

Wastewater as a Valuable Resource

By *Craig Criddle (with Brian Cantwell and Frank Wolak)*

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The Challenge: Development of cost-effective technology for recovery of clean water, energy, and materials from wastewater

The American West faces an urgently mounting water crisis due to water scarcity, competition among agricultural and urban users, aging water infrastructure, population growth, climate change and the need to maintain healthy aquatic ecosystems. By the end of the 20th century, more than 15,000 wastewater treatment systems were operating in the United States.

When these systems were constructed, energy costs were low, water scarcity was less of a concern, climate change was not a consideration and there was no demand for potentially valuable materials found in wastewater. The goal was to prevent environmental harm and protect public health. To achieve this goal, wastewater is transported to centralized facilities and treated to remove harmful agents. The remaining effluent and residual materials are discharged into local water bodies.

In the San Francisco Bay Area, 40 wastewater treatment plants protect the water quality of the bay. These plants underwent massive redesign and reconstruction in the late '60s and early '70s to provide efficient removal of waste organic matter from the treated water discharged to the bay. These plants have now reached their design life and are in need of revitalization.

Viable steps need to be taken to renew our increasingly scarce water resources. One option is to recover clean water and other valuable resources (energy, fertilizer, etc.) from wastewater. Waste treatment systems will become resource recovery centers, enabling 1) low-cost production of water that offsets demands for high quality water; 2) energy production that offsets fossil fuel demands; and 3) nutrient recovery that offsets fertilizer demands. Distributed, networked bioreactors will foster development of local markets for wastewater recovery, with low transport costs and the ability to match product quality and quantity to regional needs.

ABOUT THE AUTHOR

Craig Criddle's research focuses on the environmental biotechnology, engineering and science literacy needed for clean water clean energy, and healthy ecosystems. He is best known for large interdisciplinary field projects and studies of microbial ecology. Current projects include development of membrane bioreactors for energy recovery and nutrient removal; monitoring of microbial communities in wastewater treatment plants; processes involved in the microbial transformations of persistent contaminants; studies of mechanisms and kinetics of microbial transformations of halogenated solvents; and a field-scale evaluation of uranium remediation. To promote science literacy, Criddle worked with award-winning San Francisco cartoonist Larry Gonick on *The Cartoon Guide to Chemistry*. Criddle is a professor of civil and environmental engineering and senior fellow at the Woods Institute for the Environment.



Craig Criddle (left), faculty and students on the Stanford wastewater research team.

There is much value to be recovered from wastewater. While wastewater does contain salts and pathogens that must be removed, it is 99.9 percent water and contains valuable organics recoverable as energy and nutrients, such as nitrogen and phosphorus recoverable as fertilizer. The challenge is to develop cost-effective means for recovery and purification of these valuable commodities.

CURRENT WASTEWATER RECOVERY RESEARCH

Most wastewater treatment systems in the U.S. release treated water back into rivers, lakes or the ocean with little reuse. However, if more water were reused locally for non-potable applications, it would decrease the amount of expensive freshwater that needs to be imported. Improved recovery of energy at treatment plants could also offset costs of transporting and treating water.

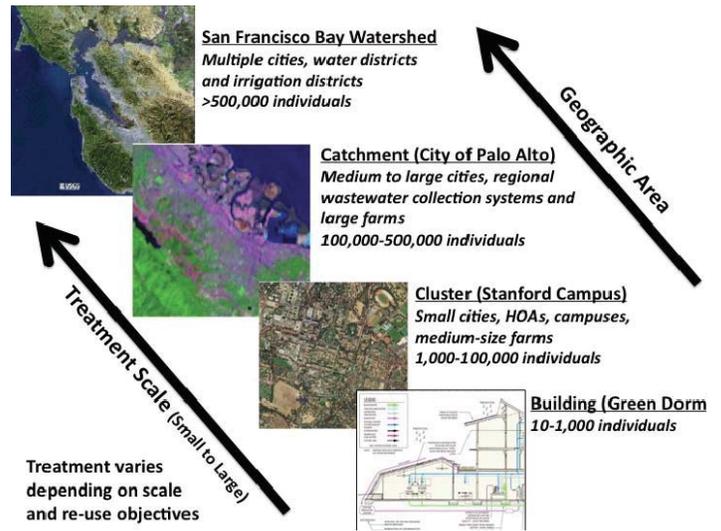
Our research group is exploring innovative techniques for recovering water and energy, offsetting demands for both. One goal is to create energy-neutral treatment systems that provide water suitable for reuse.

RECOVERY OF WATER

“Scalping” is a strategy of harvesting wastewater and treating it for non-potable reuse. The process consists of taking wastewater from a sewer, purifying the water to the required regulatory standards and then returning any residuals to the sewer. A key issue is how to cost-effectively recover wastewater at local and regional scales. Our team (Craig Criddle, professor of civil and environmental engineering; Frank Wolak, professor of economics; and other faculty, students and staff from Stanford) is collaborating with water utilities and the City of Palo Alto to address this issue. Our goal is to analyze the economics of wastewater recovery in centralized and distributed treatment facilities.

In conventional centralized systems, all stages of treatment take place at one location. Recovered resources (reclaimed water, energy, materials) must be transported to locations where the resources are used. Transport costs for reclaimed water can be high, because centralized facilities are typically located at the lowest elevation downhill - and often far - from water users. Distributed treatment systems can be more cost effective, because they serve specific localities and are closer to the point of demand.

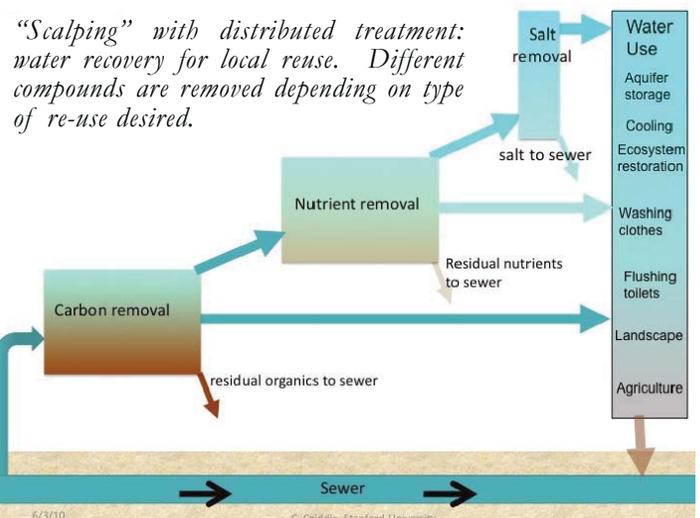
The degree of wastewater treatment required in distributed treatment systems depends on how the reclaimed water is used. Water treated to remove organic matter and pathogens may be suitable for irrigation and flushing toilets. Further treatment, with removal of nutrients and salt, may be necessary for other purposes, such as washing clothes, evaporative cooling, ecosystem restoration and aquifer recharge.



Geographic scale influences what resources can be economically recovered.

Reuse of scalped wastewater from a distributed treatment system may be more cost effective, depending on local circumstances. For example, residents who live on the Stanford campus currently pay \$4 to \$5 per 1,000 gallons of water, much of which is used to irrigate their properties. However, if reclaimed water were used for irrigation, a price as low as \$1 per 1,000 gallons is feasible.

Eventually, we envision that more water will be reused throughout the San Francisco Bay Area. By decreasing demand for imported water, the next generation of wastewater treatment systems will provide drought-resistant supplies of freshwater for the bay.



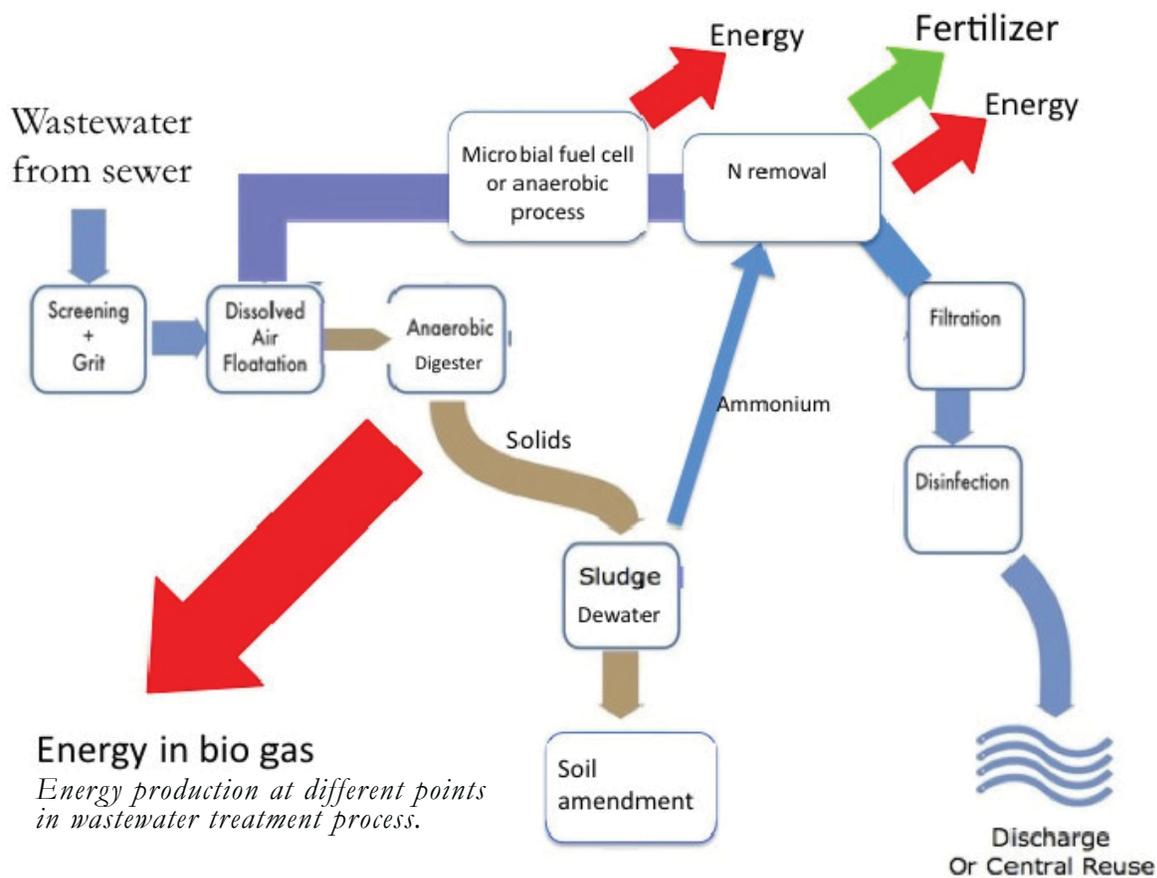
PRODUCING ENERGY

Conventional wastewater treatment is energy intensive. To address this challenge, we are pioneering two new ways of generating energy from organic compounds and nitrogen in wastewater.

In the first project, our team (Yi Cui, associate professor of materials science and engineering, and the Criddle group) has assessed the performance of a microbial fuel cell using an anode coated with carbon nanotubes. Microorganisms growing on the coated anode generate electricity by oxidizing organic matter. In recent experiments using a sugar-water solution, a microbial fuel cell with carbon nanotubes achieved 64 percent higher power density and 75 percent greater energy recovery. Future work will focus on producing electricity from wastewater.

Wastewater contains large amounts of nitrogen in the form of ammonia, a by-product of urea and protein degradation. Ammonia can kill fish and stimulate algal blooms in lakes, rivers and coastal areas, creating oxygen-depleted waters that are devoid of life. In our second project, we are investigating the conversion of ammonia into nitrous oxide as a way to recover energy from wastewater. Enhancing the formation of nitrous oxide seems counterintuitive, since it is such a powerful greenhouse gas. Brian Cantwell, professor of aeronautics and astronautics, has developed a rocket thruster that decomposes nitrous oxide into clean air and energy. The pairing of biotechnology and rocket science could result in a cost-effective strategy for nitrogen removal and energy production.

The California Energy Commission estimates that the energy used to transport and treat water used in California totals 6.5% of total electricity consumed in the state.



For more information on these projects go to <http://www.stanford.edu/group/evpilot>

GENETIC DIVERSITY

Wastewater contains another potentially valuable resource - genetic diversity. The Criddle group and Stanford environmental microbiologist Chris Francis are using DNA-based tools to study the microbial ecology of bioreactors at the Palo Alto municipal wastewater treatment plant. The diversity of microorganisms and genes brought to light through such tools could one day be valuable resources for biomedical and agricultural industries.

27,812 genes found in Palo Alto treatment plant bioreactor

THE FUTURE OF WASTEWATER RESOURCE RECOVERY

In the 21st century, wastewater treatment plants are likely to become resource recovery centers, where clean water, renewable energy, fertilizers and useful materials, such as biodegradable plastics, are recovered and used to meet society's needs. An important aspect of that collaboration is the **Program on Water in the West**, a Woods Institute/Bill Lane Center for the American West-sponsored research and policy initiative that will develop and demonstrate solutions to the major water challenges facing the western United States. We will focus on design and implementation of a non-potable reuse system for the Stanford campus and on energy-recovery strategies for centralized treatment systems. Knowledge gained from these projects can be used to scale-up technology for resource recovery.

Water reclamation and reutilization offer some of the most promising solutions for extracting optimal value from scarce water supplies. However, research is still needed on how to remove certain impurities, such as pharmaceuticals, for non-potable water reuse. Stanford researchers will focus on understanding the fate of these and other contaminants and address concerns about their impact on public health. This work will be part of an ongoing study of irrigation and groundwater recharge - two major non-potable uses - in Monterey County, California.

Over the long-term, the **Program on Water in the West** seeks to build upon the findings of the Monterey study to develop reliable metrics for water purity. Researchers plan to develop objective standards for a range of applications, including drinking water, habitat restoration and irrigation. Through continued development of technologies and economies of scale, wastewater recovery can be one solution for meeting society's future water needs.

For information on the Program on Water and the West and additional freshwater research:
<http://woods.stanford.edu/freshwater>



Dr. Kurt Rhoads, a former PhD student of Criddle's, at the Palo Alto wastewater treatment plant.

In May 2010, the Woods Institute hosted a dialogue on Resource Recovery from Wastewater. Participants discussed strategies on how systems for wastewater management and water reuse should be defined in the coming decades for the San Francisco Bay Area. Results from the dialogue are being used to inform planning efforts underway for 40 wastewater districts in greater Bay Area and Stanford wastewater research initiatives.

To learn more:
woods.stanford.edu/ideas/wastewater.html

Woods Institute for the Environment

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