**Saving energy.** Washington, D.C.'s wastewater treatment plant is making changes to become more energy efficient by converting sludge to methane.

CREDIT: PHOTO COURTESY OF TED COYLE, DC WATER

# WATER RECLAMATION GOING GREEN

**Wastewater treatment plants are revamping themselves as resource recovery operations, saving—and even producing—energy and polluting less in the process**

"There is no such thing as waste, only wasted resources," says Chris Peot, a civil engineer with DC Water, the utility that treats wastewater for the Washington, D.C., region. And with that as his motto, Peot has become a foot soldier in a revolution sweeping across the world's wastewater treatment plants.

Gone are the days when it was good enough to remove fecal matter, urine, and bacteria from wastewater and dump the resulting sludge into a landfill while pouring the cleansed water into the nearest river or ocean. Over the past few years, sewage treatment plants in industrialized nations have begun to reinvent themselves, their operators motivated by tighter regulations and economics to put the byproducts of treatment processes to good use. Aided by new technologies and old technologies put together in new ways, the facilities are becoming more efficient, cutting energy use and—in an increasing number of cases—producing more energy than they need to operate. And with the help of a common, but until recently underappreciated, bacterium, they are getting rid of pollutants for less cost (see sidebar). Treatment plants "are becoming the water resource factories of the future," says Amit Pramanik, an environmental engineer with the Water Environment Research Foundation in Alexandria, Virginia, a nonprofit organization that funds research in wastewater treatment.

## Trendsetter

Since engineers designed the first rudimentary systems for treating sewage with chemicals or sand filters in the late 1800s, specialized facilities for handling human waste have grown more common and complex. Now, there are more than 400,000 centralized sewage treatment plants around the world. Although good statistics are scarce, some experts estimate that altogether, wastewater treatment plants process more than 730 million cubic meters of wastewater daily (more than double the average flow of the Nile), and that they have helped dramatically improve water quality and reduce disease.

Video featuring a trip to the wastewater treatment plant.
**http://scim.ag/wastetx**

Increasingly, however, water-reclamation engineers are under pressure to do even more. One good place to see this evolution in action is the Blue Plains Advanced Wastewater Treatment Plant in Washington, D.C. The sprawling 75-year-old plant, which serves more than 2 million residents in the Washington, D.C., region and processes some 1.4 million cubic meters of wastewater daily, is the biggest of its kind in the world. And over the next decade, it will spend $1 billion implementing new approaches for coping with two major problems common to many plants: dealing with tainted sludge and removing nitrogen from the waste stream.

## Sludge for energy

Sludge—a goopy, mudlike mix of organic matter and dead microorganisms—is a byproduct created at almost every step of the treatment process. When sewage flows into Blue Plains and most other treatment plants, for example, it first goes through a settling stage called primary treatment that allows suspended solids to sink to the bottom of large tanks. Then, the water undergoes secondary treatment, in which microbes process food and fecal waste, creating more sludge. At many plants, the liquid effluent is returned to a local river or ocean after secondary treatment. But at Blue Plains and other plants that discharge into sensitive waterways, a third tertiary treatment is added to remove nitrogen and phosphorus compounds. All told, Blue Plains' three-step process produces some 1200 tons of sludge, or "biosolids," every day, enough to fill 50 tractor-trailers.

Historically, treatment plants simply dumped their sludge into landfills or treated it with lime and spread it on farm fields. Such practices have drawn criticism, however, because transporting sludge is expensive and dumping it wastes

## A BETTER WAY TO DENITRIFY WASTEWATER

Call it the case of the missing nitrogen. Forty years ago, wastewater treatment engineers noticed that a common process used to convert ammonia into nitrate sometimes failed to produce as much nitrate as expected. The nitrogen "must have gone somewhere," says Mark van Loosdrecht, an environmental engineer at the Delft University of Technology in the Netherlands. Fermentation engineers determined that the process was producing nitrogen gas, but nobody knew how.

Then, in the early 1990s, microbiologist Gijs Kuenen of Delft University and his colleagues discovered a new microbe in wastewater that helped solve the mystery—and turned existing dogma about ammonia's conversion to nitrogen compounds on its ear. Called anammox (for anaerobic ammonium oxidation), the microbe was converting ammonia into nitrogen gas in the absence of oxygen, a reaction previously thought impossible.

It took several years to convince the skeptics. One problem was that the bacterium—which is in the phylum *Planctomycetes*—grows slowly. It divides every 2 weeks, rather than in just half an hour like some bacteria; that means it can take months and sometimes years to get a culture up and running reliably in the laboratory. Another challenge was that the bacteria had never been found in the wild. Once researchers knew what to look for, however, they found it and its relatives living in many places—in oxygen-poor waters of the Black Sea, Lake Tanganyika, and off the coast of Namibia, for example.

Now, researchers consider anammox bacteria to be essential components of the global nitrogen cycle and estimate that they account for 50% of the world's nitrogen turnover. And they believe the microbes could dramatically improve methods of removing ammonia from wastewater streams at large municipal plants like the Blue Plains treatment facility in Washington, D.C. (see main text). "It's possibly going to be a game-changer in the U.S.," says Kartik Chandran, an environmental engineer at Columbia University.

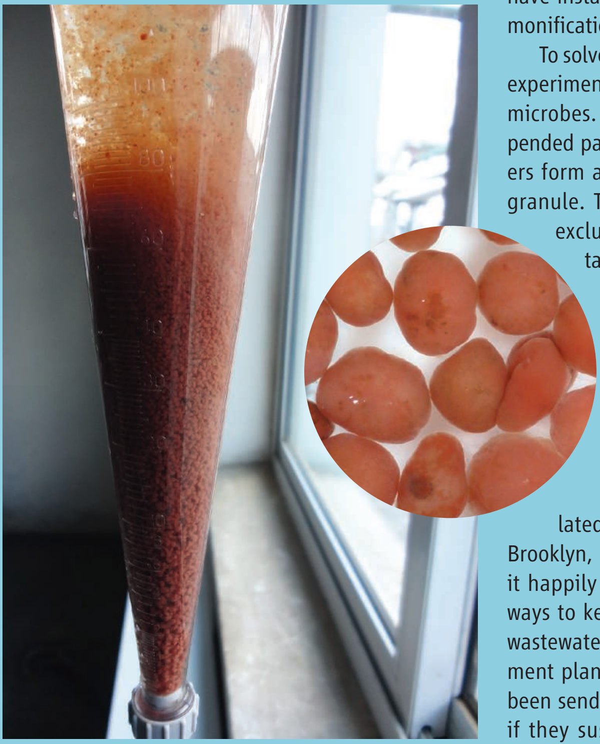
Harnessing anammox's potential, however, requires a mastery of microbial ecology. The microbe must be grown in conjunction with a second bacterium that converts ammonia to nitrite; anammox converts the nitrite into water and nitrogen gas. But to operate efficiently, the system must also exclude bacteria that make nitrate. That's proven relatively easy in industrial processes that operate at high temperatures and produce relatively warm, ammonia-rich wastewater streams; several companies have already commercialized anammox systems for use in such environments.

But excluding nitrate producers has proved harder in lower-temperature municipal wastewater treatment plants, where the concentration of ammonia can also be low, says van Loosdrecht. Under those conditions, it's been tricky to create a stable anammox community, although a number of plants have installed pilot anammox, also called deammonification, systems.

To solve that problem, van Loosdrecht has been experimenting with very slow-growing anammox microbes. Typically, dividing bacteria form suspended particles called floc. But these slow-growers form a much larger, denser particle called a granule. The larger granules somehow tend to exclude the nitrate-producing bacteria. To take advantage of that characteristic, he's engineering a reactor that retains larger granules but excludes smaller floc; he predicts the reactors will enable treatment plants to "do the same process [with] 25% of the space" used by current systems, and cut energy and other costs by about one-third.

Columbia's Chandran, who once isolated a strain of anammox bacteria from a Brooklyn, New York, treatment plant and now has it happily growing in his lab, is also perfecting ways to keep the microbe happy and healthy in wastewater treatment plants. Since 2010, treatment plants developing anammox systems have been sending him samples weekly, or more often if they suspect problems. Drawing on findings from his research, he tests the health of a plant's anammox community by sequencing the DNA that covers the microbes' 16*S* ribosomal subunits. Each type of microbe has a unique 16*S* fingerprint, and he can tell what kind and how many anammox organisms are present by the number of copies of the 16*S* genes. His team also looks at the expression of the microbe's key ammonia-fixing genes by monitoring messenger RNA. If Chandran sees 16*S* numbers and gene activity dropping, he knows the system needs tweaking—there might be too much oxygen, for example. If gene activity is dropping, but the population is stable, it's likely to be a transient phenomenon that should right itself, he says.

Such efforts are nudging deammonification into more widespread use. "There's no scientific limitation," van Loosdrecht says. "It's purely an engineering question." **–E.P.**



**Going red.** With this cone, engineers gauge the density of the clumps of red anammox bacteria (*inset*), a new way to denitrify wastewater.

a potential source of energy. In response to such concerns, Blue Plains is installing technologies that will enable it to convert one-half of its sludge into methane for use as fuel, with the remainder processed into a high-quality, pathogen-free material that could be used like compost in landscaping.

The heart of that new system is currently a construction site for a new building where biosolids will be subjected to high pressure and heat—150°C for 30 minutes. During this pasteurizing process, known as thermal hydrolysis, bacterial cells in the sludge will burst, making them more amenable to being eaten by methanogens, microbes that produce methane gas that can be used for fuel. The fuelmaking process will occur in huge new tanks called digesters, and the methane in turn will be used to fuel a turbine that will produce electricity and heat that will power the thermal hydrolysis system and net enough extra electricity to power 8000 homes. The remaining pasteurized biosolids, meanwhile, will be available for use as fertilizer. Adding thermal hydrolysis to the system saved about $200 million in digester construction costs because the process con-

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centrates the cells and less space is needed for methane conversion, Peot says. "Without that [amount of savings] we would not have been able to afford the digesters," he says.

**Waste streamlined**

A second Blue Plains project, being undertaken in conjunction with two other treatment plants in Austria and Virginia, is coming up with a better way to remove nitrogen compounds from wastewater. Ironically, part of the nitrogen problem is created by the methane-producing digesters; the microbes release a lot of ammonia into the wastewater stream. At first, Peot and his colleagues considered taking that water and putting it through the entire treatment process again to remove the ammonia. But that multistep process, which involves aerobic bacteria and methanol, is costly, in part because sustaining the bacteria requires aerating, or adding oxygen, to the water, which accounts for almost one-quarter of the Blue Plains plant's power use. The process also yields carbon dioxide, increasing the plant's carbon footprint.

Instead, they decided to use an increasingly popular bacterial process, called anammox or deammonification, to get rid of the nitrogen compounds (*Science*, 7 May 2010, p. 702). To start with, Blue Plains will use anammox on only the ammonia-rich water coming out of the digesters. But if the process works as advertised, Peot envisions using it for the entire waste stream. And "if we are successful," he says, Blue Plains will cut its power use for aeration by two-thirds and, together with other energy-saving measures, almost get by on just the power generated using its own methane. "Our goal is to investigate ways to become energy neutral or even energy positive," he says.

Other plants are finding that reaching that goal is possible. In 2004, for example, anammox combined with other measures enabled a plant in Strass, Austria, to become energy self-sufficient. A similar multifaceted approach is enabling the East Bay Municipal Utility District, which serves part of the greater San Francisco area in California, to use various types of organic waste, including chicken blood and cheese waste, to generate enough power to run its treatment process as well as 13,000 homes. As the East Bay's director of wastewater, David Williams, puts it, "We've turned wastes into commodities." It's an achievement Blue Plains and other waste-treatment plants hope to emulate. **–ELIZABETH PENNISI**

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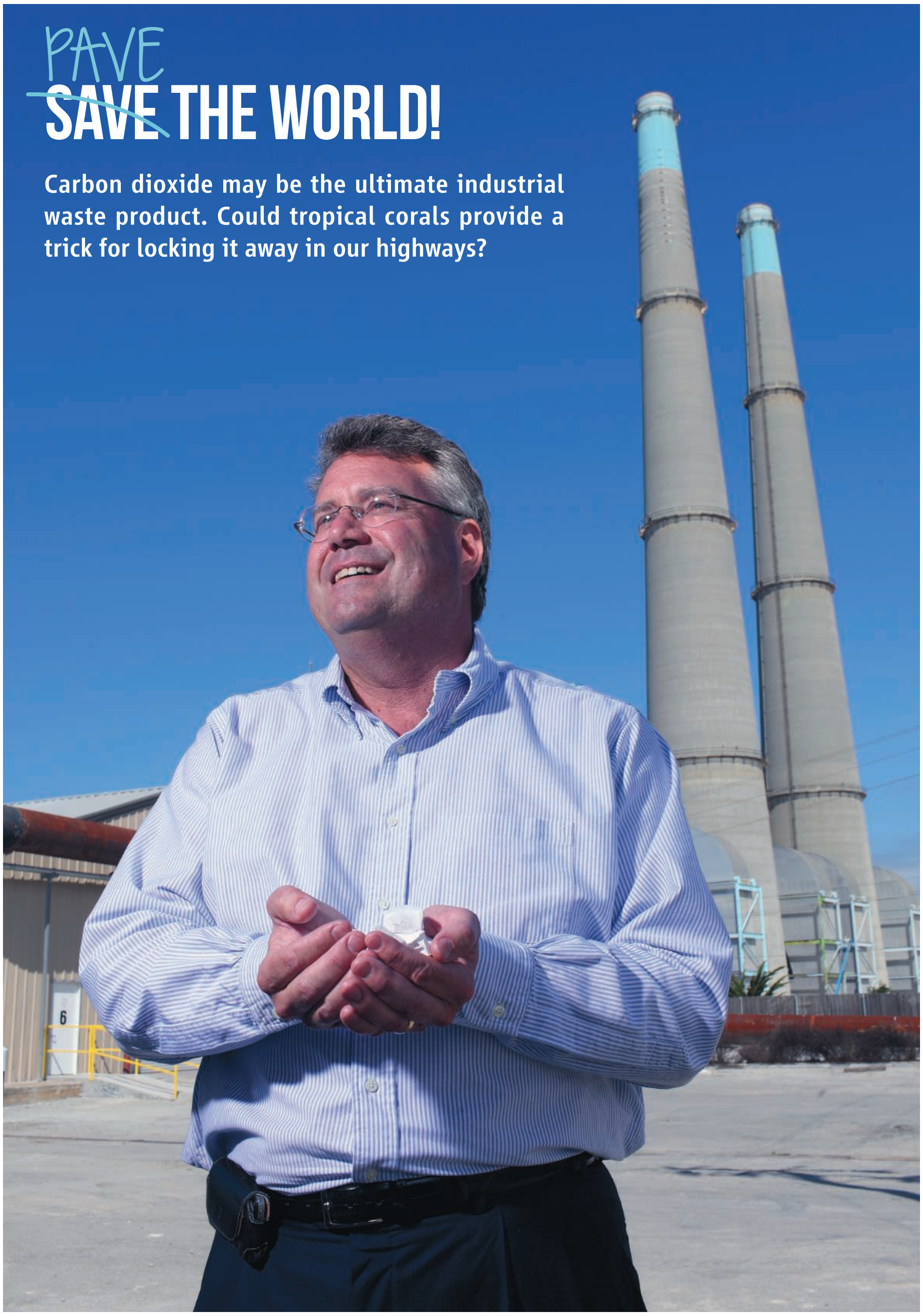
# PAVE ~~SAVE~~ THE WORLD!



CREDIT: PHOTO BY JOHN B. CAMETT/BONNIER CORPORATION/GETTY IMAGES

**Carbon dioxide may be the ultimate industrial waste product. Could tropical corals provide a trick for locking it away in our highways?**

Researchers who think about how best to stave off the worst impacts of climate change often have their favorite way of disposing of one prominent industrial waste product: carbon dioxide ($CO_2$). Some urge planting trees to soak up the greenhouse gas; others say capture it and pump it underground. For Brent Constantz, the solution is pavement, and lots of it.

Drawing on the chemistry that corals use to build their rock-hard shells, the California entrepreneur and biomineralization expert hopes to combine simple seawater with $CO_2$ to manufacture cement and concrete that would devour vast amounts of the greenhouse gas. "I honestly don't think we can address the carbon problem any other way," says Constantz, a consulting associate professor at Stanford University in Palo Alto, California.

It's an audacious idea he's already tried to commercialize once—with mixed results and plenty of criticism. And his peers are divided on the prospects for seawater cement. "Brent has been too optimistic about these kinds of processes in the past and too glib about the challenges," says Roger

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