fact sheet

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Eawag
Swiss Federal Institute of Aquatic Science and Technology

Urine source separation

Wastewater contains valuable resources. However, because existing wastewater management systems have been designed primarily for pollution control and hygiene, the recovery of resources from wastewater is cumbersome. Source separation is an alternative system which can facilitate resource recovery [13]: the waste streams urine, faeces and greywater are collected separately and treated according to their properties.

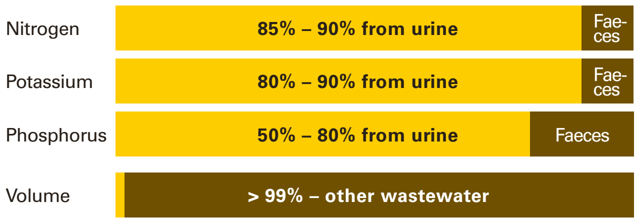
Most of the nutrients in wastewater are excreted in urine: 85–90% of nitrogen, 50–80% of phosphorus and 80–90% of potassium [14]. These three nutrients are also the main components of fertilizers. Urine additionally contains many other nutrients important for plant growth, such as sulphur. However, urine accounts for less than 1% of total wastewater volume (Figure). Recycling of nutrients from urine to agriculture is therefore an obvious goal of source separation.

To prevent dilution with flushing water, alternatives to conventional toilets and sewers are required for transport, or urine needs to be treated directly on-site. Source separation could be implemented particularly in cities and regions where sewers do not exist or are not appropriate due to low water availability. This is the case for most fast-growing cities in low- and middle-income countries.

Applications of urine source separation

Separate treatment of urine offers many advantages, for example:

- Urine is a sustainable source of nutrients. Producing a fertilizer from urine helps to close the nutrient cycle between sanitation and agriculture [7].



Proportion of nitrogen, potassium and phosphorus contained in urine, and urine as a proportion of total wastewater volume

- In many regions of the world, urine source separation is used in dry on-site sanitation systems to facilitate the drying of faeces [8]. Faeces contain organic substances, which can be used for energy production.
- In high-income countries, urine separation has been proposed as a way of increasing the efficiency of centralized wastewater treatment plants [27]. Nitrogen removal is an energy-intensive and space-consuming process. With source separation, less nitrogen would have to be removed in wastewater treatment plants.

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- It has also been proposed as a method for reducing ammonia concentrations in the River Seine, where water levels may decrease as a result of climate change [26].
- Another application is on-site production of nitrate from urine so as to prevent sulphate reduction and concomitant sewer corrosion [19].
- On-site urine treatment combined with nutrient recovery is also being investigated for life-support systems for long space missions [4].

Challenges

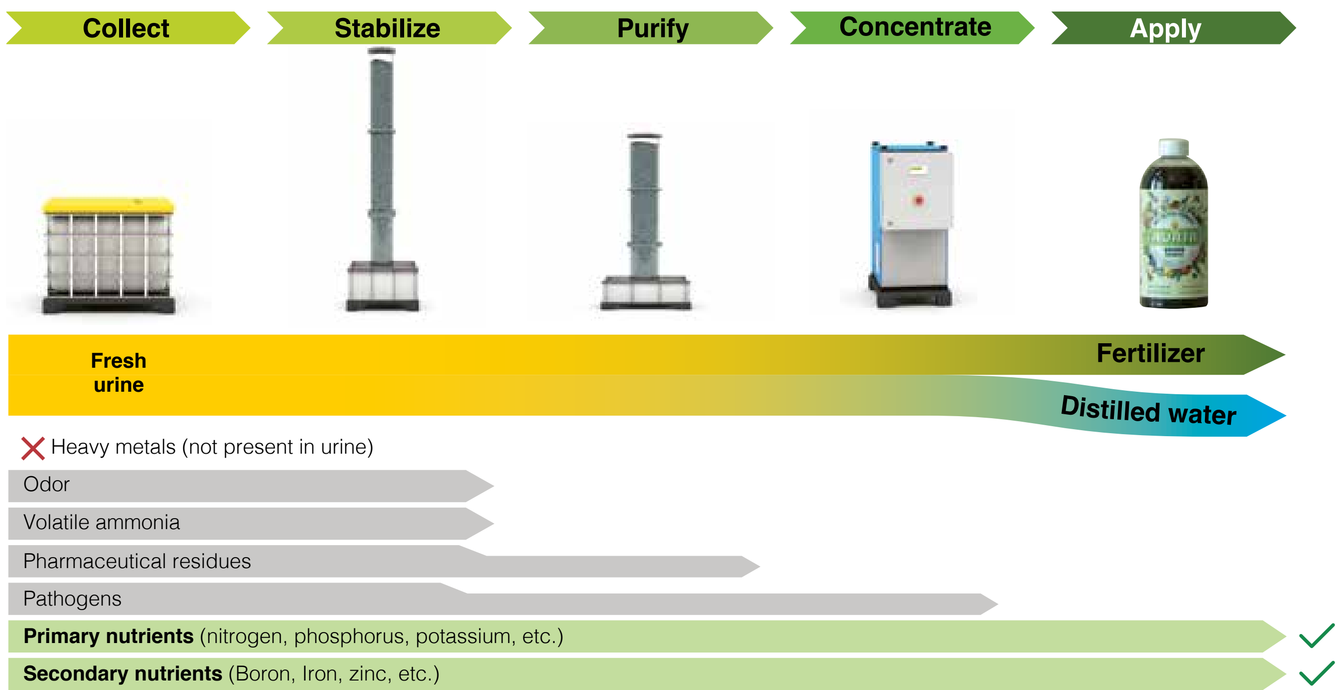
- **Cross-contamination:** Directly after excretion, urine contains hardly any microbes. However, microbes from the environment and from faeces will settle in urine when it is collected in urine-diverting toilets or urinals. This cross-contamination and the related microbial processes mean that source-separated urine differs markedly from fresh urine collected in sterile bottles [25]. Source-separated urine may contain pathogens, so it needs to be sanitized before use [10].
- **Nitrogen loss:** Most of the nitrogen in urine is present as urea, which is degraded to ammonia and carbon dioxide by the enzyme urease. This process leads to an increase in pH from neutral to about 9 [24]. After the degradation of urea, nearly all the nitrogen is present as ammonia, with about a third in the form of volatile free ammonia (NH_3). Experience has shown that, in an inadequate domestic urine diverting system, approximately half of the ammonia can be lost [22]. This loss reduces the value of urine as a fertilizer and contributes to environmental pollution. Extensive air contact must therefore be limited during storage and spreading of unstabilized urine.
- **Pipe and trap blockage:** The pH increase caused by urea degradation has important consequences for toilets, traps and pipes [24]. Calcium phosphate minerals and struvite precipitate at high pH values. In addition, calcite can develop if urine is flushed with high volumes of hard water. Precipitates, organic compounds and biofilm can accumulate in traps and pipes, causing blockages. Such blockages can be removed mechanically or by regular flushing with an acid (e.g. 10% citric acid) [16].
- **Odour:** Urea is not the only compound which is degraded in real-world urine-diverting systems. Other organic substances are degraded by fermenting bacteria [23]. The pungent odour of stale urine is the result of these fermentation processes.
- **Pharmaceuticals:** Urine contains most of the pharmaceuticals excreted from the human body: about two thirds of the active ingredients of pharmaceuticals are excreted in urine [17]. Pharmaceutical residues are of particular importance in areas where large amounts of drugs are consumed (e.g. in South Africa due to the HIV epidemic) [2]. Urine separation can help to prevent environmental pollution with pharmaceuticals, since separate collection and treatment allows specific removal of pharmaceutical residues.

Opportunities

Given the high nutrient content, most treatment processes aim to convert urine into a fertilizer. These treatment processes must ensure that pollution of the environment and risks to public health are avoided.

Direct usage without stabilization: Before spreading, six-month storage is recommended for pathogen inactivation [10]. Other authors have described gentle spreading techniques to prevent high ammonia losses and malodour [12]. This approach is limited to areas close to agricultural fields, as it requires large storage and transport capacities. In addition, malodour could still be an issue, even if gentle spreading techniques are applied, and pharmaceuticals could enter the environment.

Specific nutrient recovery: Processes for the recovery of specific nutrients usually require an additional treatment step for disinfection, and removal of organic compounds or micro-



The Vuna urine recycling process in detail: unlike artificial fertilizers, the urine-based fertilizer Aurin is free of heavy metals.

pollutants, if the effluent is not discharged to a wastewater treatment plant.

- **Phosphorus:** The process which has been most extensively investigated is phosphorus precipitation as struvite [6]. Another process for phosphorus recovery is the addition of calcium hydroxide to fresh urine [21]. producing solid calcium phosphate, which has a high nutrient value [18]. Since – to prevent calcite formation – calcium hydroxide should only be added to fresh urine, it is limited to applications where urine can be treated close to the toilet. This process has been demonstrated by Eawag researchers in the Autarky project (www.autarky.ch). where nutrients are recovered within the toilet.
- **Nitrogen:** Ammonia can be recovered from stored urine by stripping. This process can be combined with upstream struvite precipitation [1]

Processes for recovery of all nutrients:

- **Combination of electrodialysis, microfiltration and ozonation:** This process permits the concentration of most nutrients, with concomitant removal of pharmaceuticals and microorganisms [20].
- **Treatment chain with nitrification and distillation:** This process, developed at Eawag [7] is being commercialized by the spin-off Vuna GmbH. The product of the Vuna process (cf. graphic) is Aurin, a fertilizer licensed in Switzerland. Aurin production involves three main process steps. First, biological treatment prevents ammonia volatilization and malodour. The product is a solution containing ammonium nitrate and a low content of organic compounds. Second, pharmaceutical compounds are removed by activated carbon adsorption. Third, the solution is concentrated and pasteurized by distillation. The final product is a 10- to 20-fold concentrated liquid with a high nutrient value [3]. In the Water Hub of the NEST building (www.eawag.ch/waterhub) Eawag researchers are seeking to improve the urine treatment process, and Aurin fertilizer is produced. Biological treatment is challenging due to the high ammonia content and high pH of urine. Sophisticated pH control is required. As an alternative to biological treat ment, ammonia volatilization could also be prevented by the addition of acid; however, if acid is added to stale urine, large volumes are needed [5].

Other applications for source-separated urine

- **Bricks:** Urine has been proposed as a resource for brick manufacture. If stabilized urine is mixed with sand and urease-producing bacteria, calcium carbonate can be pro duced from urea. The calcium carbonate cements any sand particles together, forming sustainable biosolids [9].
- **Energy production:** Urine has also been proposed as a resource for energy production, e.g. for microbial electrochemical technologies [15]. However, due to the relatively low content of chemical energy, it is only suitable for low-power applications such as lighting [11].

How can urine best be collected?

If urine is to be separately treated, it needs to be separately drained and collected – as far as possible, without being contaminated by faeces or diluted with (flushing) water. For this purpose, the following "user interfaces" are currently available:

- **Waterless urinals:** Waterless urinals with various odour control systems are already commercially available and are being used increasingly widely – particularly at festivals and in sports facilities or restaurants. Urinals for women have not, however, become established, but they are undergoing further development.
- **Urine-diverting dry toilets:** UDDTs are the most common type of source separation system; they are frequently installed at remote locations (e.g. Alpine huts) but increasingly also in urban settings. Solid and liquid wastes are separated by means of a sloping conveyor belt below the toilet seat (Ecodomeo or Sanisphère), or by a partition in the toilet bowl. Here, the separation of waste streams is designed not only for urine collection but also to control odours and to facilitate composting of the relatively dry faeces. UDDTs do not require the addition of woodchips or sawdust.
- **Urine-diverting flush toilets:** The urine-diverting flush toilets most commonly used to date (also known as No Mix toilets) collect urine with the aid of a partition in the bowl. Depending on the model, this may be located towards the front or towards the rear of the bowl. While this system is essentially effective, it is not suitable for all users (e.g. children) and requires considerable cleaning and maintenance efforts. The unwanted dilution of urine with flushing water could be reduced to a certain extent with the aid of a valve. However, these toilets are no longer being produced. The newly developed system known as "save!" – introduced in 2019 by the design studio EOOS and Laufen Bathrooms – dispenses with a valve: the urine trap works by means of surface tension (the "teapot effect"). It is not immediately obvious that this is a urine-diverting toilet.

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More information: www.eawag.ch/nomix

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