# DIVERSION FOR SAFE SANITATION: A NEW APPROACH TO SANITATION IN INFORMAL SETTLEMENTS

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## ABSTRACT

*The project presented in this abstract is part of the 'Reinvent The Toilet Challenge' (RTTC), a call from the Bill & Melinda Gates Foundation (BMGF). Our project entry "Diversion for safe sanitation" is based on two main elements: diversion of urine and faeces at the source as basis for efficient resource recovery and linking different scales (household level and semi-centralized resource recovery) allowing for rapid implementation of family toilets. Our objective was to develop an attractive grid-free dry diversion toilet (separately diverting undiluted urine and faeces), which provides water for flushing, comfortable personal hygiene (for washers and for menstrual hygiene), and for hand washing. A service concept for linking the family scale to a community scale Resource Recovery Plant (RRP) as well as a business model with maximum profit for the local community was set up. The service including the entire sanitation value chain shall be provided as a profitable business with total fees of 5 ȼ/p/d. The toilet has been designed to fulfil all objectives, allowing for local rotational moulding of all parts. It can be installed as a shared toilet for 2 families in any available super-structure or as an in-house private toilet. The flush & wash water is recovered on-site in a maintenance-free ultrafiltration unit followed by on-site electrolytic chlorine production. Total energy consumption is 4-8 W/toilet, provided by a small solar panel. The low energy consumption is only possible because at least 95 % of urine and faeces are diverted at source directly towards resource recovery not contaminating the wash & flush water. The Resource Recovery Plant is conceptually set up for 175 families and urine and faeces are collected from each toilet twice a week. Based on smart design and standardization, the service concept is hygienically safe and in densely populated informal settings, the collection service can be provided at around 1 ȼ/person/day. Resources can be recovered from urine and faeces by a large number of processes. We have set up a methodology for comparing different technologies, e.g. with respect to costs and energy consumption. For urine, we suggest nitrification followed by distillation, a favourable process developed within another BMGF project (www.eawag.ch/vuna). For faeces, the best technology still has to be chosen. A business model "rent-a-toilet" will make sure that landlords as well as tenants have access to the technology.*

Keywords: design, innovation, resource recovery, source separation, urban, wastewater treatment

## ABBREVIATIONS

BMGF: Bill & Melinda Gates Foundation
RRP: Resource Recovery Plant
RTTC: Reinvent The Toilet Challenge
TRL: Technology Readiness Level

**INTRODUCTION**

The concept of *diversion for safe sanitation* has been developed in a project financed by the Bill & Melinda Gates Foundation within the program *Reinvent The Toilet Challenge* (RTTC). The requirements of the call were to provide a private or public toilet for dense urban areas, allowing for high personal comfort at a price of 5 US₵ per person and day. Furthermore, valuable products should be extracted from the toilet waste, and no connection to running water, grid electricity, or sewers could be assumed. In the project *diversion for safe sanitation*, we decided to combine two different scales for solving this challenging problem (Figure 1): The toilet itself was developed as a shared private toilet for two families, whereas the resource recovery was set up at a small community scale for about 800-900 people in a so-called Resource Recovery Plant (RRP). This implies a logistics concept for transport of toilet waste from the toilet to the RRP. As the name indicates, the toilet is a diversion toilet, separating three streams: undiluted urine, dry faeces, and water. The water is used for flushing the dry (!) toilet, for hand washing and for personal hygiene (menstrual hygiene and anal cleansing, where required). It is recovered on-site for re-use for the same purposes within the toilet.

Figure 1 Conceptual set-up of the *diversion for safe sanitation* system (© EOOS)

**PROJECT STRUCTURE**

In order to make the project manageable, it was organized in five different objectives:

- Objective 1: Designing and constructing an attractive source separating toilet
- Objective 2: Demonstration-of-principle for on-site wash & flush water recovery
- Objective 3: Transport logistic concept
- Objective 4: Evaluation of treatment technologies
- Objective 5: The *diversion* business model – a market-based sanitation approach

**PROJECT RESULTS**

<u>Objective 1: Designing and constructing an attractive source separating toilet (Figure 2)</u>

A main goal of the project *diversion for safe sanitation* was to design an attractive source separating toilet that everybody wants to use, in high-income as well as in low-income countries. The toilet provides running water for hand washing and personal hygiene and a comfortable "flush" button for the cleansing of the pan. These well-known functions are however translated into a "next generation" product, which works off-grid with a radical low-cost innovation approach.


Figure 2 The *diversion* toilet (© EOOS)

The toilet is designed for a setting of four families sharing two toilets. As a (re)movable piece of furniture it can be retrofitted into existing toilet superstructures (Figure 3), or in any other bathroom, and allows for setting up a *"rent-a-toilet"* system. This retrofitting concept as well as the toilet functions and aesthetics were tested in a reality check workshop in an informal settlement in Kampala, Uganda where it was well received. The toilet features an innovated dry source separating pan which can be cleaned with water from the on-site water recovery without requiring mechanical parts for cleaning. By foot activation, the squatting pan transforms by rotation of 90 degrees into a washing pan (Figure 4).

Figure 3 Photomontage of the retrofitting concept (© EOOS)

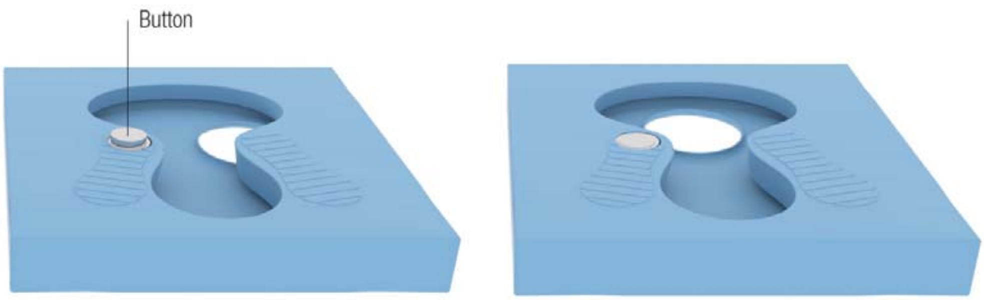


Figure 4 The squatting pan transforms by rotation of 90 degrees into a washing pan (© EOOS)

The toilet's core is the back wall containing the compact water recovery technology. While faeces and urine are collected under the separating pan, the soiled water from hand-washing, pan flushing, anal cleansing and menstrual hygiene is fully recycled on-site. Important design features of the water recovery wall are the foot pump keeping the water recovery cycle activated, the water display tank indicating the amount of clean water available to the user, a hand wash basin with running water and a shower head, providing a comfortable cleansing device for menstrual hygiene or anal cleansing (Figure 1).

Another important innovation is EOOS's design of a self-sealing container which secures the safe removal and emptying of the faeces containers, even for the end user if the transport logistics break down temporarily (Figure 5).

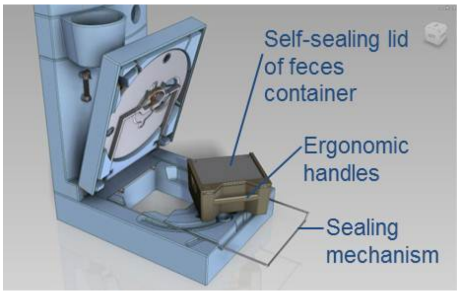


Figure 5 A self-sealing container allows for safe removal and transportation of faeces

<u>Objective 2: Demonstration-of-principle for on-site wash & flush water recovery</u>

The core principle of the on-site water recovery technology is a gravity driven ultrafiltration (UF) unit, developed by Eawag researchers for drinking water production from polluted river water (Peter-Varbanets et al. 2009). Due to the more heavily polluted wastewater to be recovered within the toilet (as compared to river water) and the recirculation of the treated water, aeration is introduced in order to keep the membrane biologically active and thus avoiding maintenance. The reactor is contained within the water recovery wall (Figure 6) and the design is based on several months of experiments in three parallel UF units. The experiments with simulate flush & wash water soiled with faeces, urine, soap, and blood showed that a stable flux could be obtained with the simplest possible reactor. Additionally, results show that technical design parameters of importance for sizing the reactor in the water recovery wall are water permeability and trans-membrane pressure, which determine the water flux.

In order to design the water recovery wall, a simple model implemented in the program Berkely Madonna was applied to simulate water availability at different reactor configurations, assuming a pattern of toilet visits modelled with a probabilistic approach. The results showed that in the chosen set-up, around 75 Litres of water can be made available per day. With the assumed 50 toilet visits per day and toilet, this corresponds to an average of 1.5 Litres of water per toilet visit. Since the toilet can be comfortably flushed with half a Litre of water, 1 Litre of water per toilet visit is available for hygienic purposes.

As the filtered water is slightly coloured – it contains around 30-40 mg COD/L and re-growth of micro-organisms will take place – we recommend polishing of the effluent in order to minimize this risk and ensure colour removal. Preliminary results with electrolysis were successful, but still need to be optimized.

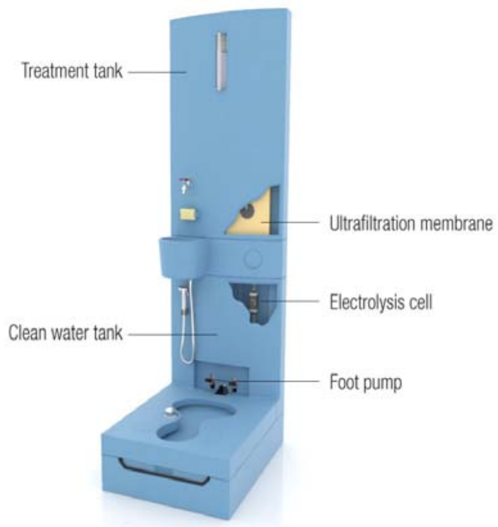


Figure 6 Water recovery wall of the *diversion* toilet

It can be concluded that safe water recovery through gravity-driven ultrafiltration is feasible and maintenance-free operation is stable. Polishing by electrolysis makes the water more appealing, increases the safety level, and minimizes the need for chlorination. Additional chlorination is possible if desired.

<u>Objective 3: Transport logistic concept</u>

The conceptual transport logistics comprise one collector per Resource Recovery Plant (RRP), collecting faeces and urine twice a week from the toilets and delivering both to the RRP. In order to obtain hygienic and aesthetic working conditions, faeces are removed in a self-sealing container (Figure 5) and urine will be pumped.

In objective 3 we explored whether a collection service system is feasible at a reasonable price, despite the labour intensive collection in rather complex contexts. Therefore, a numerical model was developed, allowing for evaluation and optimization of transport in a variety of spatial set-ups (Schmitt 2012). We used GIS data of housing structures and road networks of 4 informal settlements in Africa and India. Regression techniques were used to analyse the spatial data (especially the influence of population density on travel distances). Moreover, bivariate regressions were applied in order to identify interdependencies of system parameters, e.g. of service time on costs and capacity.

Analysing the spatial data, the results of the numerical model showed that travel distances are significantly related to user density. However, its influence on the system's performance is of minor importance as work productivity was identified as the key driver for overall system performance. This implies that the logistic system is suitable for a wide range of spatial setups from low to high population densities provided that work productivity is high. We conclude that one of the most important systems integration issues is the optimizing of collection of faeces containers, pumping of urine and discharging to the RRP.

For the business model, an exact number of users per RRPs is required to calculate the business case for Kampala. We chose a user density of 150 persons per hectare, a service time per facility of 20 minutes, resulting in an RRP for 860 users and costs of $0.01 per user and day.

Objective 4: Evaluation of treatment technologies

Objective 4 evaluates different treatment technologies for source-separated urine and faeces, which can be operated in a Resource Recovery Plant (RRP). The result of Objective 4 is the identification of viable urine and faeces treatment combinations that fulfil the treatment requirements stipulated in the RTTC call (drinking water quality for liquid side products and solid organic matter only in stabilized forms).

An excel tool for the evaluation of adequate urine and faeces treatment technology combinations was developed to support decision making. The technology combinations were compared using the following parameters: electrical energy consumption, weight of end-product output, reactor volume, revenues from nutrients, total costs (investment, maintenance and running costs) and nutrient loss.

We compared a number of technologies optimized for (a) low reactor volume, (b) high Technology Readiness Level (TRL) and (c) independence of solar energy (no solar panels and no solar evaporation). The main limitation for valid comparisons is the lack of reliable data on the still very young technologies. Furthermore, the choice of the optimal technology combination is subjective and depends on the preferences of the decision maker, which will be influenced by the local situation. Due to all these limitations, the results will be published separately with a thorough discussion of the uncertainties.

We also categorized possible technology combinations including low, medium and high total costs. For the business case we selected anaerobic digestion of faeces and partial nitrification of urine combined with distillation (Udert & Wächter 2012) as a possible treatment technology combination, because both are already available at a high TRL and are classified as low total cost technologies. The cost evaluation for the technology combination “low total costs” showed that it is economically feasible within the total cost limit of $0.05 per user and day.

Objective 5: The *diversion* business model – a market based-sanitation approach

The *diversion* business model follows the marked-based sanitation approach (Osterwalder & Pigneur 2010, London & Hart 2010). Sanitation entrepreneurs would generate sufficient revenues to cover the costs and create an attractive profit. The business model addresses two different customer groups: two families (average 5 persons) renting a single toilet and wholesalers buying end-products. The value proposition for toilet users is about offering attractive and affordable rental toilets and a safe and reliable emptying. Such a value proposition would create a demand for toilets, which, in turn, generates revenue from service fees. In the *diversion* business model, the relationship with the toilet users is managed through mobile payments and twice-a-week visits of the collector to remove faeces and urine. Efficient treatment and resource recovery due to separated faeces and urine create another stream of revenue from the sales of end-products. These two revenue streams make the business model robust and enable a positive cash flow while still allowing for the provision of attractive toilets at an affordable service fee. The corresponding revenue streams are, on one hand, the service fee of 5¢ per user and day, which covers toilet rent, emptying, and maintenance costs as well as most of the RRP costs. Sales of end-products such as recovered water, nutrients and energy are estimated to reach about 2¢ per user and day. Such a value proposition means significant improvement compared to the existing situation (e.g. high emptying costs for the latrine ($ 30) or public toilet fees (7¢)).

The *diversion* business model enables the entrepreneur to develop a sanitation business. At full scale, the entrepreneur will manage a small firm with about 40 employees mostly collectors and RRP operators. At the RRPs, the urine and feces are treated to become valuable end-products. The end-products are sold to wholesalers at market-price levels. The value proposition for wholesales refers to secure delivery of nutrients or fertilizers at a stable price (independent of marked fluctuations), low-cost supply of distilled water because of the synergy with excreta management, stable supply of energy carrier, most probably in the form of bio char.

Key competencies for executing the business model include logistic, operational, and management skills. Logistic skills ensure hygienic and safe removal of excreta, operational skills are necessary to convert urine and feces at the RRPs into valuable end-products, and management skills to promote and market the "rent-a-toilet" service. Entrepreneurial skills to develop and scale-up the business model are also a key concern.

Necessary business partners are local toilet manufacturers, which produce the user interface, ultrafiltration membrane manufacturers, which produce the ultrafiltration membrane, treatment technology equipment providers, which provide the RRP equipment, and finally, local contractors, which assemble and retrofit the toilet into the existing superstructure and provide repairing of toilets and RRP machinery. Finally, to make the business model successful, the local community has to support the development of the sanitation business.

**DISCUSSION**

Within a relatively short time, we succeeded in setting up a concept for safe sanitation relying on the principle of diversion (source separation). We based the work on more than a decade of experience in the area of urine source separation (see for instance Larsen et al., 2009) and appropriate sanitation in low-income areas of low- and middle-income countries (Lüthi et al., 2011). Furthermore, the work was highly interdisciplinary as well as transdisciplinary, involving not only a number of different disciplines, but also a design company (EOOS in Austria) and future users of the toilets (focus groups in an informal setting in Kampala, Uganda).

The approach of the present project was to include technical aspects of the whole value chain as well as the personal preferences of the users. Whereas we are convinced that technical solutions are best obtained based on a dry urine diverting toilet (UDDT), experience in the field tells us that users are normally not very happy with such a toilet. Instead of trying to develop technology for a conventional flush toilet, however, we chose to develop a new type of UDDT, which would provide a maximum of comfort to the users. We identified the possibility of using water for flushing and personal hygiene as the most important deficits of the present UDDT technology and consequently set out to develop such a toilet. At the same time, we wanted to provide a toilet design, which would at the same time be attractive *and* affordable for the users.

**CONCLUSION**

Generally, we believe that it is productive to invest in the development of a superior toilet technology including the whole sanitation value chain in order to solve the problems of poor sanitation in dense informal urban settlements. This takes time, but granted that the right technologies are developed, this investment will allow for rapid dissemination of mass produced technology in a large number of informal settlements. The integration of designers in the technology development process already from the beginning is probably the most important single reason that we could come up with a design that seems promising for further development towards full scale implementation.

**ACKNOWLEDGEMENTS**

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