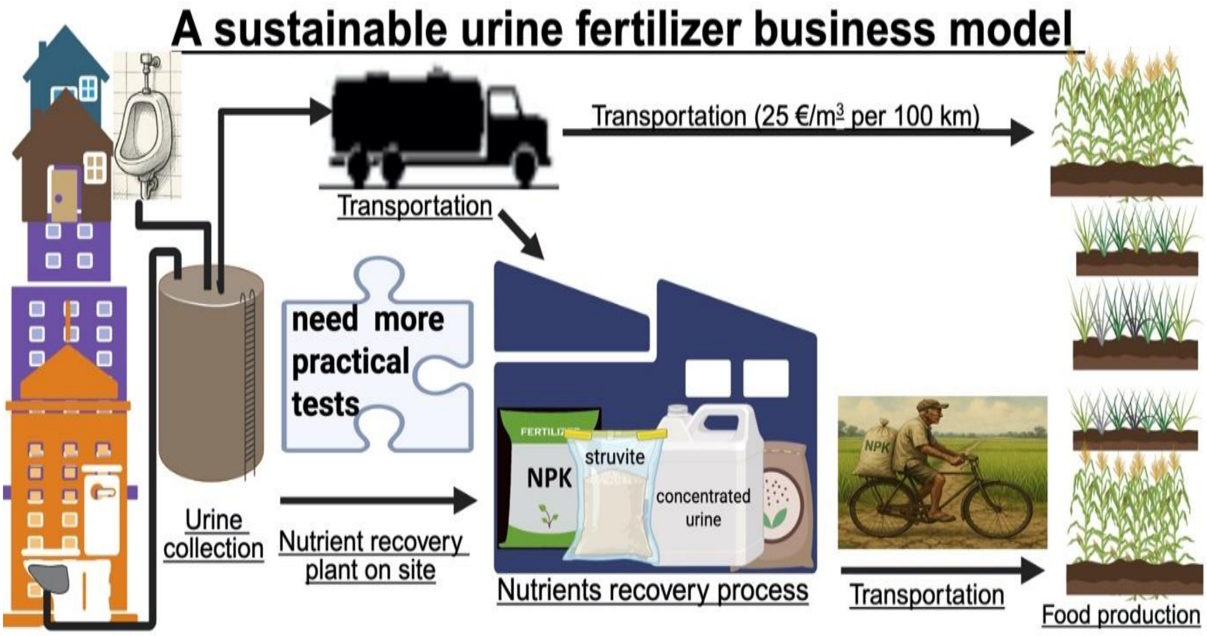
Human urine fertilizer business – constraints and possibilities

[1,2] Surendra K Pradhan, [1]Helvi Heinonen-Tanski, [3]Alisa Puga Keesey
[1]Department of Environmental and Biological Sciences, University of Eastern Finland
[2]Department of Agricultural Sciences, University of Helsinki
[3]Department of Anthropology, University of California, Santa Cruz

Background.

Human urine is rich in essential plant nutrients nitrogen (N), phosphorus (P), and potassium (K). One person produces about 500 L of urine per year, corresponding to an estimated 2 kg of N, 0.3 kg of P, and 1 kg of K. These nutrients are sufficient to fertilize 0.4 hectares of land, which can produce some 270 kg of rice or 180 kg of wheat, or 190 kg of maize. To capture these nutrients, various types of urine-diverting toilets (UDTs) and urinals have been developed. Urine recycling provides multiple environmental and social benefits, including nutrient recovery, reduced water pollution, improved sanitation, and enhanced food security. Despite these advantages, large-scale urine collection and the use of urine-derived fertilizer remain uncommon globally. Key barriers include insufficient infrastructure for large-scale urine collection, technological limitations, economic uncertainties, and social perceptions.



Large-scale urine collection, constraints, and motivations –

A key challenge for urine-based nutrient recovery business might be reliable large-volume urine collection. Most of the urine collection projects are small to medium scale, which limits the feasibility of larger nutrient recovery plants. For example, struvite production is used in commercial-scale wastewater treatment plants, and still, the urine-to-struvite business remain uncommon.

Many households in developed countries use UDT and urine-diverting dry toilet (UDDT), especially in areas without sewage networks, such as rural areas, islands, and summer cottages. However, collecting urine from scattered households on a small scale is often not economically feasible for urine to fertilizer business. There is an ongoing discussion about installing UDTs in public places. In principle, urine can be easily collected from men's urinals in public places, such as schools, colleges, airports, ships, and malls. Although these urinals often separate urine at the source, the collected urine eventually leads into the sewage network, except for a few pilot projects. Changing existing sanitary infrastructure to include UDT and installing the urine collection tank are expensive. As a result, large-scale urine collection is unlikely to expand as long as there is a high demand for urine as a fertilizer resource.

Local governments need policies that subsidize housing companies to install urine collection facilities and provide urine tank emptying services. Such incentives are essential to motivate households and property owners to adopt separate urine collection.

Urban population is increasing, and cities are becoming the hotspots for large-scale urine collection. Collecting urine from individual households or apartment buildings is technically feasible, but replacing existing conventional toilets with UDTs in apartment complexes is expensive. Developing add-on urinals or urinal-diversion modules compatible with conventional toilets could significantly increase adaptation to urine collection without requiring full toilet replacement.

In many developing countries, cities are densely populated, and most households rely on onsite sanitation systems, mainly septic tanks. Regularly emptying septic tanks can be costly- about € 90 for 0.1-3 m^3 in Finland, $ 62/household in Kenya, and $ 13/household in Bangladesh. However, most septic tanks in developing countries are not fully sealed: they often have an unsealed bottom that allows liquid to seep into the soil, and an overflow outlet discharges excess liquid into drain. Under this condition, separating urine does not significantly increase the lifespan of the septic tank, reducing the motivation for households to collect urine separately. Additionally, the release of untreated septic effluent into the environment poses serious public health risks. Therefore, the use of fully water-sealed septic tanks should be mandated in national sanitation policies, which might eventually encourage urine separation.

Appropriate technology for urine to fertilizer production.

Several techniques have been developed to recycle nutrients from urine. An easy method is to collect urine at the household level or small community scale and use it in back yard, or a nearby garden. This practice is going on a very small scale and is usually driven by individual initiatives or community-led programs, with minimal challenges due to its voluntary nature.

Dehydration and concentration of urine are studied broadly to reduce the volume and produce concentrated fertilizer from urine. These ideas are good, but the end product might contain pharmaceutical residues and pathogens, especially when urine is collected from public toilets. On the other hand, dehydration of a large volume of urine, i.e., 95% of water contained in urine, might be energy-intensive, especially dehydration of diluted urine. Furthermore, the urine drying process also uses ash and other substrates to recover nutrients, which might reduce the fertilizer value due to ammonia losses, as well as increase the operation costs. Struvite production from urine is another promising technique to recover nutrients from urine, but it primarily targets P recovery. However, dried urine, concentrated urine, and struvite are new products for farmers and are struggling for market. It is important to develop new techniques based on targeting to produce market-driven products, such as mineral fertilizer from urine.

Nutrient extraction from urine and production of mineral fertilizer is another potential technique for urine management. Ammonia stripping using aeration and membrane separations is the main principle used for this technique. This process produces ammonium sulfate and calcium phosphate from urine, which are chemically similar to typical conventional mineral fertilizers and can be used in the same supply chain for promising revenue generation. But these processes typically do not recover K from urine. Integrating K recovery into N striping techniques would make these techniques a complete nutrient recovery process from urine.

Despite significant progress in recent years, most urine-to-fertilizer techniques remain at laboratory or pilot scales. To move towards commercialization, it is important to develop a minimum viable product (MVP)- scale pilot plant and evaluate its performance under real-life operational conditions. When developing technology for business, the key factors to consider are: (1) Develop a simple, low-tech process for small, medium and large-scale business, and (2) Develop a semicontinuous to a complete automation plant.

Urine-to-fertilizer economy

Several studies have shown that recycling human urine as it is collected is not economically feasible at medium or large-scale operations due to the high transportation costs. Transportation remains one of the most expensive components of urine management, especially when collection points are far from treatment facilities.

Demonstrating strong feasibility results and investment guarantees from local authorities are critical to attracting entrepreneurs. On its own, the urine-to-fertilizer business might not always be profitable, but integrating it with other waste recycling businesses can create synergetic revenue streams. Combined business models can reduce operational costs, improve market reach, and enhance overall economic sustainability.

From an economic perspective, 10 m^3 of urine contains about 40 kg of nitrogen which is equivalent to 80 kg of N mineral fertilizer, worth about $ 40 (the current price of N fertilizer is 500 $/ton). Processing 10 m^3 of urine per day generate annual revenue of $ 14,600. This revenue level is comparable to a modest annual income of about 8 people ($ 1790/person/year) in Sub-Saharan Africa (SSA) highlights the potential for urine-to-fertilizer businesses to support local livelihoods. It is therefore evident that even a small- to medium-scale urine-to-fertilizer technique can generate enough revenue to support 2-5 workers. Such a process typically produces 250 kg of ammonium sulfate mineral fertilizer from 10m^3 of urine, demonstrating that nutrient recovery from urine can serve both economic and social development goals.

Economic calculation of some urine to fertilizer studies for 10m^3 urine.

Urine to fertilizer processes	Treatment cost €/10 m^3	Profit €/10 m^3	Profit €/year	Literature
Aeration		22.50	8210	doi/10.1021/acs.est.6b05402
Membrane		15	5480	doi.org/10.1016/j.jenvman.2019.06.046
concentration	980			Vuna
Alkaline drying	15 000*			A Case Study in Finland
Struvite		8	2920	Eawag

*0.11 Euros/kWh, 21-76 Mj/kg of urine

Motivation for the urine to food security.

Fertilizer demand is especially high in tropical regions, where farmers can grow 3-4 crops in a year, and soil fertility is a growing concern. Many Sub-Saharan African (SSA) countries use less than 23 kg/ha fertilizer, compared to more than 120 kg/ha in developed countries. This fertilizer gap is key factor of food insecurity in the region. Given SSA'st dependency on imported fertilizers, and the high cost and limited availability of mineral fertilizer, policymakers must prioritize the potential of linking United Nations Sustainability Development Goal (SDG6) for improved sanitation for all to fertilizer production. By bridging the WASH and food security agendas through ecological sanitation (EcoSan), policymakers can unlock the potential of urine as a source of mineral fertilizer- paving the way for a viable circular economy and embedded urine recycling into national fertilizer and sanitation policy.

Possible implementation model.

The NGOs and INGOs working in the humanitarian sector invest substantial funds in the WASH (water, sanitation and hygiene) sector. There is a great untapped potential for collaboration between WASH organizations, technology developers, entrepreneurs, and researchers to pilot recently developed urine-to-fertilizer technologies in real-life settings. Such collaboration and improved user-interface would help evaluate and refine such technology, ensuring it becomes a practical, profitable, or even self-sustaining urine-to-fertilizer business. A successful demonstration would attract entrepreneurs who can deliver high-quality sanitation services at low cost. As a result, even relatively small funds could support improved sanitation for a large population while also strengthening local food security through the production of affordable, high-quality mineral fertilizer locally.

Reference: -

- Eawag - Swiss Federal Institute of Aquatic Science and Technology - Eawag
- Nutrient Recovery Solutions | Ostara
- **Pradhan, S.K**., https://doi.org/10.34416/sanitation.00061
- **Pradhan, S.K**., DOI: 10.1021/acs.est.6b05402
- Simha, P., https://doi.org/10.3389/fenvs.2020.619901
- Tettey-Lowor, Frederick 2008: MSc. Thesis. Wageningen University, The Netherlands. 121pp.