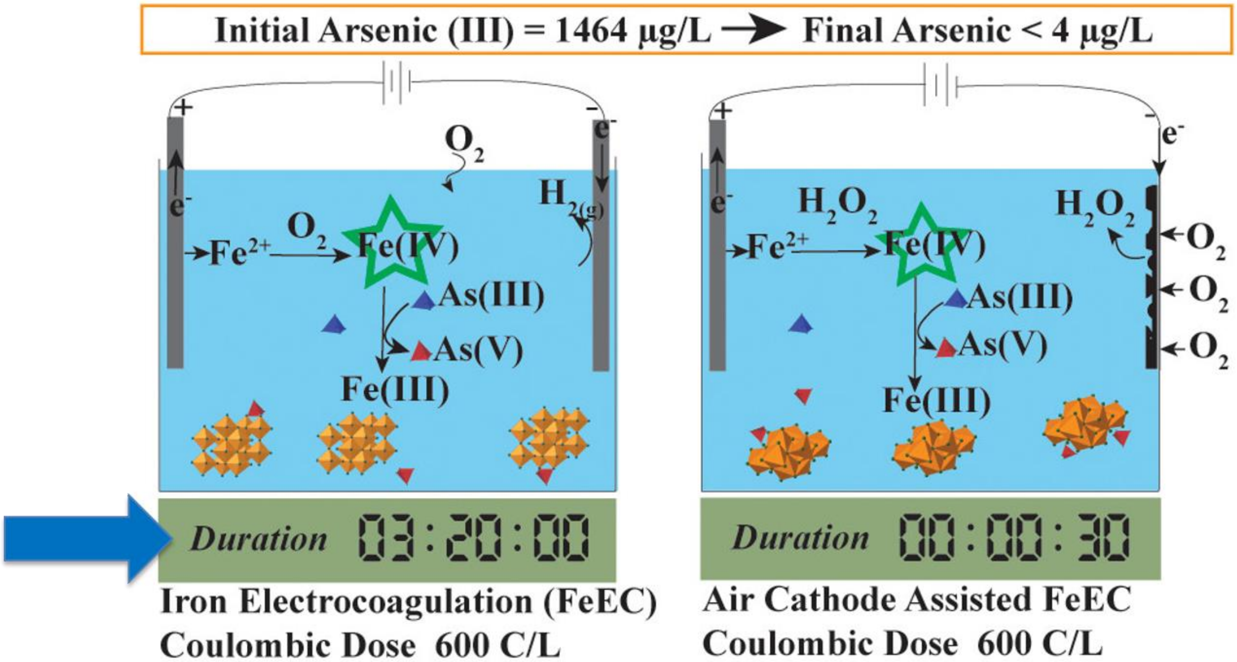
ECAR



$$O_{2(air)} + 2H_2O + 2e^- \rightarrow H_2O_2 + 2OH^-$$

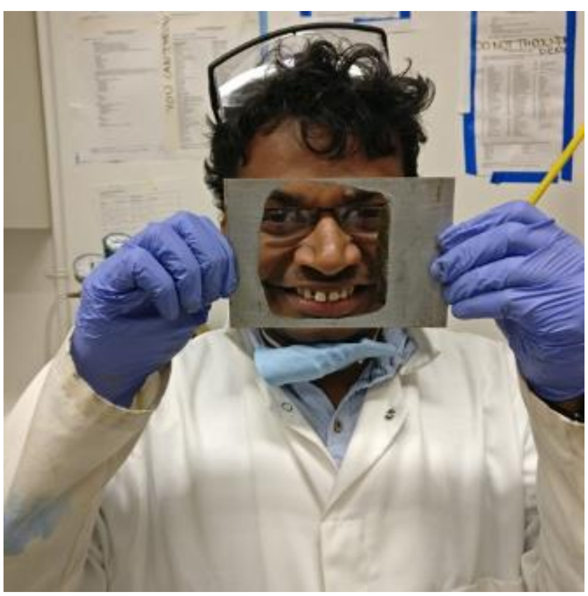
ACAIE

Unlike ECAR with steel plate as the cathode, in ACAIE, we use an air-diffusion cathode which allows atmospheric oxygen to penetrate the cathode and interact electrically with the water, producing a small amount of H_2O_2 with a Faradaic efficiency of 80%. The amount of H_2O_2 is small because the current is small, but it is plenty for our purposes. The results are amazing. The kinetics of the reaction are sped up by 10,000 times which allows us to operate at very high flow rates, because the reaction is almost instantaneous. By the time the water leaves the reactor, it has converted Fe(II) into Fe(III), converted all arsenic As(III) into As(V), and has attached it all to Fe(III) oxyhydroxides, which begin to coagulate. All that remains is to remove the sludge, which we can dispose of properly in an appropriate waste facility. With this system, we have achieved a flow rate of 600L/h.



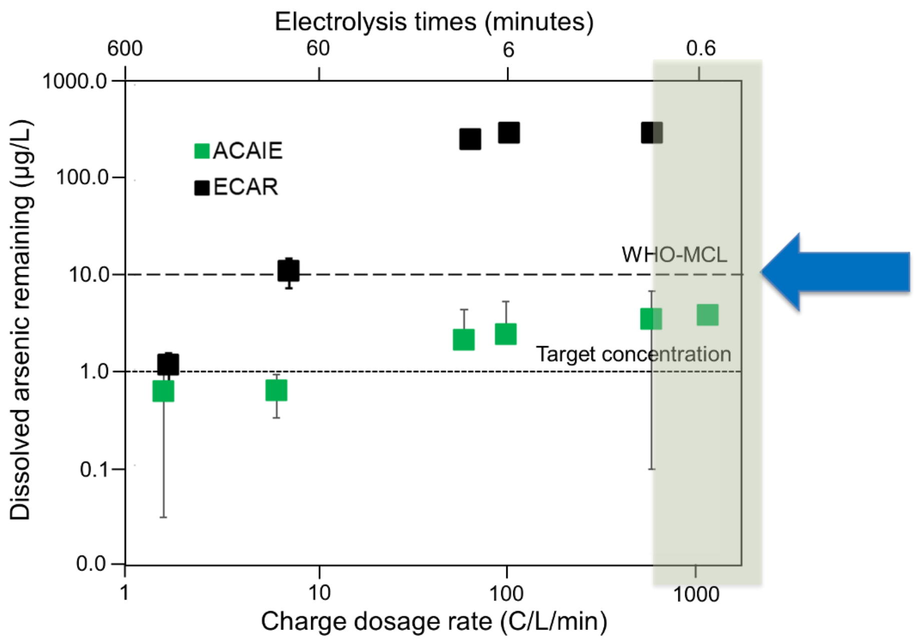
Better still, what would take us 3 hours and 20 minutes with ECAR in India, we can do in 30 seconds now. So, the logical next step forward is scaling this up into a continuous-flow reactor, rather than the quasistatic, intermittent batch reactors of ECAR.

With a continuous-flow ACAIE reactor, we achieve rapid arsenic removal, short retention time, high throughput, and we don't need to clean the anodes. We simply consume the anode almost fully through electrical dissolution. Figure below shows one such anode with a dissolution hole!



One would logically ask why can't we push ECAR harder, just increase the voltage across the electrodes, get higher current, higher iron dose per minute. Then can't it match ACAIE in rapid treatment of water? The answer, theoretically, and experimentally too, is a "no". If one simply operates ECAR at higher current, and therefore a higher rate of anodic dissolution, the rapidly released Fe(II) in the water builds up, and begins to compete with As(III) in reducing the intermediate unstable stage of Fe(iV). Thus, ECAR operated at a high current (i.e., high charge dosage rate) begins to fail in capturing As(III).

Here below are experimental results showing this failure in the lab. Here the electrolyte was synthetic groundwater at pH 7, with initial As(III) of 1500 µg/L. In all experiments, the same charge dose 600 C/L was delivered to the water.
(Bandaru et al 2020, ES&T)



Lightly shaded area shows that at fast rates of arsenic removal, ECAR fails to deliver arsenic below 10 ppb, while ACAIE can do so.

In other words, only ACAIE with its self-generated H2O2, is successful in achieving excellent arsenic removal even at a short residence time and high flow rate of water through the reactor.

And we are working on cloud-based monitoring to reduce labor and increase ease of use. The space requirements have also shrunk dramatically. Instead of needing two classrooms worth of floor space (1400 sq. ft., or 140 sq. m.), we now fit the equipment into a small shed (120 sq. ft, or 12 sq.m.), and still treat 600 Liters of water per hour. The improvements achieved with ACAIE have demonstrated there is an affordable way to provide clean, arsenic-free water to a small community even under the economic conditions in the US.

Complete set up with ACAIE reactor being tested at UC Berkeley before shipping to Allensworth, May 2022.

Technological innovation has an opportunity to completely change what we used to see as impossible just a short while ago, and to make human life better. And this is just one of those many examples. All the more power to all of us who are working to make the world better, through research, technology, and disruption.

Thank you.