A Contribution to Sustainable Growth by Research and Development

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Abstract

Developed in industrializing countries 100 to 150 years ago and improved ever since, centralized systems for water supply and wastewater management have become the norm. We call this an “end of pipe” solution for wastewater management. It is a matter of fact that sewage collection and central treatment have been a success in view of its original objectives to reduce the spreading of wastewater born diseases and to solve the water pollution problems. Centralized sanitation is highly recognized all over the world and is viewed, particularly in developing countries, as a status symbol for wealth and lifestyle.

In respect to sustainability, however, our centralized system for wastewater management is no longer adequate. Longevity of its infrastructure, long lockup of capital, waste of drinking water for flushing and conveying of faecal matter, energy consuming nutrient removal and, last but not least, pollution of surface waters with micro-pollutants are only some reasons why conventional sanitary systems are increasingly criticized. In addition, because of its high consumption of construction materials, energy and freshwater, our flush canalization can hardly be a model for arid or semi-arid regions.

To permit sustainable development, innovative sanitary systems are needed; systems that simultaneously achieve the economical, ecological and social objectives of sustainable water management. Recycling and integrated resource management take thereby centre stage. Adapted concepts and solutions, adapted to local conditions and constraints as well as to the needs of the local population, which guarantee orderly wastewater treatment, must be developed, tested and implemented. Ideal solutions would include energy recovery and reuse of solid waste as an integral part.

This paper introduces research projects of the Hans Huber AG that have been carried out with the objective to develop and test, under practical conditions, innovative wastewater systems that generate service water of various quality and recover nutrients as well as energy from wastewater. We focus particularly on our experience with innovative technologies for the treatment of separated wastewater flows that we have operated and investigated within the framework of our demonstration project “ReUse Concept” at our headquarters in Berching. Finally we discuss holistic and integrated approaches called “**s**hort **W**ater, **M**aterial & **E**nergy **c**ycles” (sWMEc).

Key Words: Adapted solutions, **De**centralised **Sa**nitation and **R**euse (DeSa/R®), production of service water, recovery of nutrients, energy production, yellow water, brown water, grey water, **s**hort **W**ater, **M**aterial & **E**nergy **c**ycles (sWMEc)

Introduction

For decades, in industrialized countries, the infrastructural “status quo” has been continuously upgraded and extended. Under the assumption that centralization permits better monitoring and control, existing water supply and sewage collection networks are simply extended. Almost ubiquitous networks guarantee water supply. Various kinds of wastewater are collected through extensive sewer networks, treated in central plants and then discharged into surface water. In this way, wastewater management achieves its original objectives of safeguarding public health and controlling water pollution.

Traditional water infrastructures in industrialized countries have become, for historic reasons, “end of pipe” systems. Such systems have admittedly the benefit to provide safe and secure water supply and wastewater collection, but on the other hand, they have a large number of characteristics preventing sustainable development. The constraints of such systems can be listed as follows (Dalkmann et al., 2004; Steinmetz, 2007):

- Centralized water and wastewater systems require long-term planning, design and construction

- Over many decades investment must be done into an infrastructure having a long technical and economical life. In addition repair and maintenance of centralized sewer systems is expensive.
- Central wastewater treatment plants for nutrient removal are also costly to operate.
- Centralized systems have low flexibility. They are extremely difficult and expensive to adapt to changing conditions and requirements (e.g. to decreasing population as in eastern Germany).
- Flush canalization systems require large volumes of freshwater for flushing and transportation of faecal matter. Water conservation can even compromise their proper function due to sewer deposits.
- Wastewater flows of different quality are blended, e.g. domestic, commercial and industrial wastewater, storm water and infiltrating groundwater. Dilution results in higher treatment costs.
- Valuable nutrients are removed during wastewater treatment under consumption of much energy. Industrial production of ammonium for fertilisers is energy-intensive and global resources of sufficiently pure phosphorus minerals are limited and depleting.
- Effluent reuse is impractical with centralized systems due to the disposal in receiving waters.
- Effluents of wastewater treatment plants contain micro-pollutants, such as persistent chemicals, pharmaceutical and endocrines, and thus contaminate surface waters.

For above reasons, experts are increasingly doubtful whether it would be reasonable to implement the conventional sanitary systems around the globe. Flush canalization, due to its massive resource consumption, is absolutely unsuitable for regions with freshwater scarcity. Such regions often suffer freshwater as well as fertilizer shortages, and especially, they don't have the necessary finances to build and operate an expensive infrastructure. In theory, our traditional infrastructure would be beneficial for densely populated cities in developing and emerging countries, but fast growth, particularly of their slums and suburbs, resulting from rapid urbanization, usually constrains or even prevents construction and extension of water and sewer networks. Governments and administrations of fast growing mega-cities can not cope with their hygienic, social and ecological challenges. In most cases, a contra-productive "policy of no action" prevails, and in the end no viable concept of wastewater management is pursued.

Innovative Sanitary Concepts – DeSa/R®

According to a 2006 report of the United Nations, 1.1 billion people worldwide (one fifth of world population) have no access to clean potable water and around 40 % of the global population have to live without proper sanitation and wastewater treatment. Most of these people live in developing or emerging countries. In order to achieve the **M**illennium **D**evelopment **G**oals (MDG) to half the numbers of people without access to clean drinking water and without proper sanitation by the year 2015, it is imperative to develop adapted concepts and customized solutions, achievable with available resources and adapted to the needs of the people.

In view of different climatic, geographic, ecologic, social and political conditions in every country it is demanding to develop sanitary concepts that guarantee proper wastewater treatment and, at the same time, avoid intensive consumption of scarce resources and extreme inflexibilities of traditional systems. Sanitary concepts for mega-cities must differ from such for rural areas. Generally, decentralized and resource-saving solutions must be preferred; solutions permitting sustainable development by consequent recycling and integrated management of resources.

Innovative sanitary concepts are often called **De**centralised **Sa**nitation and **R**euse (DeSa/R®) concepts. It is a concept for "Proximal Ecology" (Larsen et al., 2005) and based on integration of water supply and wastewater treatment. Besides the traditional objectives of public health and water pollution control, two further objectives come to the fore: resource conservation and recycling.

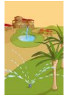
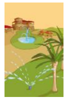
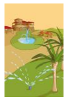
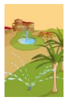
Reuse of wastewater for irrigation is supported by the World Health Organization (WHO). Their guidelines state: "The use of wastewater (i.e. excreta and grey water) in agriculture can help communities to grow more food and make use of precious water and nutrient resources. However it should be done safely to maximize public health gains and environmental benefits." In this context, wastewater becomes a "secondary raw material", raw material for the production of service water of various quality, for production of phosphorus and nitrogen and, last but not least, for power and/or heat generation. A fundamental paradigm shift, turning our traditional way of thinking on its head, is happening: The era of wastewater discharge is ending **-** a new era of wastewater reuse has dawned.

Research at Hans Huber AG

Implementation of alternative and innovative sanitary concepts in developing and emerging countries is often impeded or even inhibited by the fact that traditional wastewater management of industrialized countries is still conceived as state-of-the art. Successful export of DeSa/R® solutions is only feasible if we have reference installations at home and gain experience with their operation. This is the reason why Hans Huber AG invests in several research and demonstration projects that we conduct either in cooperation with universities or alone. It is our objective to promote public acceptance of innovative system solutions and, finally, to improve our chances to export our own technologies, by transfer of know-how and participative processes (Paris et al., 2007).

Our approach is multifaceted (Table 1). For arid or semi-arid regions, such as Algeria, it is obvious to reuse partially treated wastewater for park irrigation. Suitable treatment systems are compact, easy-to-operate and cost-effective combinations of solid/liquid separation and subsequent disinfection (BMBF Algeria). Freshwater consumption in households can be reduced by use of high-quality service water for toilet flushing, laundry washing and irrigation. Big and rapidly growing cities, like Beijing and Shanghai, need wastewater or grey water recycling (BMBF China). An immense challenge is water supply and sanitation for mega-cities like Lima. A promising approach is the common digestion of wastewater compounds and kitchen waste for biogas generation (BMBF Peru).

Table 1: R&D projects of Hans Huber AG concerning DeSa/R® Solutions

Project	Objective			Resource	Machine of Hans Huber AG	Location
	Service Water Production	N and P Recovery	Energy Production			
BMBF Algeria[1)] – Decentralized reuse of raw sewage for park irrigation				Municipal wastewater	Ultra-fine screens	Algeria (Emirates)
BMBF Jordan[1)] – Development of innovative wastewater treatment with membrane bio-reactors and requirements for ground infiltration and groundwater replenishing in Jordan River valley				Municipal wastewater	Ultra-fine screens and MBR	Jordan
BMBF SMART[1)] – Pre-project: Lower Jordan Valley "SMART": Design, installation and start-up of a research and demonstration system for wastewater treatment and farmland irrigation				Municipal wastewater and sludge	Ultra-fine screens and anaerobic reactor	Fu Heis (JOR)
BMBF Peru[1)] – Water and wastewater management in mega-cities: Conceptual study for metropolitan Lima				Municipal wastewater and sludge	Anaerobic reactor	Lima (PER)
DBU Storm Water[2)] – Development and optimization of a multi-stage system treating runoffs from streets and parking lots for flood control				Storm water runoff from traffic areas	Adsorptive filter	Munich (D)
BMBF China[1)] – Semi-central water supply and wastewater treatment systems for urban areas in China				Grey water	Micro-strainer, sand filter and MBR	Darmstadt (D); later China
"ReUse Concept" [3)]**;** **BMBF Vietnam**[1)] – SANSED II: Closing nutrient loops via hygienically harmless substrates from decentralized water management systems in the Mekong delta				Yellow, brown and grey water	MAP-precipitation reactor, stripping and absorption column, anaerobic reactor and MBR	Berching (D); Can Tho (VIE)

Legend:

1) Project with 50 % funding by BMBF (German Federal Ministry for Education and Research)
2) Self-financed with support by DBU (German Federal Environment Foundation)
3) Self-financed

Ecological Benefits of ReUse Concepts

Early in 2006 we implemented our basic ecological recycling concept, the "ReUse Concept", at our headquarters in Berching. Our integrated water and wastewater concept for our new office building is based on separate collection and specific treatment of different wastewater flows. It is our objective to recover a maximum amount of nutrients and service water from the wastewater generated by our employees. We use innovative technologies in our "Recovery Plant". With our "ReUse Park" we demonstrate various possibilities for reuse of treated wastewater and its components, such as irrigation and fertilization of fruit and vegetable plants, and feeding a fish pond with treated effluent (Fig. 1).

Furnishing our office building with no-mix-toilets, waterless urinals and three parallel drain pipelines allowed us to separately collect urine, brown and grey water from their source. We use specific processes for the treatment of these separate flows:

- Precipitation, stripping und absorption for the urine
- Digestion for brown water together with bio-waste
- **M**embrane **b**io-**r**eactor (MBR) treatment for grey water

We report about our results and experiences with these innovative processes in the following chapters.

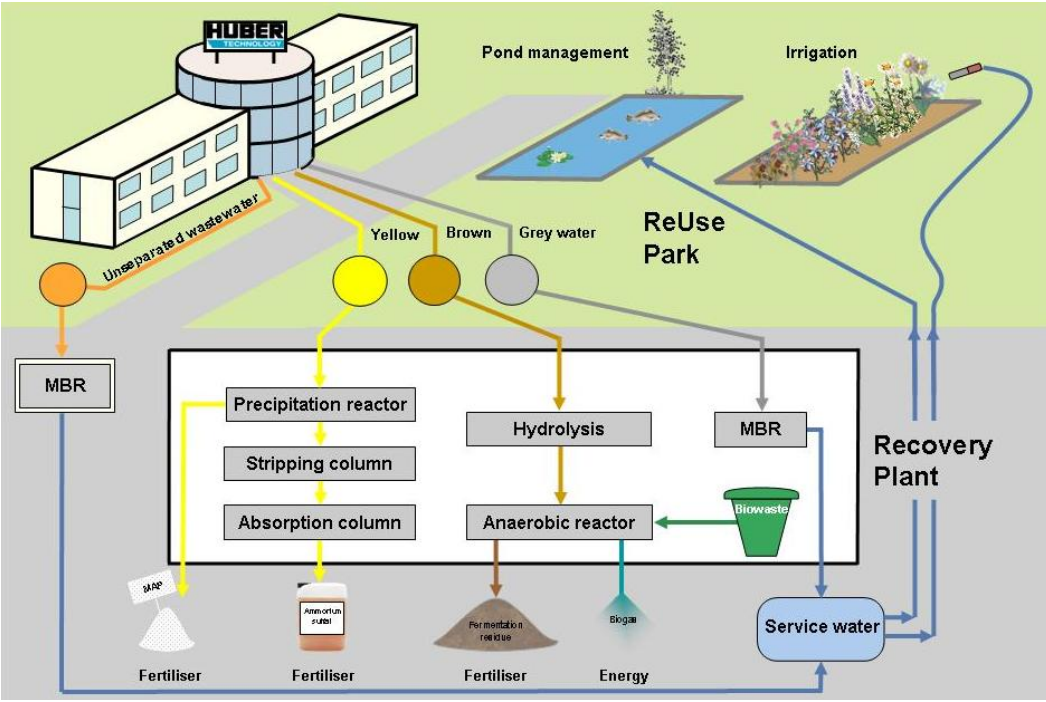


Figure 1: ReUse Concept of Hans Huber AG as implemented in Berching

Urine Treatment for Recovery of Valuable Nutrients

Most of the nutrients in wastewater are introduced with urine: Around 87 % of the nitrogen and 50 % of the phosphorus are dissolved in only 1 to 1.5 l/(P*d) of urine. They are dissolved in the form of ions and can easily be resorbed by plants. In addition, urine contains a lot of pharmaceutical residues that are excreted un-metabolized by the human body. It is suggestive to collect undiluted urine, recover its valuable nutrients and eliminate micro-pollutants. We developed a process for nutrient recovery from undiluted urine. Our **Nu**trient **Rec**overy (NuRec) process is comprised of two chemical-physical stages: The first stage is a **m**agnesium **a**mmonium **p**hosphate (MAP) precipitation; the second is a combination of stripping with air and absorption in sulphuric acid. We operate and continuously optimize this process for treatment of urine from our office building.

Characteristics of Urine

In fresh urine nitrogen is dissolved in form of urea (Table 2) which is after only a few hours of storage completely transformed by the enzyme urease into hydro-carbonate and ammonium ions. During this enzymatic process the pH-value rises from initially 6 to approx. 9.3. Now the urine contains about 4.7-9.4 g/l NH_4-N and 200-800 mg/l PO_4-P (Hanaeus et al., 1994; see also our averages in Table 2). MAP precipitation and stripping / absorption are suitable processes for such concentrations.

Table 2: Composition of fresh (Udert et al., 2003) and stored urine (own results)

Parameter	Unit	Fresh urine (Udert et al. 2003)	Stored urine of Hans Huber AG
NH_4-N	mg/l	254	3,870
Urea	mg/l	5,810	-
N_{tot}	mg/l		4,570
PO_4-P	mg/l	367	204
Ca	mg/l	129	-
Mg	mg/l	77	-
Na	mg/l	2,670	-
K	mg/l	2,170	-
SO_4	mg/l	748	-
Cl	mg/l	3,830	-
COD	mg/l	8,150	2,870
pH-value	-	7.2	8.9

NuRec Process

With the two-stage NuRec process nutrients are recovered in a MAP precipitation reactor and a series of stripping / absorption columns with closed air recirculation (Fig. 2 and 3).

MAP Precipitation Reactor

Stored urine, having a favourable pH-value, is fed in batch into the reactor. When magnesium oxide powder is added above its saturation concentration, orthorhombic MAP crystals precipitate (their molar $Mg:NH_4:PO_4$ is 1:1:1) and are then separated in a filter bag. With a β-ratio > 1.5 we achieved P elimination of over 96 %.

The dried precipitate is a white powder and has nutrient composition that is comparable to that of a valuable multi-component fertilizer. Investigations by Ronteltalp et al. (2007) proved that MAP from urine is virtually free of pharmaceutical residues and hormones, and that heavy metals are below their detection limit. Our composite sample from 21 cycles had a copper (Cu) concentration above the limits set by the German Fertilizer Regulation (DüMV, 2003; See Table 3). This high concentration can be explained by our use of brass components for our system and can be avoided by use of other materials.

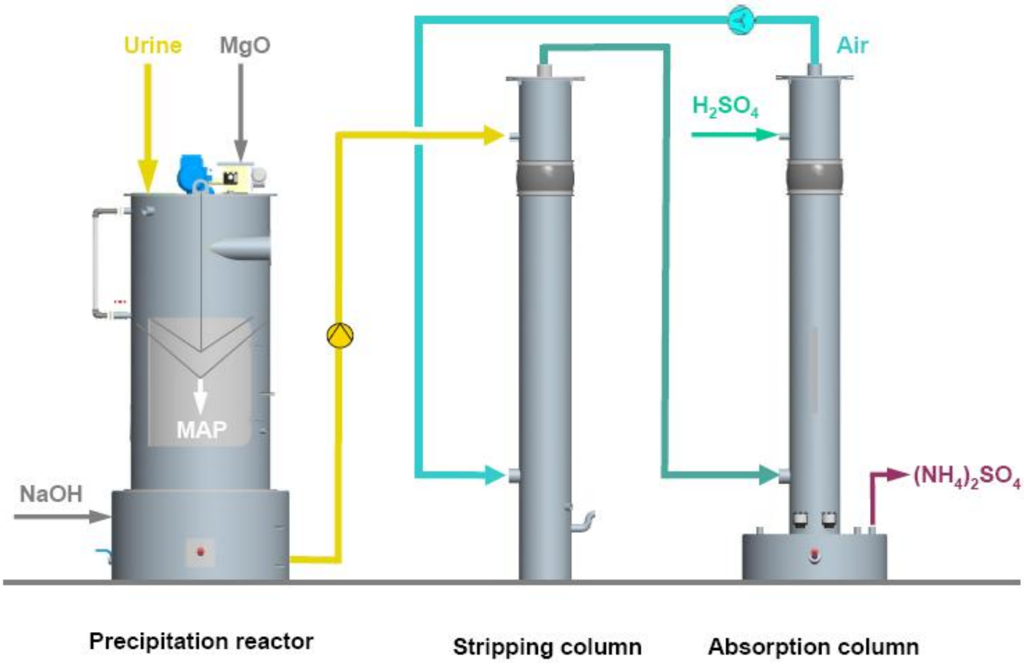


Figure 2: Process flow diagram of our NuRec process with MAP precipitation reactor, stripping and absorption columns

<u>Operational data</u>:
- Batch volume: approx. 48 l
- Cycle duration: approx. 4 h
- MgO cons.* : 1.29 mg MgO per kg PO_4-P
- H_2SO_4 cons.* : 3.5 kg H_2SO_4 per kg NH_4-N

* stoichiometric calculation

Figure 3: Photo and operational data of our NuRec system with MAP precipitation reactor, stripping and absorption columns

Stripping Column

After MAP precipitation, the liquid phase still has a high ammonium concentration that is in a thermodynamic equilibrium with its ammonia concentration. By raising its temperature and pH-value (so called conditioning) we move the dissociation equilibrium towards ammonia. By air stripping alone we transfer NH_3 into the gaseous phase. We could transfer approx. 95 % of the nitrogen from conditioned urine with a temperature of 40°C and a pH-value of 10.5 when we operated the stripping column near its flooding limit and re-circulated the media for 2 hours.

Table 3: Heavy metal concentrations in our MAP precipitate and ammonium sulphate solution in comparison with the limits set by the German Fertilizer Regulation (DüMV 2003)

Heavy Metal	Limits of the German Fertilizer Regulation (DüMV, 2003) [mg/kgDS]	MAP of Hans Huber AG [mg/kgDS]	Ammonium sulphate of Hans Huber AG [mg/kgDS]
As (arsenic)	40	< 2.8	< 0.3
Pb (lead)	150	< 2.8	< 0.3
Cd (cadmium)	1.5	< 0.3	< 0.03
Cr (chromium)	-	9.2	2.0
Cu (copper)	70	**521**	0.7
Ni (nickel)	80	2.8	1.9
Hg (mercury)	1.0	0.1	< 0.003
Zn (zinc)	1,000	183	24.0
Ti (titanium)	1.0	< 0.4	0.3

Absorption Column

We operated the absorption column that is filled with a packed medium with a 10 %-sulphuric acid. By chemisorption gaseous ammonia in the air is absorbed in sulphuric acid and instantly reacts to ammonium sulphate which is a fertilizing chemical. This reaction is exothermic and raises the pH-value to a saturation value of 4.4. Our results showed almost complete absorption occurring even at higher pH-values as a result of physical absorption.

Heavy metal analysis of the ammonium sulphate showed good quality. Their concentrations were far below the limits set by the German Fertilizer Regulation (DüMV, 2003) as Table 3 shows. However, we can get certification as a commercial nitrogen fertilizer only when we increase its nitrogen and sulphur content to above 8 and 9 % respectively. For this reason it is convenient to operate the process with higher concentrated sulphuric acid (> 30 %).

Future Activities

Further experiments have the objectives to produce fertilizers that comply with the German Fertilizer Regulation (DüMV, 2003) while also further optimizing our process. We applied for funding of a further research project with the objective to analyze our products for pharmaceutical residues.

Anaerobic Treatment of Brown Water for the Production of Biogas and of Bio-solids for Soil Improvement

Brown water is wastewater consisting of faecal matter, toilet paper and flush water. An average volume of 18.8 l/(P*d) is generated by use of water saving no-mix toilets (Starkl et al., 2005). Brown water, of course, is very odorous and contains many germs and organic solids. Nutrients are organically bound and only slowly resorbed by plants. Precondition for reuse is stabilization and disinfection which is achievable by thermophilic digestion, or mesophilic digestion in combination with thermal pre- or post-treatment. Anaerobic treatment generates biogas that can be used for power and heat production. Disinfected bio-solid product contains much organic carbon and is useful for soil improvement. In Berching we operate mesophilic digestion for stabilization.

Characteristics of Brown Water

Brown water from our office building is in accordance with data published in literature (Tab. 4). As a result of beginning hydrolysis in our storage tank, our brown water has higher concentrations of organic acids and thus a slightly lower pH-value; and it has somewhat higher concentrations of N and P indicating that some urine is blended with the brown water in our no-mix toilets.

Table 4: Composition of brown water (averages at Hans Huber AG and data from literature)

Parameter	Unit	Average at Hans Huber AG	Data from Literature	
DS (Dry solids)	%	0.74	0.5 – 1.9	Heerenklage et al., 2003
Volatile DS	%	82.5	80.5	Peter-Fröhlich et al., 2006
COD_{hom}	mg/l	8,741	7,627	Peter-Fröhlich et al., 2007
COD_{fil}	mg/l	1,986	-	
N_{tot} (Nitrogen)	mg/l	282	156	Peter-Fröhlich et al., 2007
NH_4-N (Ammoium)	mg/l	125	44 - 92	Heerenklage et al., 2003
P_{tot} (Phosphorous)	mg/l	77	40	Peter-Fröhlich et al., 2007
PO_4-P (Phosphate)	mg/l	58	10 - 27	Heerenklage et al., 2003
Organic Acids	mg/l	786	462	Peter-Fröhlich et al., 2006react
pH-Value	-	6.4	6.7 – 7.6	Heerenklage et al., 2003

Anaerobic Plant

Our system for brown water treatment combines hydrolysis and mesophilic digestion (Fig. 4). We also use the hydrolysis stage for thickening. In order to achieve quasi-continuous supply of substrate, we feed the anaerobic reactor four times per day. Operational data are also included in Figure 5.

Continuous operation with a 14 d hydraulic retention time and a volumetric organic solids loading of 0.54 kg VS/(m³*d) produced 110 l/d biogas. Slumps of biogas generation were the result of interrupted feeding for one or two days, but biogas production recovered quickly after feeding was restarted. It even rose to a short peak before it decreased back to its average level (Fig. 6). The average specific biogas yield was 645 l per kg of fed volatile solids. Compared with specific values of 350-500 l for sewage sludge (Lenz, without date), brown water contains more energy.

The parameters pH-value, and the concentration of ammonium and organic acids, that are relevant for process monitoring and control, remained almost constant during our operation and indicated good process stability (Fig. 5). Volatile solids were degraded by an average of 64.4 %.

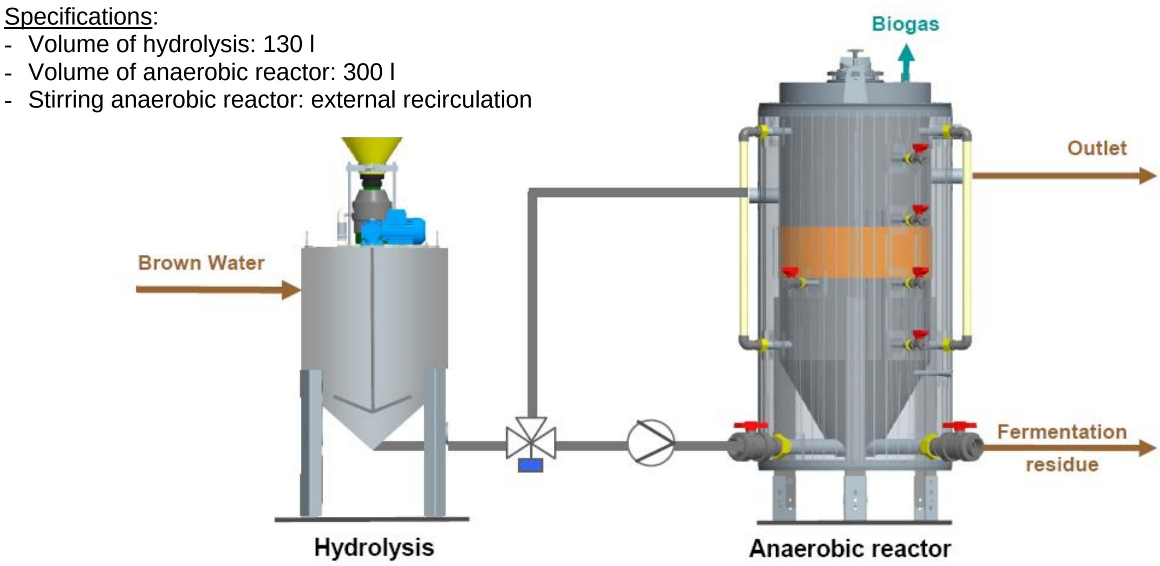


Figure 4: Process flow diagram and data of the anaerobic plant at Hans Huber AG

Hydrolysis	
HRT	approx. 5 d
Temperature	ambient temperature
DS	0.7 - 1.1 %
VS	81 - 88 %
Organic acids	1,100 - 1,900 mg/l
pH-value	5.0 - 5.8

Anaerobic reactor	
HRT	14 d
Temperature	40 °C
DS	2.5 - 3 %
NH_4-N	220 - 390 mg/l
Organic acids	190 - 240 mg/l
pH-value	6.9 - 7.2

Figure 5: Photo and operational data of the anaerobic plant at Hans Huber AG

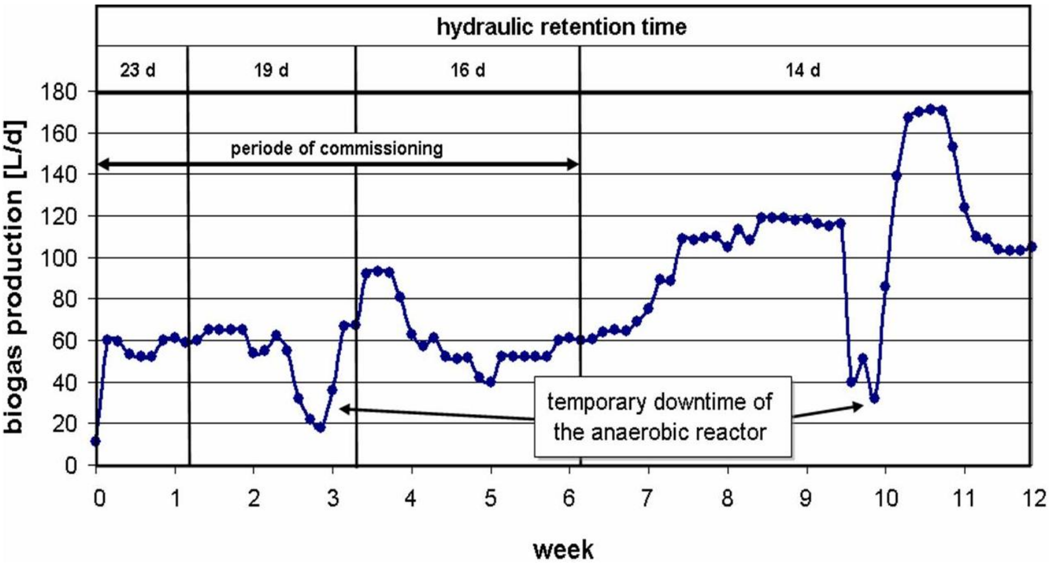


Figure 6: Daily biogas generation in the anaerobic reactor

Future Activities

We plan further investigation of disinfection efficiency by mesophilic digestion of brown water. On the basis of these results we want to select a suitable method for disinfection. We also plan to add bio-waste to increase biogas production.

HUBER GreyUse® – Grey Water Recycling and MBR

Grey water is the effluent from bath tubs, showers, washbasins, dishwashers and laundry machines. In German households that are equipped with modern appliances an average of 70 l of grey water are generated per person and day, which is over 50 % of the entire domestic wastewater (Mehlhart, 2001). In comparison with blended domestic wastewater grey water contains only little organic pollution, has a low nutrient concentration, but high concentration of detergents. Effluents from bath tubs, showers and wash basins contain by one or two orders of magnitude lower concentrations of total and faecal coliform bacteria (Nolde, 1995; Bullermann et al., 2001). It is suggestive to collect grey water separately, to treat it with comparatively little effort and to produce service water that can be used for toilet flushing, laundry washing or irrigation, depending on its quality. For grey water treatment and service water production we have developed a compact and efficient unit that includes a **m**embrane **b**io-**r**eactor (MBR). We use such a GreyUse® unit to treat the grey water from our office building.

Characteristics of Grey Water

In our office building we collect grey water from washbasins, kitchen sinks and dishwashers. Its concentrations of organic substance, nutrients and coliform bacteria are within the typical range for grey water from bathrooms, kitchens and laundry rooms (fbr-Guideline H201, 2005). Its COD/BOD ratio is about 2 and indicates normal biological degradability (Table 5).

Table 5: Characteristics of grey water of different origin (extract from fbr-Guideline H201 and averages at Hans Huber AG)

Parameter	Unit	From bathrooms, kitchens and laundry rooms (fbr-Guidlines H201, 2005)	From wash basins kitchen sinks and dishwashers in the offices of Hans Huber AG
COD	mg/l	400 – 700 (Ø 535)	514
BOD_5	mg/l	250 – 550 (Ø 360)	257
SS	mg/l	n.n.	11.0
P_{tot}	mg/l	3 – 8 (Ø 5,4)	7.3
N_{tot}	mg/l	10 – 17 (Ø 13)	15.5
pH-value	[-]	6.9 – 8	6.9
Total coliforms	1/ml	$10^2 – 10^6$	$3.3 – 10^5$
Faecal coliforms	1/ml	$10^2 – 10^6$	$1.3 – 10^4$

HUBER GreyUse®

Our GreyUse® unit (Fig. 7) consists of three main components:

- Screen and grey water collection tank
- **M**embrane **b**io-**r**eactor (MBR)
- Service water storage tank

The membrane bio-reactor includes a submersed ultra-filtration membrane module. Some technical data can be found in Fig. 8.

Our investigations showed that, with our grey water's nutrient concentrations, a good biocoenosis grew in the MBR. The system operated stable throughout our test period. COD reduction was in average 94.8 %. Changes of the feed concentration in the range of 351-700 mg/l did not cause any problems. The COD concentration in the effluent was always below 40.2 mg/l (Fig. 9).

Because of its low BOD concentration (< 2.4 mg/l) the permeate could be well stored without odour generation. The permeate was also free of solids and virtually free of germs. Its quality easily complied with the requirements of fbr-Guideline H201 (2005) for toilet flushing, laundry washing and irrigation (Tab. 6).

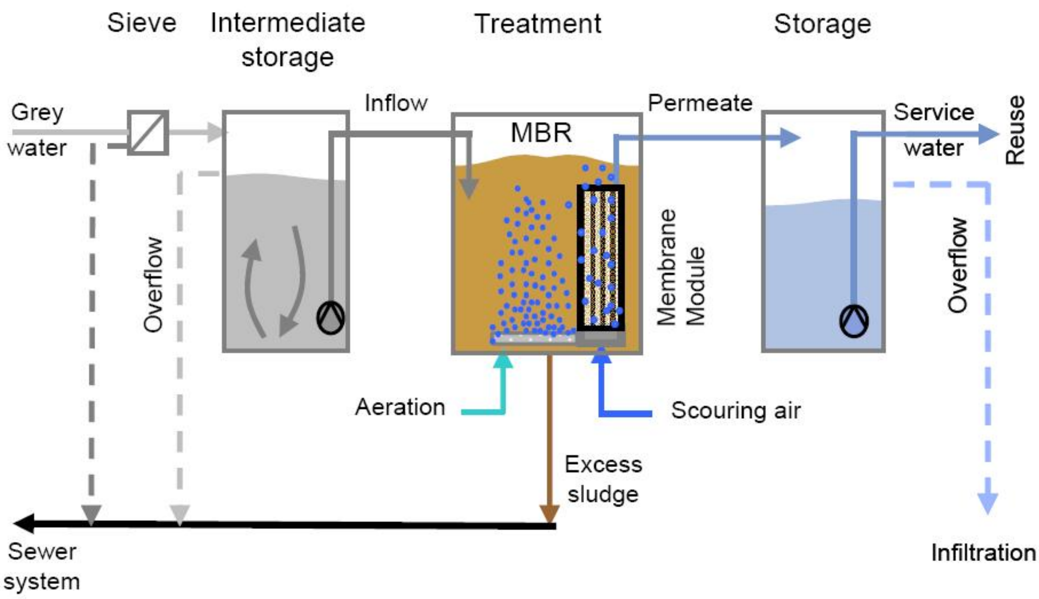


Figure 7: Process flow diagram of the HUBER GreyUse®-unit

Technical Data:
- MBR volume: 0.7 m³
- Membrane surface: 4 m²
- Membrane material: PES
- Average pore size: 38 nm

Operational Data:
- Capacity: 60 l/h (450-800 l/d)
- Suspended solids: 5-7 g/l
- Sludge load: ≤ 0.1 kg COD/(kg SS *d)
- Power cons.: 2.2 kWh/m³ (for MBR)

Figure 8: Photo and technical data of the HUBER GreyUse® unit

Table 6: Requirements on service water for toilet flushing, laundry washing and irrigation (fbr-Guideline H201) and effluent quality at Hans Huber AG (Paris and Schlapp, 2007)

Parameter	**Guide values of fbr-H201 (Limits of Directive 76/160/EEC)**	**Service water at Hans Huber AG**
BOD_7	< 5 mg/l (-)	< 2.4 mg/l
Oxygen saturation	> 50% (80-120%)	> 50%
Total coliforms	< 100/ml (100)	< 1/ml
Faecal coliforms	< 10/ml (20)	< 1/ml
Pseudomonas aeruginosa	< 1/ml (-)	-

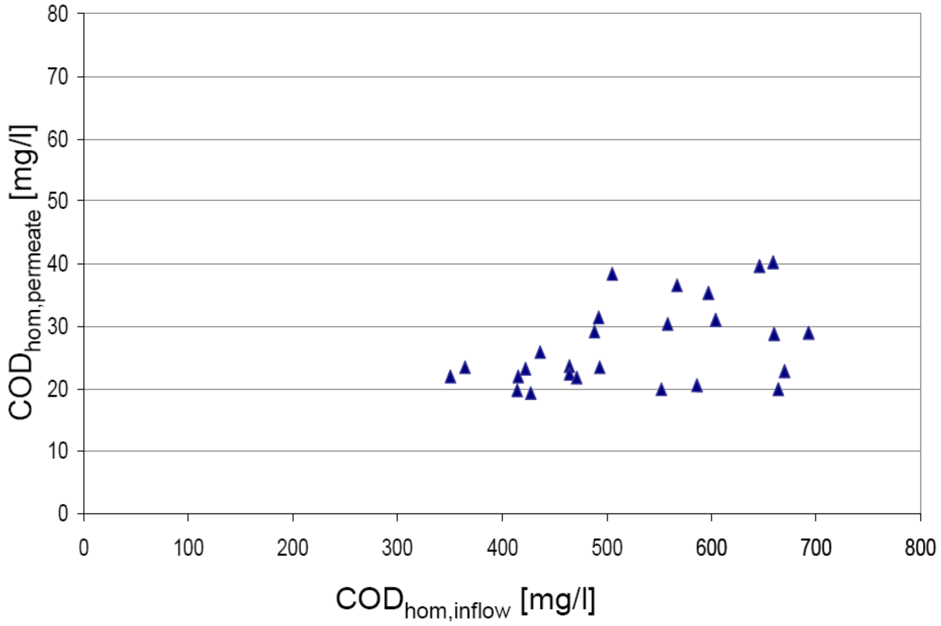


Figure 9: COD concentration of the permeate depending on COD feed concentration

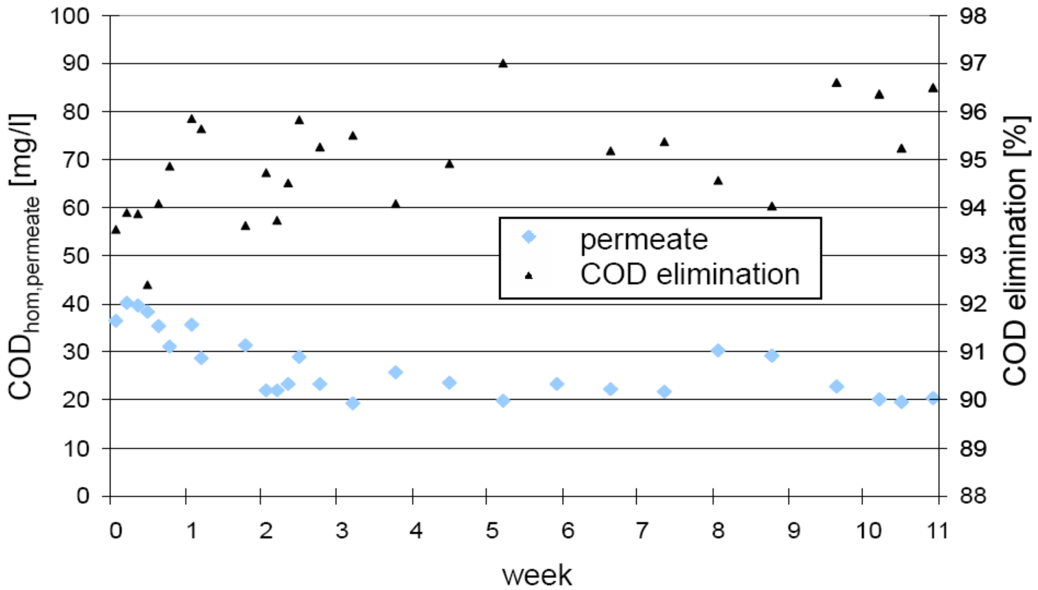


Figure 10: COD concentration of the permeate and COD removal ratio

Future Activities

So far we used the treated grey water from our office building for irrigation of our company garden, our so-called ReUse Park. In future, it shall also be used, together with collected rain water, for toilet flushing in our office building extension that we plan to inaugurate on 28th of September 2007.

Economic Considerations – Example of Grey Water Recycling

It is generally difficult to determine representative investment and operation costs of new technologies since available data are only available from manufacturing, installation and operation of not yet optimized pilot systems. For "on source" innovations, such as the treatment of separated material flows for reuse, it is even harder because the introduction and implementation of such new technologies in industrialized countries require modification of the existing infrastructure, which again requires a certain investment. In order to carry out a realistic cost analysis for such cases, the costs of this changed or new infrastructure and also the savings by substitution of freshwater and industrially produced fertilizer must be taken into account in addition to the investment and operation costs of the new technology itself. Furthermore all consequences for the general public and the environment, resulting from the introduction of alternative systems, must be evaluated and taken into account.

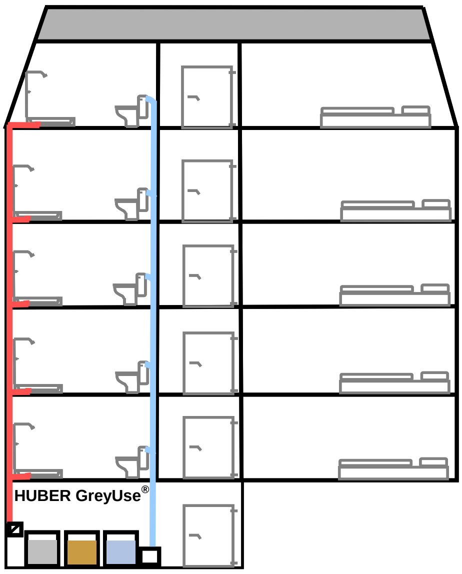
However, for a scenario of decentralized grey water recycling and treatment of black water in existing wastewater plants, its economics can be calculated relatively easily because the existing infrastructure remains in use for some time. The monetary advantage by freshwater substitution can be calculated from the savings of drinking water and wastewater costs. As an example we here present a payback calculation for a HUBER GreyUse® solution for a new-built business hotel in Berlin.

The 4-star hotel with a capacity of 410 beds shall be built with separate grey water collection and flush water distribution pipelines. The average flush water consumption in hotels is 31.5 l/(P*d) (Nolde, 2000) and therewith higher than in normal households. If we assume that 400 beds are occupied in average, the drinking water consumption for toilet flushing is reduced by 12.6 m³/d.

A compact HUBER GreyUse® unit shall be installed in the basement. Thanks to modular design of the building, the additional pipelines can be installed in a relatively easy way (Fig. 11).

Table 7 shows the investment and operation costs of the HUBER GreyUse® unit. To guarantee its reliable operation we assume yearly maintenance, replacement of spare parts and exchange of the membrane module. The total cost savings are calculated from the sum of water and wastewater costs that are 4.73 €/m³ (net) in Berlin.

Drinking water and wastewater costs have remained stable in Germany for the last 10 years (wvgw, 2005), i.e. they rose only by about 2 % per year, in parallel to the general costs of living. We assume that this trend will continue. For power, however, we assume yearly cost increases of 5 %. Under such assumptions the payback period is a little below 4.5 years of operation. Savings after 10 years of operation are approx. 87,800 € (Fig. 12). If water and wastewater costs should rise faster, the payback period would be shorter and the savings are significantly higher.



<u>Technical data ot the HUBER GreyUse® unit</u>:

Space required: L = 5,800 mm
W= 2,900 mm
H = 2,100 mm

Max. capacity: 14.6 m³/d

Power cons. incl. pumping: 3.8 kWh/m³

Figure 11: Schematic diagram of the 4-star hotel in Berlin with 410 beds and technical data of its Huber GreyUse® unit

This calculation shows that both economical and ecological benefits can be achieved by grey water recycling. If service water is used for toilet flushing, laundry washing and house cleaning, German households can reduce their tap water consumption by more than 41 %. Economical water savings can be particularly achieved by businesses, such as hotels, camping places or sport facilities, because of their high water consumptions. Grey water recycling is also a suitable method to save valuable and scarce freshwater in densely populated cities.

Table 7: Net costs of the HUBER GreyUse® unit of Figure 11

Costs	Amount
HUBER GreyUse® unit (investment)	47,553 €
Pipelines	20,000 €
Total investment (Interest rate 4 %/a)	**67,553 €**
Maintenance and spare parts (Cost increase 2 %/a)	2,301 €/a
Power costs (14.5 ct/kWh) (Cost increase 5 %/a)	2,560 €/a
Total annual costs	**4,861 €/a**
Annual water and wastewater savings* (Cost increase 2 %/a)	**21,753 €/a**

* cost savings are calculated from the reduced freshwater consumption and the lower wastewater treatment costs

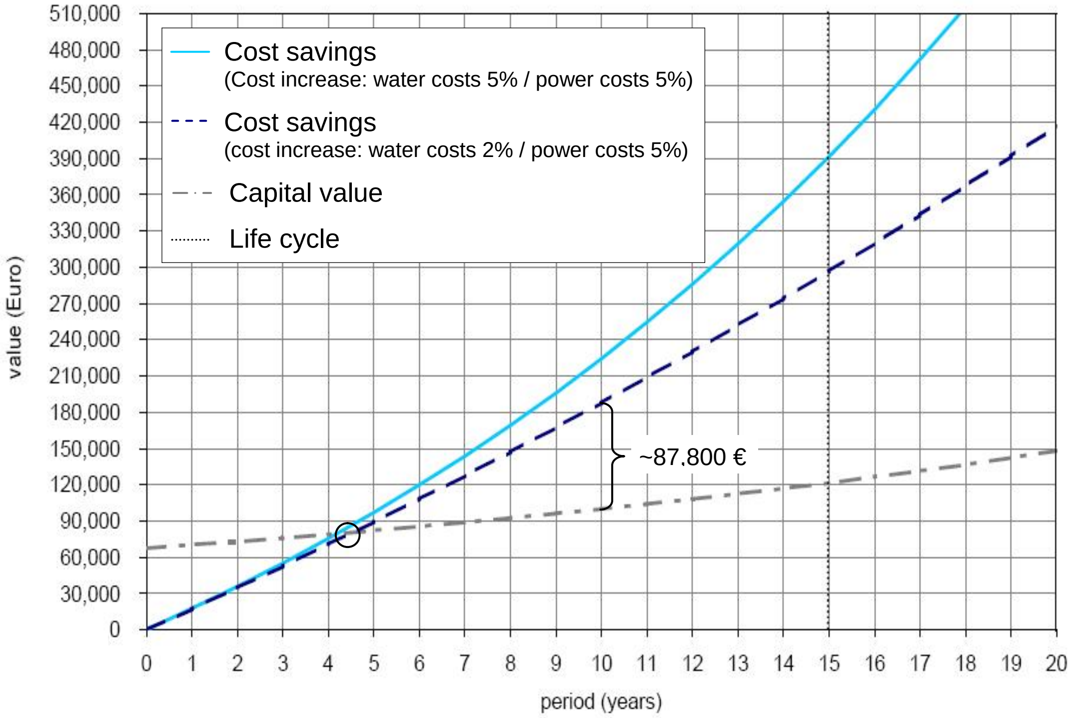


Figure 12: Cost savings over time

Heat Recovery from Grey Water

Grey water is also interesting in respect of its heat content. Most of the energy households consume is for room heating, but second is warm water heating. German household consume in average 35 l/d of warm water per head. About 25 % thereof are used in kitchens, the remainder is used for personal hygiene and cleaning (www.stmwivt.bayern.de). To heat 35 l water from a temperature of 12°C to 40°C heat of 4,100 kJ (1.14 kWh) is necessary. This is about the same amount of heat that is lost when warm grey water is discharged into the sewer.

If grey water is collected separately it is possible to recover at least some of the input energy by use of a heat pump and a heat exchanger. An advantage of decentralized systems is that grey water is warm where it is collected. If 55 % of the grey water heat is recovered, CO_2 emission is reduced by about 71 kg per person and year.

Significant synergy effects can be utilized where decentralized solutions are combined with water and energy recovery. Not only water, but also energy that is contained in this water can be recovered. The required technology can be installed in a basement since it is quiet and almost odourless. Intelligent systems will be controlled by their heat demand, i.e. they are automatically switched on and off depending whether warm water is needed.

Forecast – Short water, material and energy loops

Systematic cooperation is necessary for implementation of complex and holistic solutions that are based on integrated water, energy and, last but not least, solid waste management. The ambitious objective of achieving integrated resource management on a small and local scale requires cooperation by experts in various fields, cooperation by consulting engineers, architects, urban planners, waste management experts, energy engineers, economists, politicians and others. Most important hereby is that we close and consequently integrate "**s**hort **W**ater, **M**aterial and **E**nergy **c**ycles" (sWMEc) under consideration of preventive health and environment protection. We are convinced that decentralized concepts with adapted technologies will be preferred in future, such as technologies permitting economical reuse of human excreta and bio-waste in biogas generating plants, collection of undiluted urine and reuse of its nutrients as fertilizer on farmland, or generation of service water and heat recovery from grey water. First pilot systems and experiences with such technologies are already available (e.g. Hans Huber AG, Berlin Water Works, GTZ).

In respect to planning, "**s**hort **W**ater, **M**aterial and **E**nergy **c**ycles" (sWMEc) have to be integrated into urban development concepts, whereby all local components are to be considered that are relevant for sustainable development of the infrastructure. As planned in a demonstration project for Amman (Huber und Arnold, 2007), the urban master plan shall take account not only of the spatial, but also of the social constitution of the urban development area. By flexible and modular design of individual quarters, a fair and just ground utilization is achieved that can be adapted to changing specific needs. It would be ideal if all water, material and energy systems could be integrated within the development area, even located in its centre.

Due to the wide range of sWMEc solutions, interesting markets open up for manufacturers, suppliers and consulting engineers. Great demand for holistic, innovative and decentralized solutions is expected particularly in emerging and developing countries where no widespread infrastructure has been built. But only those exporters will be successful who had the opportunity to test and demonstrate these technologies in their home countries. To safeguard her competitiveness in international markets, Germany must provide more experimental opportunities, must generate a favourable framework for innovative concepts and must strengthen policies supporting alternative projects. This would support our own efforts to develop and test new technologies and to conquer new markets for Hans Huber AG.

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