Inner Workings: Finding precious metals in unlikely places

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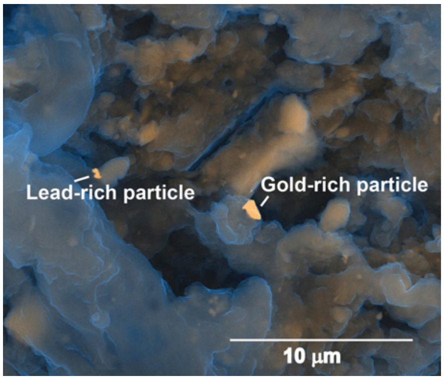
Making a valuable, unexpected discovery while exploring an unrelated hypothesis is a classic theme in the history of science. But literally striking gold? And in sewage, of all places? That's what actually happened to Paul Westerhoff, a professor in the School of Sustainable Engineering and The Built Environment at Arizona State University (ASU).

Westerhoff heads up an Environmental Protection Agency-funded center to study the threat posed by engineered nanomaterials. Tiny particles of substances like titanium dioxide are used in thousands of products, such as paints, fabrics, cosmetics, and sunscreens. Such items are routinely flushed down toilets and deposited into rivers and streams; Westerhoff and his colleagues wanted to know their potential effects on people and the environment.

The best way to measure the flow of nanomaterials into the environment, Westerhoff reasoned, would be to examine sewage sludge. There already was good precedent. More than a decade of research by engineering professor Rolf Halden, director of the Center for Environmental Security at ASU's Biodesign Institute, has shown that the stuff piling up in waste treatment plants is a sensitive indicator of all of the chemicals society uses. "Wastewater moving through the city is like blood in the body," says Halden, who used to design wastewater treatment systems. It captures everything dumped into sewers by households, industrial plants, and runoff. Initially, many scientists thought that most chemicals were degraded during wastewater treatment because they weren't detected in the effluent exiting the plant. "When I started looking for organic chemicals in sewage sludge, people were shaking their heads," Halden recalls. But he found more than 150 chemicals in sewage, from flame-retardants to antibacterial substances. "Sewage sludge is a very inexpensive place to monitor toxic exposures in humans," he says.

Westerhoff wanted to build on Halden's findings by looking for nanomaterials. He didn't have to look far to find sludge. Over the past 10 years, Halden has collected more than 30,000 samples that shed light on levels of toxins in humans, including hundreds of sludges from wastewater treatment plants across the nation. Those samples are housed in his Human Health Observatory at ASU, which includes the National Sewage Sludge Repository, a dozen freezers stocked to the brim with sludge, with more samples arriving "all the time," Halden says. Westerhoff and his colleagues put the samples under their transmission election microscope (TEM). Sure enough, they saw titanium from nanoparticles. But they also spotted gold.

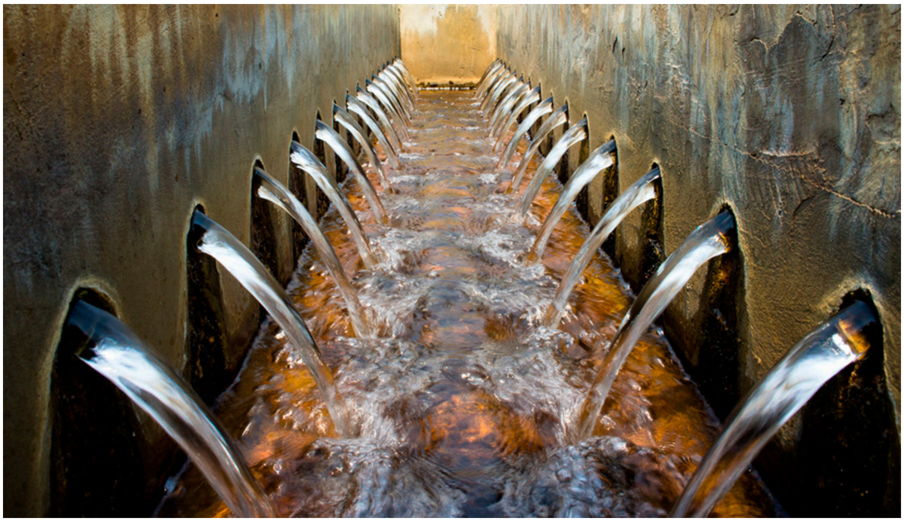


A close-up view of the minute quantities of gold found in municipal biosolids. Image courtesy of Heather Lowers (USGS Denver Microbeam Laboratory).

It can't be really there, Westerhoff thought at first; it must be the result of contamination from the laboratory. After all, scientists often sputter gold onto electron microscopy samples to enhance the image. So to eliminate the possibility of contamination, the team took more sewage, digested it with acid to extract the metals, and measured their concentrations.

Yes, the gold was there. So were platinum, silver, and other valuable metals. And the concentrations of precious metals were high enough—with gold at about 1 part per million and silver 20 to more than 100-times higher, depending on the sample—that every ton of sewage would contain nearly $300 worth, or $13 million per year in a city of a million people, the researchers calculated. "Everyone got fascinated by the theoretical amount of wealth in our sewage," says Halden. The group published their findings in *Environmental Science & Technology* and received widespread media attention soon after (1).

Even before Westerhoff's group published its findings, their conclusion was confirmed independently by another research group, led



Two groups of researchers found that sewage contains precious metals potentially worth millions. Image courtesy of shutterstock/gameanna.

The National Sewage Sludge Repository at Arizona State University keeps hundreds of municipal sewage sludge samples in freezers at −20 °C. Reproduced from ref. 3, with permission from Springer Science and Business Media.

by Kathleen Smith at the US Geological Survey, who reported their results at an American Chemical Society meeting in late March (2). Smith has been studying the metal content of the waste society throws away, trying to figure out where it comes from and what might be worth recovering. She decided to study municipal wastewater treatment sludge from a variety of cities, to learn if metal concentrations varied between, say, a semirural mining area's treatment plant or one in a big urban area. Previous work had shown that sewage typically harbors regulated metals like lead, copper, and zinc. Smith found those metals using standard techniques, such as neutron activation analysis, which bombards samples with neutrons and detects the resulting signals to directly measure concentrations (unlike Westerhoff's electron microscope technique). But like Westerhoff, Smith was surprised to find similarly high concentrations of gold: about one part per million. Her reaction? "We thought 'Wow, cool,'" Smith recalls. "Let's re-run it and make sure we got that right."

It's not clear yet where the gold is coming from. "We've been scratching our heads," says Smith. Westerhoff wonders about gold faucets, teeth fillings, or gold leaf on fancy pastries, whereas Halden suspects that the main sources may be in industry, where gold is used in making electronics and other products.

It's also not clear if it will be possible to actually make money mining precious metals from excrement. Westerhoff, though, is already finding interest from a foundation and companies in pursuing the approach. The foundation is interested in boosting recycling and reuse, and private companies are interested in selling technologies related to retrieval. Wastewater utilities are intrigued by the prospect of "mining" piles of sludge they have accumulated over the years, says Westerhoff.

Extracting both valuable metals and fertilizers, like phosphorus, from sludge is an idea whose time is coming, adds Halden. Not only is phosphorus in particular a prime environmental culprit, causing harmful algal blooms in rivers, lakes, and estuaries, but the element is also increasingly scarce. "We cannot keep extracting all our precious metals in the way we're doing now," he says. "We have to close the loop." Westerhoff envisions creating a compact waste processor that can kill pathogens, destroy the organic pollutants, and snatch out both the valuable metals and the heavy metals like lead, thus solving both big environmental problems and making a buck.

However, ironically, Westerhoff's discovery bordered on sewage serendipity: statistically, he probably should never have struck gold at all. "All the stories in the press missed the most interesting point," he says. Once Westerhoff's group measured the concentration of gold, they were able to calculate the odds of actually seeing a gold particle in their first TEM grid. Those odds were vanishingly small. "The story behind the story is that we should have had to look at 1,000 TEM grids to find that gold particle," says Westerhoff. "We just got lucky."

1 Westerhoff P, et al. (2015) Characterization, recovery opportunities, and valuation of metals in municipal sludges from U.S. wastewater treatment plants nationwide. *Environ Sci Technol*, 10.1021/es505329q.

2 American Chemical Society (2015) Sewage—yes, poop—could be a source of valuable metals and critical elements. Available at www.eurekalert.org/pub_releases/2015-03/acs-s-y022015.php. Accessed June 26, 2015.

3 Venkatesan AK, et al. (2015) United States National Sewage Sludge Repository at Arizona State University—a new resource and research tool for environmental scientists, engineers, and epidemiologists. *Environ Sci Pollut Res* 22(3):1577–1586.