Urine diversion shows multiple environmental benefits when used at city scale

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Diverting urine away from municipal wastewater treatment plants and recycling the nutrient-rich liquid to make crop fertilizer would result in multiple environmental benefits when used at city scale, according to a new University of Michigan-led study.

The study, published online Dec. 15 in the journal *Environmental Science & Technology*, modeled large-scale, centralized urine-diversion and fertilizer-processing systems—none of which currently exist—and compared their expected environmental impacts to conventional wastewater treatment and fertilizer production methods.

The researchers found that urine diversion and recycling led to significant reductions in greenhouse gas emissions, energy use, freshwater consumption and the potential to fuel algal blooms in lakes and other water bodies. The reductions ranged from 26% to 64%, depending on the impact category.

"Urine diversion consistently had lower environmental impacts than conventional systems," said lead author Stephen Hilton, who conducted the study for his master's thesis at U-M's School for Environment and Sustainability.

"Our analyses clearly indicate that the well-defined benefits—reduced wastewater management requirements and avoided synthetic fertilizer production—exceed the environmental impacts of urine collection, processing and transport, suggesting that further efforts to develop such systems are warranted."

Urine contains the essential nutrients nitrogen, phosphorus and potassium and has been used as a crop fertilizer for thousands of years. In recent years, urine recycling has been studied as a way to produce renewable fertilizers while reducing the amount of energy and chemicals needed to treat wastewater.

While no city-scale urine-diversion and recycling systems exist, several small-scale demonstration projects are underway, including one at U-M and a Vermont project led by the Rich Earth Institute. Hilton used data from both projects to model the likely environmental impacts of city-scale urine diversion and recycling.

Wastewater treatment was a major focus of the study, and data from treatment plants in Michigan, Vermont and Virginia were used in the analysis. The Virginia plant is located in the Chesapeake Bay region and served as an example of treatment plants with strict requirements for nitrogen and phosphorus removal.

Using a technique called life-cycle assessment, which provides a comprehensive evaluation of multiple environmental impacts, Hilton and his colleagues compared the performance of large-scale, centralized urine-diversion and fertilizer-production facilities to conventional wastewater treatment plants and the production of synthetic fertilizers using non-renewable resources.

Urine diversion and recycling was the clear winner in most categories and in some cases eliminated the need for certain wastewater-treatment chemicals. On the downside, one method for making urine-derived fertilizer led to consistent increases in acidification.

A few previous life-cycle assessments have compared the environmental impacts of urine recycling to conventional systems. But the new U-M study is the first to include detailed modeling of wastewater treatment processes, allowing the researchers to compare the amount of energy and chemicals used in each method.

"This is the first in-depth analysis of the environmental performance and benefits of large-scale urine recycling relative to conventional wastewater treatment and fertilizer production," said Greg Keoleian, senior author of the ES&T paper and director of the Center for

Sustainable Systems at the U-M School for Environment and Sustainability. He also chaired Hilton's thesis committee.

About half of the world's food supply depends on synthetic fertilizers produced from nonrenewable resources. Phosphate rock is mined and processed to make phosphate fertilizer. The production of nitrogen fertilizer is an energy-intensive process that uses natural gas and is responsible for 1.2% of world energy use and associated greenhouse gas emissions.

At the same time, water and wastewater systems consume 2% of U.S. electricity, with nutrient removal being one of the most energy-intensive processes.

Diversion of urine to recover and recycle nitrogen and phosphorus has been advocated as a way to improve the sustainability of both water management and food production. It has the potential to reduce the amount of energy and chemicals needed to treat wastewater while decreasing the flow of nutrients that fuel harmful algal blooms in lakes.

However, large-scale diversion and recycling would require systems to collect and transport urine, process it into fertilizer, then ship the end product to customers. Each of those steps has environmental impacts.

In 2016, U-M researchers were awarded a $3 million grant from the National Science Foundation to study the potential of converting human urine into safe crop fertilizer. The project is led by Nancy Love and Krista Wiggington of the U-M Department of Civil and Environmental Engineering and involves testing advanced urine-treatment methods and investigating attitudes people hold about the use of urine-derived fertilizers. Love is also a co-author of the new *Environmental Science & Technology* paper.

As part of the NSF-funded effort, urine-diverting demonstration toilets were installed on U-M's North Campus, along with a lab where the urine is converted to fertilizer. Hilton, who was a dual-degree master's student at the U-M School for Environment and Sustainability and the Department of Civil and Environmental Engineering, used data from the project to help model a large-scale system that diverts urine to make fertilizer.

"These new findings are encouraging because they demonstrate the potential environmental benefits of large-scale urine-diversion and recycling systems, suggesting that we're on the right track and should continue to develop these technologies," said study co-author Glen Daigger, a U-M professor of civil and environmental engineering and a member of Hilton's thesis committee.

More information: Stephen P. Hilton et al. Life Cycle Assessment of Urine Diversion and Conversion to Fertilizer Products at the City Scale, *Environmental Science & Technology* (2020). DOI: 10.1021/acs.est.0c04195

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