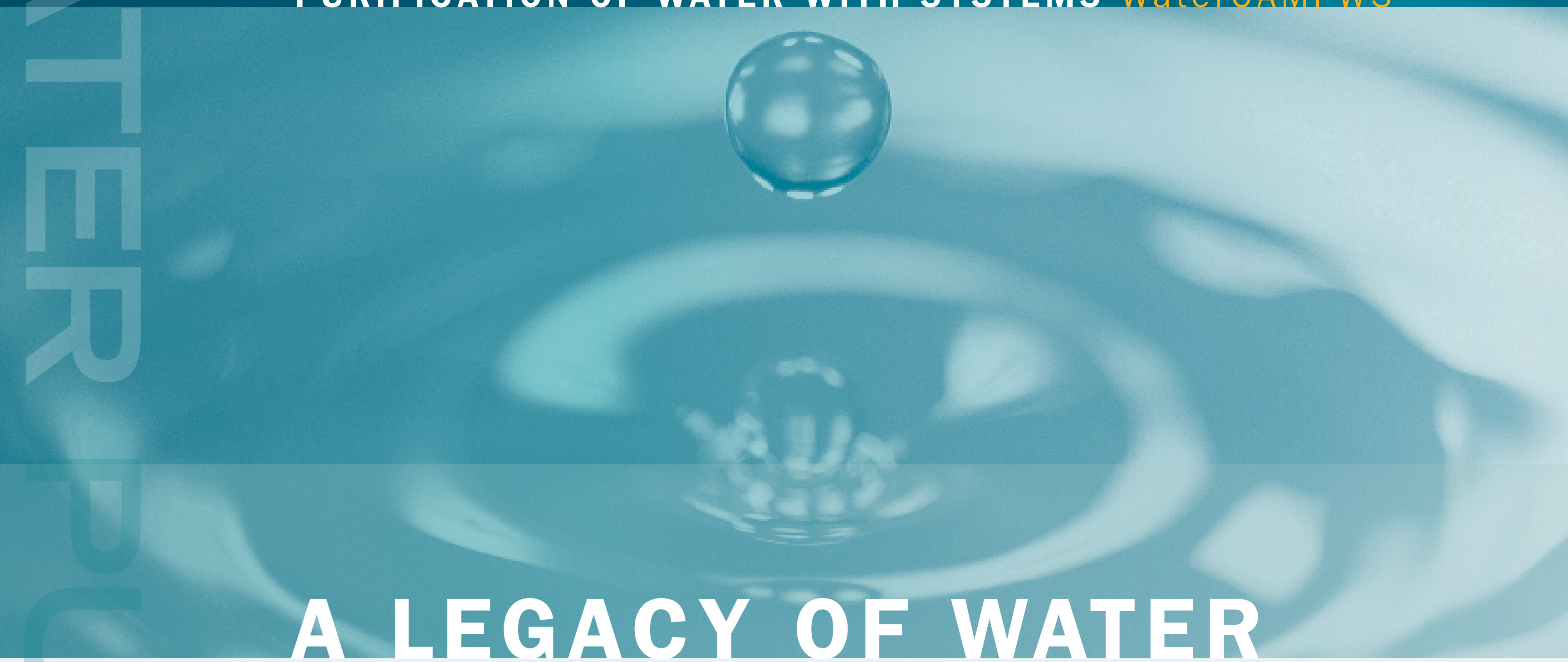
WATER PURIFICATION

THE CENTER OF ADVANCED MATERIALS FOR THE PURIFICATION OF WATER WITH SYSTEMS WaterCAMPWS



A LEGACY OF WATER

Safe and abundant water is a basic requirement for every aspect of human health and an essential component of many human activities. However, decreasing water quality and increasing water scarcity and cost are threatening the health and well-being of people worldwide.

The quality of existing water sources is being compromised by water-borne pathogens from inadequate sanitation, toxic compounds from industrial wastes, pharmaceutical compounds introduced into water systems, agricultural practices, heavy metals in aquifers, and toxic disinfection byproducts from the water treatment process. Aquifers are suffering from declining water levels, saltwater intrusion, and inadequately replenished fresh groundwater. Major river systems are experiencing periodic water shortages because of declining snowpack storage and the loss of glaciers. The competing and ever-increasing demands on limited water supplies of energy production, agriculture, and industry are increasing water scarcity, pushing up water costs, and threatening economic development.

Addressing these complex issues to ensure the availability of clean, abundant water for human use is one of the most critical problems facing the U.S. and the world, says Mark Shannon, director of the WaterCAMPWS. Fortunately, the development and application of new technologies offers some important solutions.

For almost 10 years, the research mission of the WaterCAMPWS, headquartered at the University of Illinois at Urbana-Champaign (UIUC), has been to increase the supply of potable water through the development of novel ideas and the facilitation of supply-enhancing technologies. Team science efforts, organized around the dual themes of water and health and water and energy have focused on the technologically promising areas of desalination and reuse, disinfection, and decontamination.

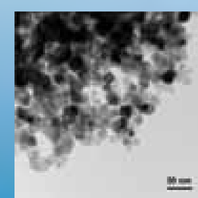
The WaterCAMPWS is currently in its final year of a ten-year funding cycle, and the results of the Center's sustained research efforts clearly demonstrate the value of team science. Significant results range from important additions to the body of fundamental knowledge that are essential for future breakthroughs in water science to the development of devices that will immediately and directly benefit the public.

One such research result is a type of sensor called the catalytic beacon, developed by the Yi Lu research team and their collaborators at the WaterCAMPWS. Yi Lu is a professor of chemistry, biochemistry, and physics at UIUC. This technology is a general platform for detecting a wide range of metal contaminants. A DNA sensor can be made to recognize a particular target with up to million-fold selectivity compared to other metal ions in the water. The sensors are biocompatible and biodegradable, so the technology is environmentally benign. A device using this technology has been transitioned into commercial production via a start-up

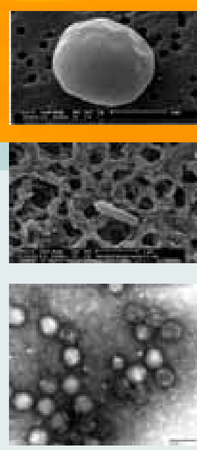
THREATS TO AMERICA'S WATER SUPPLY

More details can be found at http://www.watercampws.org/index.php?menu_item_id=8

- Increased demand by energy production
- Agricultural run-offs, such as:
  - Nitrates
  - Herbicides
  - Phosphates
  - Hormones
  - Pesticides
- Leaching of radioactive materials and heavy metals
- Depletion of aquifers
- Contamination of aquifers by:
  - Salt water
  - Pollution
  - Toxins



TiON nanoparticles. Nitrogen-doped titanium dioxide shows promise for photocatalytic water disinfection. *Image courtesy of Jian-Ku Shang, materials science and engineering, UIUC.*



Disinfection Targets: Waterborne pathogens (top to bottom: protozoa, bacterial spores, viruses) are a major cause of disease/death in developing countries, and an emerging threat to public health in the U.S.

company, DzymeTech. The approach enables rapid, on-site, and real-time detection and quantification of toxic metal ions such as lead, uranium, and mercury in water and other environmental samples. Detection and quantification is down to 11 parts-per-trillion–much lower than the maximum contamination levels defined by the U.S. EPA. Products based on this patented technology will change the way water testing is carried out, making it possible to identify water contamination issues rapidly, monitor the progress in decontamination efforts, and ensure the safety of drinking water.

In continuing research, teams led by Yi Lu and Benito Mariñas, a professor of environmental engineering at UIUC, are pushing the boundary of this technology to achieve detection of infectious viruses over other targets, including non-infectious viruses.

Technologies are needed that can harvest water for reuse from municipal or industrial wastewater streams. However, when used for wastewater treatment, most commercial membranes become fouled by dissolved or suspended biological molecules. A successful team science effort by center researchers resulted in the commercial production of nanotechnology-enabled membranes via a start-up company, Clean Membranes. The new membranes have substantially higher fluxes than commercial nanofiltration membranes and are completely resistant to fouling. The work was led by the now late Anne Mayes of MIT.

The unique feature of these membranes is their special "comb" copolymer coating formed by the local separation of hydrophobic "spines" and short, hydrophilic "teeth" of the combs into distinct domains. The water-absorbent teeth form a brush-like coating on the membrane surface that completely inhibits the adsorption of biological molecules, delivering unsurpassed fouling resistance.

A team at the WaterCAMPWS also has addressed the problem of disinfection byproducts in treated water. The disinfection of water was a major public health achievement of the twentieth century, but an unintended consequence of disinfecting water is the production of toxic drinking water disinfection byproducts (DBPs). The WaterCAMPWS team produced the world's largest mammalian cell toxicity database for drinking water disinfection byproducts. The effort, led by Michael Plewa, a professor of genetics at UIUC, developed and calibrated in vitro mammalian cell cytotoxicity and genotoxicity assays to integrate the analytical biology with the analytical chemistry of these important environmental contaminants. The results demonstrate that these data can be used to direct human cell toxicogenomic studies on DBPs to determine biological mechanisms of toxicity, select specific DBPs for future in vivo animal toxicity studies, and aid in the processes to rationally regulate drinking water contaminants to protect the environment and human health.

Key accomplishments of the WaterCAMPWS team science research efforts are:

- Comparison of nanomaterials such as graphene and carbon nanotubes for suitability in purification membranes by means of molecular dynamics and spectroscopy studies.
- Development of new membrane designs with improved uniformity and fouling resistance.
- Ion-exchange fibers that promise low-cost water treatment options for problem contaminants like perchlorate.
- Evaluation of the cytotoxicity and genotoxicity of drinking water disinfection byproducts.
- Assessment of the effects of natural organic matter on visible- and ultraviolet-light disinfection mechanisms.
- Demonstration and evaluation of chlorine-free disinfection systems using metal-oxide photocatalysts. □

Students and Oaxaca, Mexico, community members taking water samples.

STUDENTS MAKE WATER RESEARCH WORK

Pictured above at left: On site interviews with women in the Bondo communities. One of the Bondo water representatives is there translating for Dana Al-Qadi (UIUC) from English to Swahili.

Moving research findings from the laboratory into the real world and educating students in a hands-on, team-science environment are key components of an integrated engineering design course offered by the WaterCAMPWS at UIUC. The course, CEE 449, also has a humanitarian mission: it focuses on developing sustainable approaches for providing safe drinking water and adequate sanitation to impoverished rural communities throughout Mexico, Ethiopia, and Tanzania.

Developed by Benito Mariñas, a UIUC professor of environmental engineering and acting director of the WaterCAMPWS, CEE 449 is continually updated and improved through incorporation of current WaterCAMPWS research and creates a hands-on, team science experience for students from the WaterCAMPWS and UIUC in collaboration with faculty and students from the Nelson Mandela Institute of Science and Technology in Tanzania, the Addis Ababa University in Ethiopia, the King Abdula University of Science and Technology in Saudi Arabia, and the Universidad de Las Americas–Puebla in Mexico.

One important aspect of CEE 449 is international trip participation. Team members from UIUC participate in week-long trips to Mexico, Ethiopia, or Tanzania. Activities include field trips to target communities to gather data on relevant local socioeconomic and cultural priorities; recruiting local authorities as partners; exploring possibilities for

SPOTLIGHT ON START-UPS

Not only do start-up companies serve an important role in transitioning laboratory research to industry and society, but they also effectively leverage the Center's funding. Because customers are an important source of product evaluation and development ideas, start-ups are a source for market input. Even as the Center's research provides and expands underlying science, start-ups speed the expansion/extension of technologies to new applications.

Cbana Labs, Inc., (www.cbana.com) is one of four start-up compaes with roots in the WaterCAMPWS research laboratories. Founded by Mark Shannon, UIUC professor of mechanical engineering and center director, Cbana Labs develops novel adsorbents and microanalytical devices for the capture and analysis of pollutants, drugs, and other dangerous materials. Three major components are needed for advanced microscale detection systems: preconcentrators for gas/liquid sampling; separators to minimize false positives; and microscale sensors. Cbana has developed novel and proprietary technologies in all three areas, including a family of novel adsorbents built on upon proprietary metal-organic frameworks (MOFs). Previously, MOFs were not widely used because of their relative instability and because synthesis was a long and costly process. Cbana's MOFs, called Banasorb®, are thermally and mechanically stable and can be synthesized in as little as 25 seconds. They are made of a fully customizable, three-dimensional nanoporous material that can be engineered to selectively adsorb species of interest and have a capacity that is an order of magnitude better than adsorbents such as granulated activated carbon.

The Center's three other start-up companies are:

- DzymeTech: functional DNA-based sensor technology–Prof. Yi Lu (UIUC)
- Clean Membranes: new UF membranes with high flux and fouling resistance–Prof. Anne Mayes (MIT)
- Oasys Water: forward osmosis based desalination process–Prof. Menachem Elimelech (Yale)

Sensor researcher Yi Lu of the WaterCAMPWS works with students.

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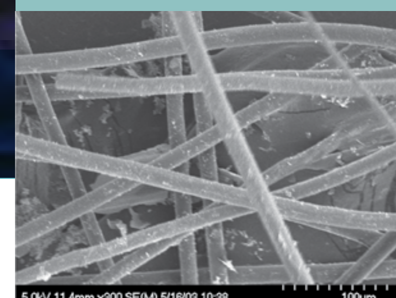
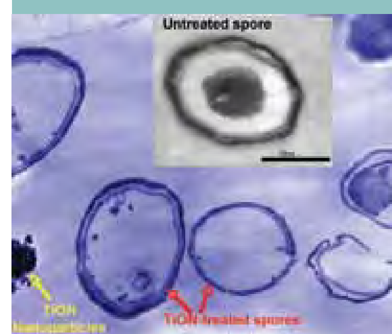
Students from UIUC and community members in Oaxaca, Mexico conducting drinking water tests in 2011.

Top Photo: Metropolitan Water Reclamation District of Greater Chicago



Left: TiON fibers. *Image courtesy of Jian-Ku Shang, materials science and engineering, UIUC.*



Bacillus Subtilis spores killed by TiON. *Image courtesy of Jian-Ku Shang, materials science and engineering, UIUC.*

creating an educational component for design implementation and maintenance; determining the water quality of potential water sources in-situ; collecting water samples for subsequent analyses; and water quality process testing. Samples are also brought back to UIUC for specialized measurements such as toxic metal analyses.

Based on data gathered in the field and laboratory, students select candidate water quality control processes to produce safe drinking water and adequate sanitation. Faculty members design laboratory experiments to assess the efficiency of these various processes at treating the contaminated waters.

Most recently, CEE 449 teams targeted two communities in Mexico, Tarriahua and Las Cucharas. In their final presentations, students outlined the issues confronting those communities and detailed plans for water treatment as well as community education. With the completed plans, the communities can make proposals to their respective governments for funds to implement the building of the plants.

DEVELOPING DIVERSE HUMAN RESOURCES TO ADDRESS THE WATER CRISIS

Developing the diverse human resources needed to conduct water research into the future is an essential part of the WaterCAMPWS effort. Communities across the U.S. and the world need plentiful potable water. Today's decreasing water quality coupled with increasing scarcity and cost signal a crisis that will reach pandemic proportions within the next two decades if revolutionary advances in the science and technology of water are not made.

Fortunately, students who take up the challenge of water research are deeply committed to addressing this global problem. Many WaterCAMPWS students have first-hand knowledge of the health risks caused by poor water quality and have undertaken personal missions to solve this crisis.

Graduate, undergraduate, and sometimes even high school students are research team members and active partners in the Center's activities. They co-author papers appearing in major scientific journals, make presentations at national and international professional conferences, and support WaterCAMPWS activities directed at educating elementary and secondary school teachers and students and the general public about the issues surrounding water. The Center's students are also active in hands-on national and international humanitarian projects that apply and enhance the knowledge they have gained in the laboratory and classroom.

Early in the Center's history, all high school, undergraduate and graduate activities, and diversity and education programs were melded into one seamless effort. To achieve this, the Center applied the cross-cutting themes of academic development, research experience and professional development to its internal and external education programs.

External undergraduate recruitment programs and pre-college educational programs that incorporated the most recent findings from the Center's research efforts were crafted to create a sustainable "pipe-line" of qualified candidates, with emphasis on increasing the participation of traditionally underrepresented students (URG). This demonstrated dedication to an integrated, high-quality experience for all undergraduate students yielded enormous benefits for all students and the Center. It also resulted in a 45% graduation rate among URG students at the WaterCAMPWS, a rate 10% above the norm nationwide and for the University of Illinois College of Engineering.

As the end of its 10-year funding cycle approaches, the Center leaves a legacy of students who have already emerged as dedicated, well-qualified researchers and whose work has, and will continue to have, significant impact on real-world water problems.