Researchers aim to stem deaths from arsenic-containmated water in the developing world

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ARUBA Arsenic Removal Plant Prototype installed at the Bangladesh University of Engineering and Technology (BUET), Dhaka, Bangladesh (July 2008). Photo credit: Mahbuba Iasmin.

One in five of all deaths in Bangladesh are caused by drinking water contaminated with arsenic, according to a study published recently in the medical journal The Lancet by an international team of researchers. Some 70 million people are drinking arsenic-contaminated water. The study's publication has generated renewed public interest in finding a quick, cost-effective solution to a problem that is turning into a human catastrophe.

Arsenic occurs naturally and contaminates many shallow groundwater aquifers. Bangladeshis began a massive shift from biologically contaminated surface water to cleaner groundwater for drinking supplies in the 1970s. They installed more than 10 million shallow bore-wells fitted with hand-pumps to access this groundwater—which, it turned out, is frequently contaminated with toxic levels of arsenic. The situation is often called "the largest mass poisoning in human history." Arsenic contamination of groundwater is a problem in other parts of the world as well in such countries as Argentina, Chile, Mexico, Ghana, Hungary, Greece, Vietnam, China, and India.

"We are not aware of locally affordable modern pharmaceutical methods to reverse chronic arsenic poisoning, but the first and most urgent step must be to switch to safe drinking water for the tens of millions of people who are still drinking water with highly toxic levels of arsenic" says Ashok Gadgil, leader of the group at the Lawrence Berkeley National Laboratory (Berkeley Lab) that is working on this problem. Gadgil is also the Acting Director of the Lab's Environmental Energy Technologies Division (EETD).

"The *Lancet* study raises the question 'why aren't low-cost technologies for arsenic removal being used in Bangladesh now?'" says Susan Addy, a guest researcher at Berkeley Lab, and postdoctoral scholar at UC Berkeley's Department of Civil and Environmental Engineering. As a former research associate at Berkeley Lab, Addy served on Gadgil's development teams for ECAR (ElectroChemical Arsenic Remediation) and ARUBA (Arsenic Removal Using Bottom Ash).

Berkeley Lab Approach Combines Technology and Community Deployment

ARUBA and ECAR are novel low-cost arsenic-removal technologies that are proven effective in lab studies.

One technology, ARUBA, is fully field tested and could be deployed now to provide safe drinking water. Meanwhile, a working prototype for ECAR has been completed and is scheduled for field-testing later this fall.

"We started working on an affordable, robust, and technically effective approach to remove arsenic from Bangladesh groundwater back in the year 2000, as soon as I became aware of the enormity of the human tragedy that was in the making," says Gadgil. "Now that this catastrophe has come to major media attention in CNN, Reuters, and elsewhere, we have not one but two different inventions that meet our above criteria."

While many researchers are developing technologies that can remove arsenic from water, affected areas in Bangladesh have not adopted these technologies widely enough to make an impact on the health problem. The Berkeley Lab/UC Berkeley team has studied both the technological dimension of the problem, as well its sociopolitical dimension—how can local institutions create the economic and social conditions that facilitate the adoption of these low-cost, effective technologies for reducing arsenic in water?

The business deployment model they have outlined, called the micro-utility, provides economic mechanisms for financing community-scale water treatment facilities, and a market mechanism for sustaining the operation of these facilities.

Ash, Iron, and Electricity

ARUBA is a proven technology for removing arsenic that uses bottom ash, a widely available waste material from coal-fired power plants. The fine powdered ash is coated with an iron-containing chemical, which absorbs and chemically binds to arsenic in the water. The resulting solids settle to the bottom of a container, and can be filtered out, leaving the water safe for drinking. "The technology is innovative" says Addy "because it used a low cost, ubiquitous waste material as a substrate and can be manufactured using simple room temperature and pressure processes."

Lab testing shows that this process can reduce arsenic concentrations from 1,000 parts per billion to 3 ppb. (The World Health Organization standard for drinking water is 10 ppb). Tests have also shown that the arsenic in the waste is securely chemically bound, so that the small amount of solid waste produced in the process can be safely disposed per U.S. Environmental Protection Agency standards, and the arsenic won't dissolve back into the water cycle.

ARUBA is inexpensive—raw materials would cost about 8 cents per year per person, and the total treated water costs would be $7 to $15 per person per year, assuming 10 liters of drinking water per person per day. ARUBA would require an in-country centralized facility to manufacture the arsenic-removing raw material, which would be distributed to local communities for use in their micro-utilities for safe drinking water.

In ECAR, a small amount of electricity continuously dissolves an iron electrode immersed in a container of the contaminated water. The iron forms rust particles in the water, and the arsenic binds to the rust. The resulting material is filtered or settled out of the water. Lab-based testing has demonstrated that when applied to water with arsenic concentration as high as 2,000 ppb, the ECAR process reduces arsenic concentration to below the 10 ppb WHO limit, and it is possible to reduce concentrations even down to 2 ppb or less. Waste generated in this process also binds arsenic securely, and is safe for disposal.

Help From a Car Battery

Electricity could be supplied from a grid, a solar power system, or even a

12-volt automotive battery. The use of electricity in the process increases the efficiency of arsenic removal compared to passive chemical processes, so ECAR generates much less waste than ARUBA and many other chemical processes for arsenic removal. Neither ARUBA or ECAR use toxic or corrosive chemicals at any stage in the field application—an important point for technologies intended for use in remote rural areas where technically trained personnel would be generally unavailable.

The ECAR team estimates that the total energy and materials cost to provide 10 liters of treated water per person is $0.99 per person per year. Some additional electricity is needed to agitate the water during treatment, so they estimate the total cost of treatment to be a little under one cent per person per day—$3.65 per person/year, for the bare treatment alone. The cost of a shed for housing the equipment, and salaries of operators, and other need will somewhat raise these costs.

Why two technologies for one problem? "The arsenic remediation problem is not going to be solved by just one technology," says Addy. "ARUBA is very low cost, requires no electricity, and it's easy to manufacture the materials because this can be done at room temperature and pressure. But it requires a central facility for making the materials, which then need to be distributed throughout the country."

"ECAR requires electricity but it doesn't need a central manufacturing facility for process chemicals. It's also low-cost, produces less waste than ARUBA and other chemical methods, it's easy to maintain the equipment, and ECAR doesn't require an extensive supply chain." ECAR might be suitable for harder to reach areas where an ARUBA supply chain is less likely to reach.

Market Mechanism for Community-Scale Facilities

The development teams have gone beyond just developing and proving the technology itself, they have analyzed the economics and outlined a financing and operations model called the "micro-utility" for deployment in communities in Bangladesh and elsewhere it is needed. This model is based on the successful dissemination experience with a previous invention, UVWaterworks, that also came out of Berkeley Lab, from Gadgil's team.

"Technology development alone will not solve this problem. It needs local community education in Bangladesh about the risks posed by arsenic and the importance of switching to safe water. This needs strong local community partners and continuous feedback from the field on which aspects of solutions work, and which ones need improvement," says Addy.

She continues: "Our team is dedicated to this approach—we collaborate intensively with researchers in other fields, gather and incorporate feedback continuously from the field, and work with all stakeholders from the beginning of the technology/implementation design effort.

"In 2009, we held open-mike meetings in Kolkata, India—one for the scientific/engineering community at a major University in Kolkata, and another one in a remote village for the population of a severely arsenic-affected community. Our teams have spent time both in Bangladesh and West Bengal (India) to talk to local NGOs and community advocates, government officials, and religious leaders, and we have had in-depth conversations with affected families. We work with UC Berkeley's School of Public Health, Haas School of Business, and other departments at UC Berkeley, as well as the Economics Department and Global Change Programme at Jadavpur University, India. We try to engage with and learn from other efforts, public and private, to solve this problem."

Experience has shown that household-scale water-treatment filters and devices have not worked well in developing economies such as Bangladesh. They are too expensive, or they require too much maintenance and training to operate. A locally-owned community-scale facility is likelier to succeed, as shown by successful examples in India, which use another of Gadgil's water treatment technologies, UV Waterworks.

Developed in the 1990s, UV Waterworks-based treatment facilities for removing disease-causing bacteria are now gaining traction in India and other developing nations, serving more than a million people daily with safe drinking water, through Berkeley Lab's licensee, WaterHealth International.

Both ARUBA and ECAR provide the most cost-effective water remediation in small facilities designed to supply drinking water for about 500 to 1,000 people. "A local financial institution can provide capital to a local government which would contract with a private company to build a treatment facility," says Addy.

The company operates and maintains the facility under contract to the local government, which sets the price of water to the community. Community members don't have to learn how to operate and maintain the equipment. Revenues from sales provide the funding to keep the facility operating over the long term.

This fall, with funding from the Blum Center and Sustainable Products and Solutions Program, and the US EPA P3 Program, the ECAR team will set up a pilot program in West Bengal in India in collaboration with Jadavpur University (Kolkata) to undertake a technical trial of the ECAR technology in a field setting. Meanwhile, ARUBA is ready for deployment, and in search of non-governmental agencies, funding institutions, and private sector licensees.

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