Technology

An accessible version of the article is available at http://waterresources.fona.de/reports/bmbl/annual/2010/nb/English/40/2-technology.html
Ensuring a basic sanitary supply for the world’s growing population and for the future is a global challenge. Research into flexible concepts and efficient and financially feasible technologies enables the constantly growing requirements for environmentally friendly water supplies and wastewater disposal to be met. Decentralised and transdisciplinary approaches play a crucial role in this area.
Global sustainability through customised local solutions – recycling and resource efficiency
Around a billion people still have no access to clean drinking water, and around 2.5 billion are without regulated wastewater disposal. The 2002 UN summit in Johannesburg highlighted the huge importance of drinking water supplies and wastewater disposal: the proportion of people having to live without clean drinking water and basic sanitation is to be halved by the year 2015. A simple direct transition of our methods to affected areas will not work as demographic change is storming ahead; adapted and efficient technologies and concepts are therefore required.

Designed decades ago for a much greater consumption of water, conventional, central supply and disposal systems depend on a high flow of water. However, household water consumption in Germany has been decreasing for years now, and the country’s demographic change suggests that this trend is set to continue further over the next few decades. To generate the pressure required to prevent solids from being deposited in the sewer systems, many areas are already having to pump in additional water. Smaller, decentralised concepts that can adapt to changing needs are therefore essential for the future.

Areas with a lack of water and ecologically sensitive regions can also implement customised, decentralised procedures so the available resources are used efficiently. However, this approach requires the entire local water system to be considered as a single entity, from water collection, treatment and distribution through to wastewater cleaning and recycling. Through integral examination and management, household wastewater can be treated and used as process water, and solids can be processed and used as fertiliser or converted into biogas for energy. Numerous projects funded by the Federal Ministry of Education and Research (BMBF) have investigated how tried-and-tested methods can be combined on site to form system solutions.

Example of China. “Semi-centralised”: this was the name given to a structure extending beyond individual building units, thus different from conventional centralised solutions. The “Semizentrale Ver- und Entsorgungssysteme für urbane Räume Chinas” project (semi-centralised supply and disposal systems for urban areas in China) primarily investigated the potential of this approach in China’s large, fast-growing cities (project 2.1.01).

Example of Germany. The “Sanitary recycling Eschborn” (SANiRESCH) project focussed on how to reduce water consumption for toilets and how the resultant urine water can be used in an environmentally compatible manner (project 2.1.02). The KOMPLETT project (2005 to 2009) was able to demonstrate that reusing all domestic wastewater and solids of a high yield density (e.g. in hotel complexes) could be made economically viable (project 2.1.03). Development, combination and implementation of innovative system components of process engineering, information technology and sanitary equipment to create a sustainable key technology for closed-loop water systems. “Production integrated measures for environment protection in hotel and catering industry in special consideration of existing built volumes” investigated how the concept described in its title could be implemented (project 2.1.04). “Recycling of Phosphorus – Ecological and Economic Evaluation of Different Processes and Development of a Strategic Recycling Concept for Germany” (PhoBe) is a project funded by the BMBF to see how scarce phosphorus can be efficiently recovered from effluent sludge; the researchers are also determining the production costs of the procedures involved (project 2.1.05). When it comes to connecting new building developments, local areas need to consider whether to expand existing sewer systems. At a new building development in Knittlingen near Pforzheim, a “Decentralised Urban infrastructure System 21” (DEUS 21) was drafted and implemented (project 2.1.08).

Example of Vietnam. The issue of resolving contamination through mineral fertilisers and human excrement is being investigated under a German-Vietnamese project called “Closing Nutrient Cycles in Decentralised Water Treatment Systems in the Mekong-Delta – SANSED” (project 2.1.06).

Example of Turkey. Environmentally friendly waste and wastewater disposal or energy supplies are a rarity among tourist facilities. One solution could be “Integrated modules for high-efficient wastewater treatment, solid waste disposal and regenerative energy production in touristic resorts” (MODULAARE) (project 2.1.07).
Semi-centralised supply and disposal systems – dynamic solutions for China’s growing major cities

China’s cities are growing at a rapid rate: hoards of people are drawn to these overcrowded areas in search of work. The supply and disposal infrastructure is not designed to cope with this, and high pollution levels are the result. “Semi-centralised” concepts for water supplies and the treatment of waste and wastewater in rapidly growing urban areas are one solution to this: they are flexible and can be adapted to the population growth within cities.

With growth rates of up to 1,000 people a day, conventional centralised and above all sectoral-based supply and disposal strategies in urban areas are quickly hitting their limits. This problem is also evident in the People’s Republic of China: the rapidly expanding cities have outgrown the water supply, waste and wastewater treatment and spatial planning; the environmental problems are equally acute.

This is the area tackled by the project cluster “Semizentrale Ver- und Entsorgungssysteme für urbane Räume Chinas” (semi-centralised supply and disposal systems for urban areas in China), which was led by the IWAR institute at the Technische Universität Darmstadt (Technical University Darmstadt) and ran from 2004 to 2010. “Semi-centralised” is still new in terms of spatial reference planes; it is a structure that extends beyond individual building units and is thus different from conventional centralised solutions. The aim of this: to enable flexible adaptation of supply and disposal units to the dynamic development of major cities, which in China are characterised by rapid growth and quickly changing structures.

An initial subproject in 2004/2005 tackled the structural and legal frameworks; subsequent projects investigated technical aspects in pilot facilities in both Germany and China, conducted public relations (EXPO 2010 in Shanghai) and produced a cost comparison between examples of a conventional and an integrated semi-centralised supply and disposal unit.

The aim of the second phase of the project (which ran from 2005 to 2008) was to develop supply and disposal systems that could actually achieve sustainable use of resources through an extensive water and energy cycle. This required integrated planning for the technical facilities. The project team developed a modular system for supply and disposal (water, wastewater, waste) that is flexible enough to adapt to local conditions and applies both technical and organisational synergies. The wastewater-related research involved investigations into greywater treatment and inner-city water recycling. Various procedures were examined in terms of the achievable drainage qualities, space and energy requirements and more.

Integrated approach

Semi-centralised supply and disposal systems provide a consistently high level of quality for water infeed and drainage, a secure way to treat sewage sludge and waste and autonomously produce enough energy to run the systems independently. The concept combines the various technical infrastructure elements for water, wastewater and waste both with each other and within spatial planning. This needs specific legal, socio-cultural, ecological and economic considerations to be taken into account, as well as the administrative and technical structures and resources available locally. In order to promote synergies, it is important to make efficient use of interfaces between spatial and infrastructural planning and also between the individual technical modules. For example, this could be energy recovery through integrated treatment of waste and sewage sludge or reusing inner-city water to flush toilets (integrated infrastructure planning).
Proven technologies

The main aims of combining various modules to form one overall technical system are to achieve a material flow cycle and to reuse nutrients and energy found in wastewater and waste. Proven technology is used in these modules: aerobic and anaerobic wastewater treatment, fermentation and mechanical-biological waste treatment, energy and material recycling and water collection and treatment. Industrial-scale test facilities were also used to examine new technical challenges such as membrane cleaning via ultrasound and industrial greywater treatment using a variety of treatment procedures.

The semi-centralised approach has attracted immense global interest in the meantime; this was reflected at its appearance at EXPO 2010 in Shanghai, where it was presented within the "Urban Planet" pavilion as a forward-looking infrastructure solution for cities of the future.

Project website ▶ www.semizentral.de
Knowledge of new sanitary systems is growing in Germany. However, further research and development is required for all system components before production can begin. The “Sanitary recycling Eschborn” is helping to achieve this: the focus of its work is on how to implement the alternative solution approach and use wastewater in an environmentally compatible manner. A federally owned company is being used for the demonstration, and the initial results of the project are coming in.

The current level of knowledge within Germany about innovative sanitary systems is not yet sufficient to allow large-scale implementation: many of the technologies involved must be developed further (e.g. diversion-flush toilets), and approval is not yet in place for recovered products such as urine and struvite to be used in farming. A research and demonstration project is looking into how this situation could be amended: “Sanitary recycling Eschborn” (SANIRESCH) is being run by the Deutschen Gesellschaft für Internationale Zusammenarbeit (GIZ, German association for international co-operation) with scientific support from RWTH Aachen University, the University of Bonn, Gießen university, Huber SE and Roediger Vacuum (period of study: 2009 to 2012).

The GIZ installed a sanitary system for the separate collection of urine, brown water and greywater when it modernised its main building in Eschborn near Frankfurt in 2006. This system includes diversion-flush toilets, waterless urinals, separate piping systems for urine, brown water and greywater and urine storage tanks. SANIRESCH is looking at how to treat and recycle wastewater, examining both staff acceptance of the new sanitary system and also how urine could be used in farming. Economic efficiency and ability to transfer the approach to other countries are additional considerations.

Numerous project modules

The project consists of various components, with the project partners working on these alone or in collaboration.

Sanitary and in-house installations: The GIZ headquar- ters features 25 waterless urinals (Keramag) and 48 diversion toilets (Roediger Vacuum) to separate the wastewater – the latter are being tested in continuous operation.

Wastewater as a resource – the promising SANIRESCH demonstration project

The GIZ installed a sanitary system for the separate collection of urine, brown water and greywater when it modernised its main building in Eschborn near Frankfurt in 2006. This system includes diversion-flush toilets, waterless urinals, separate piping systems for urine, brown water and greywater and urine storage tanks. SANIRESCH is looking at how to treat and recycle wastewater, examining both staff acceptance of the new sanitary system and also how urine could be used in farming. Economic efficiency and ability to transfer the approach to other countries are additional considerations.

Numerous project modules

The project consists of various components, with the project partners working on these alone or in collaboration.

Sanitary and in-house installations: The GIZ headquar- ters features 25 waterless urinals (Keramag) and 48 diversion toilets (Roediger Vacuum) to separate the wastewater – the latter are being tested in continuous operation.

Plan technology: A precipitation reactor is treating the collected urine using a chemical-physical process; magnesium oxide is added to produce solid magnesium ammonium phosphate (MAP), which is a valuable fertiliser for use in agriculture. Brown water treatment takes place in a membrane bioreactor (MBR), once the solids have been removed. The MBR uses ultrafiltration to remove solids and bacteria, as well as almost all viruses. The resultant filtrate is then hygienic enough to use for irrigation. An MBR is also used to treat greywater (water from the kitchen sink/hand-washing), with the resultant process water being used to flush the toilets.

Quality of the products / Storage of urine: When urine is stored, the pharmaceutical substances can degrade; this degradation is to be quantified. Lab tests are also being used to adapt the storage conditions (e.g. by varying the pH value) so that urine storage can be improved in terms of removing harmful substances.

Agricultural production SANIRESCH is conducting fertiliser tests using stored urine and MAP in the open field. The primary focus is the effects on renewable raw materials (miscanthus) and crops. The legal framework conditions for recycling urine in Germany are being clarified and recommendations are being developed for authorities.
Acceptance: Studies intend to determine the level of acceptance of urine as a fertiliser among users and cleaning staff at GIZ and also farmers and consumers.

Economic feasibility: One project module is dedicated to determining the costs of investment, operation and reinvestment, and also the amortisation point. The project also seeks to make an economic comparison of this concept with other technical solutions.

International adaptability: The objective is to determine regions particularly suited to the sanitary concept and the technologies used and to identify the ways in which they can be used. The necessary adaptation to be able to implement the technologies successfully in specific cases in emerging and developing countries is also being determined.

Initial project results

The research project was launched in July 2009; the following results relate to the first year of the project.

When it comes to employees, the urinals and toilets are the only visible components of the system. The state of the sanitary facilities is thus crucial to their acceptance. It became evident that the Roediger diversion toilets need to be modified: the valve responsible for diverting the urine has already been improved in order to facilitate installation and improve throughput.

The urine storage tests showed that the urine contains pharmaceutical residues that even at the end of the six-month storage period were not completely eliminated. Initial measurements showed concentrations of heavy metals to be beneath the limits of the German Drinking Water Ordinance (TrinkwV, 2001); it is therefore assumed that this could be used within agriculture without any issues. Tests on the urine precipitated as MAP indicated that no active pharmaceutical agents were included within the precipitated product. Analysis is still required to determine whether agents are adhering to the surface of the MAP crystals and forming part of an organic matrix.

Regarding the effect of the fertiliser, an ongoing field test is fertilising parcels of land containing wheat and broad beans with urine. These crops have displayed good growth, equivalent from a visual perspective to those on parcels of land receiving mineral fertiliser. Although more detailed results are still pending, it is expected that there will only be slight differences in comparison with mineral fertiliser.

The economic feasibility study analysed the investment and operating costs of the sanitary installations implemented within the building (toilets, urinals, piping systems, urine tanks) compared with the conventional system, which was installed in the wings of the building at the same time. The sanitary installation costs for the SANIRESCH version were EUR 0.088 per use, compared with EUR 0.071 for the conventional version. This difference is due to the considerably higher investment costs.

Project website ► www.saniresch.de
The objective of the "Komplett" project was to separate out domestic wastewater for treatment and to reuse virtually all of this resource. The project also intended to develop new sanitary ceramics for WC’s that are lighter (and thus save resources during production), reduce water consumption and possess antibacterial properties.

There are still around 1.1 billion people without access to clean drinking water and around 2.5 billion with no sanitation facilities – meaning that a considerable proportion of the global population has either no or insufficient access to basic human needs. According to forecasts produced by UNESCO, between two and seven billion people worldwide – depending on the scenario – will suffer from a lack of water by the middle of the century. Regions particularly affected are those that supply tourists in addition to their native population (at approx. 400 litres per person per day, tourist water consumption is extremely high). The provision of hygienic, problem-free water is also one of the major future tasks faced by states in central and southern Europe. Reusing treated domestic wastewater has the potential to make a vital contribution to this.

A research project funded by the Federal Ministry of Education and Research (BMBF) saw practical tests conducted for a concept involving almost entirely closed water cycles. The project was run by sanitation firm Villeroy & Boch from 2005 to 2009 and was called "Development, combination and implementation of innovative system components of process engineering, information technology and sanitary equipment to create a sustainable key technology for closed-loop water systems – Komplett project". The objective was a system that enables the reuse of all the wastewater produced domestically and also all solids.

The project comprised a preliminary testing, pilot-plant and full pilot phase. Phase one involved tests to characterise the two different wastewaters (greywater and blackwater). Lab tests were then performed in order to evaluate and improve individual system components (the biological treatment of wastewater in particular). Initial tests to compost the solids were also conducted, and new sanitation products were developed. The project enabled the development of new sanitary ceramics and lighter sanitary items.

Test facility in Kaiserslautern

The pilot-plant phase used a testing facility on a semi-technical scale to treat the two partial flows of greywater (from showers, hand basins, washing machines) and blackwater (from toilets) from a block of flats in Kaiserslautern for ten months. As well as biological treatment stages, the trial tested process stages for additional chemical-physical water treatment and the disinfection and elimination of trace elements. Functional tests of the sanitation products, the system’s measuring technology and the software for displaying the readings took place at the same time. The project team also tested vermicomposting (which is processed using special worms) of the remaining substances.

Pilot facility in Oberhausen

The final test phase was the operation of pilot-scale treatment facilities on the premises of the Fraunhofer Institute for Environmental, Safety, and Energy Technology (UMSICHT) in Oberhausen – with the wastewater from one of the institute’s buildings and the nearby “Centro” shopping and leisure complex. The systems for sanitation and...
treatment technology were coupled with those for recycling and visualisation, while the blackwater cycle was fully closed (treated water used to flush toilets and urinals) and the greywater cycle was largely closed (treated greywater used for showers and washing machines). This made it possible to inspect the accumulation of non-degraded substances in both water cycles. The project partners investigated acceptance of the sanitation products and water recycling in order to assess the recycling potential. The concluding tasks were a cost analysis of the Komplett system and a comparison with the costs of conventional technology for water supply and disposal. The results showed that the system can be used economically in areas lacking the infrastructure for supply and disposal and with a high use density, e.g. in hotel complexes. The aims of the project were therefore achieved.

Flushing with just 3.5 litres

The flush-optimised toilets and urinals with photo-catalytic surfaces were pilot tested in Oberhausen. A new, 20% lighter sanitary ceramic was developed during the project; this saves considerable resources during production and also provides an antibacterial surface. The new 3.5-litre WC can flush away faeces and paper without any problems using two litres less water. Compared with a 6-litre WC, it saves 17,000 litres of drinking water a year in a four-person household. However, there is a higher proportion of solids in the blackwater portion of the Komplett system; while this reduces the cost of blackwater treatment, it does require adapted pipes to be installed in the home.

Project website  www.komplett-projekt.de

Villeroy & Boch AG
Environment/Safety/Research – Corporate Coordination
Danuta Krystkiewicz
Postfach 11 20
66688 Mettlach, Germany
Tel.: +49 (0)6 86/4 81 13 32
Fax: +49 (0)6 86/4 81 14 16
E-mail: krystkiewicz.danuta@villeroy-boch.com
Internet: www.villeroy-boch.com

EnviroChemie GmbH
Dr.-Ing. Markus Engelhart
In den Leppsteinswiesen 9
64380 Rossdorf, Germany
Tel.: +49 (0) 61 54/69 98 57
Fax: +49 (0) 61 54/69 98 11
E-mail: markus.engelhart@envirochemie.com
Internet: www.envirochemie.de
Funding reference: 02 WD 0685
Water recycling in hotels – business as usual during conversion work

Water consumption per person is much higher in hotels and guesthouses than it is in private households: a guest in a German hotel uses around 300 litres of water a day on average – more than twice the amount they would use at home. If the venues also have golf courses and swimming pools, consumption can be as much as 1,000 litres per overnight guest per day. The amount of fresh water used could be reduced significantly if the greywater produced on site were to be treated. One project shows that it is possible to make the necessary conversions without suspending business operations.

“Production integrated measures for environment protection in hotel and catering industry in special consideration of existing built volumes” was a research project run by the Institute for Environmental Engineering (ISA) at RWTH Aachen University from June 2006 to May 2009 that investigated how the concept described in its title could be implemented. The focus was on demonstrating that even standard systems for treating process water can considerably reduce the consumption of drinking water in hotels, and that the conversion work can take place with hotel business running as usual.

The ISA was able to secure the four-star “Hotel Am Kurpark” in Bad Windsheim (Middle Franconia) as a project partner. Founded in 1981, the hotel has 50 guest rooms with 90 beds, a restaurant seating around 100, plus conference rooms and a sauna. The bulk of the accommodation is located in the main building, with 20 guest rooms and the seminar rooms in a separate building (built 1992, extended 1998). The hotel’s water consumption increased considerably between 2001 and 2007 (see diagram).

Greywater treatment system

The greywater treatment system was installed by Hans Huber AG (Berching) in November 2008. The structure of the building made installation of the new water pipes unexpectedly difficult as they had to be integrated into the existing pipeline shafts. As hotel business was not to be interrupted, chasing and tiling was restricted to a bare minimum. While the seminar building was connected within the ten-day construction phase, work in the main building’s cellar and the connecting shaft between the two buildings was conducted outside of this period. Overall, 460 metres of piping were laid for greywater and process water.

Other sources integrated

The low amount of greywater specifically from the guest rooms (shower, bath, hand basin) made it necessary to connect other sources of greywater to the treatment system in order to make it financially viable. The ISA therefore split operation of the system into three phases for evaluation purposes.

During the first phase of operation, a greywater yield of 35 to 130 litres per guest per day was recorded, with the average being 52 litres. When the washing machines were added as an extra source in the second phase, the average guest-specific greywater yield rose to 72 litres per guest per day. The bar and the glass/dishwashers were connected in the third phase of operation, bringing the specific yield to a final average of 82 litres. Including other sources
of greywater in the treatment concept (connecting the bar and glass/dishwashers) meant that automated extraction of excess sludge was required.

Connecting extra greywater streams resulted in increased outflow concentrations: operating phase I recorded only three breaches of microbiological limits in the white water, but the microbiological quality of the white water deteriorated when other sources of greywater were connected. For some microbiological parameters, for which the ultrafiltration membrane (ultrafiltration) serves as a secure barrier (particularly for E. coli), the increased concentrations could only be traced back to recontamination effects within the permeate pipe. Adapting the recirculation rate enabled the required hygienic quality of the white water to be maintained even after tests in operating phase III (the diagram opposite provides a properties summary for the greywater and process water at all three phases).

Greywater becomes process water

The wastewater from the showers and baths is treated to turn it into high-quality process water, which is hygienically harmless and meets the requirements of the German Drinking Water Ordinance. This process water is used to flush toilets, in the prewash cycle of dishwashers and for irrigation and cleaning.

The project has demonstrated that concepts for water recycling can be implemented without affecting the running of the hotel. However, the extra construction effort involved may sometimes be considerable, thus increasing costs. Implementation is more economic in new builds or as part of general sanitation measures.
Phosphorous recycling – wastewater and sewage sludge sources of a valuable resource

Phosphorous is essential to all life. It requires a great deal of energy to take mined phosphate ore and produce mineral phosphorus fertiliser. What’s more, these ores are finite: current knowledge indicates that the known reserves economically viable for mining will be exhausted in around 100 years. Scientists have therefore been working for some years now on procedures enabling the efficient recovery of phosphorus from wastewater and sewage sludge.

One of these research projects was funded by the Federal Ministry of Education and Research (BMBF). Entitled “Recycling of Phosphorus – Ecological and Economic Evaluation of Different Processes and Development of a Strategical Recycling Concept for Germany” (PhoBe), it involved five institutes from various faculties and was led by the Institute for Environmental Engineering (ISA) at RWTH Aachen University. PhoBe (completion date: end of 2011) was an all-encompassing project summarising the results of the projects funded under the BMBF “Recycling management of plant nutrients, especially phosphorus” initiative and providing global analyses. This funding initiative was launched in 2004 in conjunction with the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU).

As the price of mineral raw phosphate is a deciding factor in evaluating the economic feasibility of recycling procedures, a medium to long-term assessment (2030) of the global price development was conducted within one of the eight work packages. The relevant phosphate-rich material flows in Germany were also identified and qualitatively measured. The phosphate products obtained from the recovery processes developed as part of the funding initiative were analysed for impurities and evaluated for their effectiveness as a fertiliser compared with conventional phosphate fertilisers (such as triple superphosphate).

In an additional step, the specific production costs of the developed processes were determined using a cost assessment and the processes were balanced in terms of ecological aspects. The step to follow this was to use the results gained to develop a recovery concept for Germany that demonstrates which material flow is appropriate for recycling. Another key focus was to look ahead from a technology perspective, by means of a survey of experts and the identification of future prospects for phosphorus recycling in Germany.

Forecast for price development

A methodical approach was used for the medium and long-term price development of phosphate, beginning by analysing the fundamental data separately – the development of supply and demand – and then merging them for a subsequent price development. Two scenarios were examined, assuming a rise in phosphate consumption (one or two percent a year). The slow increase mirrors the development of recent years (Business as Usual, BAU); the faster increase would be due to increasing cultivation of plants for biofuels.

As phosphoric acid is the base substance in producing phosphate-based fertiliser, the price development of both raw phosphate and phosphoric acid was assessed: the first scenario saw an increase in the price of phosphoric acid to USD 660 a tonne by the year 2030 and the second saw an increase to USD 760 (see graph on the price development of phosphoric acid).

The analysis of the secondary phosphate obtained in the funding initiative showed that all the magnesium ammonium phosphate (MAP) produced was beneath the limits (and almost all products beneath the level for labelling obligation) of the 2008 German Fertiliser Ordinance. The effectiveness of the fertiliser was tested on the first and second crop of maize planted in sandy and clay soil in comparison with triple superphosphate, raw phosphate and a zero control. Results so far indicate that the...
recovered secondary phosphate is in no way significantly different from triple superphosphate and is therefore comparable with conventional fertilisers in this regard.

**Secondary phosphate is not yet competitive**

The cost assessment of the processes developed during the funding initiative showed that the specific production costs for a kilogram of secondary phosphate are – depending on the technical effort required and the recovery potential of the process – between EUR 2 and 13 per kilogram and are therefore not yet in a position to compete with conventional phosphate fertiliser (approx. EUR 1.50/kg). And yet phosphate recycling is worth it even today: in cases where there is an additional benefit – such as avoiding pipe blockages due to deposited MAP or improving the drainage of sewage sludge.

The material flow balance produced for Germany states that the amount of phosphorus in wastewater and sewage sludge theoretically available for phosphorous recycling is around 70,000 tonnes a year. The contribution from sewage sludge is particularly significant, around a quarter of which is currently disposed of in mono sewage sludge incinerators. The combustion process destroys most of the germs, odorous substances and organic matter, but the phosphorus content is still fully present as a residue in the ashes. Tests have shown that the proportion of phosphorous in sewage sludge ashes is around 6% and thus the highest concentration of phosphorus compared with other sources (sewage plant outflow, sludge liquor, sewage sludge).

---

**Potential of up to 45,000 tonnes**

The mono-incineration capacities in Germany are around 520,000 tonnes of sewage sludge a year, with current operation at more than 90%. If all sewage sludge ashes produced from mono incineration were fed into phosphorous recovery, around 13,000 tonnes of phosphorous could be recovered every year. If sewage sludge that does not undergo mono incineration or agricultural recycling were to be included, the major sewage plants (for >100,000 residents) could recover a further 5,000 tonnes. Assuming that agricultural recycling of sewage sludge will be further restricted in future and thus that heat recycling will increase, a scenario has been calculated in which all sewage sludge is burned in mono-incineration facilities and then used for recovery: this would recover around 45,000 tonnes of phosphorous a year, equating to around a 60% substitution of phosphorus fertiliser.

Experts believe that phosphate recycling could be implemented in industrial countries between now and 2030 and be economically viable – this is the result of a survey called “Dringlichkeit der Phosphorrückgewinnung, Erfolgsfaktoren der Phosphorrückgewinnung aus Abwasserbehandlung und Klärschlamm, Potenziale der Rückgewinnung aus Klärschlammmasche und Phosphatrückgewinnung im Kontext eines Systemwandels in der Wasser- und Abfallwirtschaft” (phosphate recovery as a priority, success potential of phosphorus recovery from wastewater treatment and sewage sludge, potential of recovery from sewage sludge ash and phosphate recovery within the context of change of system to a water and waste economy).

Project website ➤ [www.phosphorrecycling.eu](http://www.phosphorrecycling.eu)
Although Vietnam gets plenty of rain, many regions lack both clean drinking water and water for farming. The Mekong Delta is one such region: a German-Vietnamese project is developing water supply and disposal solutions to suit the conditions found there. This not only involves securing drinking water for the population, but also recovering recyclable products from wastewater treatment for use in agriculture, e.g. compost and biogas.

The Mekong Delta in southern Vietnam is home to around 17 million people, about a fifth of the country’s population. Most of them work in agriculture or fish farming. Around half those living in the cities have access to a regulated water supply and disposal facility, as opposed to just 10% in rural areas. As there are only a few sewage plants, most of the wastewater ends up getting into the rivers without being treated, and often fish ponds too in the rural regions.

Increasing water consumption in the Mekong Delta is causing the groundwater level to drop. Seawater is frequently getting into the groundwater in coastal areas, resulting in rising salt concentrations. Farming is the region’s greatest consumer of water: farmers use around 90% of the water for growing rice because although the precipitation is plentiful, rice fields still need intensive irrigation.

Obtaining organic fertiliser from sewage water

Farmers use large amounts of expensive mineral fertiliser in order to increase the crops from their rice fields. But there could be cheaper and more environmentally friendly ways to add nutrients to the soil: human excrement, which currently contaminates the water. The German-Vietnamese SANSED project investigated how this could be achieved (full name “Closing Nutrient Cycles in Decentralised Water Treatment Systems in the Mekong-Delta”). The universities of Bonn and Bochum, Can Tho university in Vietnam and numerous German companies were involved in the project.

Decentralised systems aim to process drinking water as cost-effectively as possible while simultaneously treating wastewater so that local farmers can make use of the sludge and compost. In an ideal scenario, the 120,000 or so tonnes of nitrate and 19,000 tonnes of phosphorous produced in the Mekong Delta every year could be returned to the nutrient cycles through an environmentally friendly process.

Seven aspects

Decentralised wastewater disposal and water supply systems that are adapted to local structures and also factor in the low income of the population are especially useful. The second phase set up demonstration systems and operated them together with Vietnamese partners: SANSED wants to demonstrate that the cost of constructing and operating the systems can be refunded through the sale of the products produced (biogas, fertiliser, compost). There were seven sub-projects within SANSED.

Biogas: The country’s typical biogas plants, which use bacteria to break down waste, either do not produce enough gas or allow excess amounts to escape unused. The approach followed by SANSED uses fungi to break down degradation-resistant polymers in sugar; this triggers increased activity in the bacteria and thus increases the gas yield. Excess gas can be converted into power or stored in bottles.

Partial wastewater flow treatment: The project team installed toilets that separate the wastewater from the faeces in two university halls of residence to serve as models for wastewater cleaning. The urine and solids were used to obtain fertiliser for farming and biogas. Pathogens and organic contaminants from the urine were either removed or at least considerably reduced through sun-drying. The earthworms added to the solids converted the substrate into compost (cold rotting).
Wastewater sieving/soil filtration: At one of the halls of residence, fine sieves filter out solids from the wastewater. The water is then cleaned further through soil filters, and the solids are composted.

Drinking water from surface water: One system treated surface water polluted with organic substances and micro-organisms – using slow sand filters and sunlight (UV disinfection) among other things – to supply water to one of the halls of residence.

Drinking water from groundwater: The scientists optimised the drinking water supply for around 100 households: quick sand filters treated the heavily ferrous groundwater.

Further training: Many districts in Can Tho have a central supply of drinking water that could be described as process water at best. There is also a system that involves filling containers with drinking water. The project team devised a special information and training programme for the staff at the Can Tho Water Supply and Sewerage Company.

Handling recommendations: The team collaborated with the local supply company to create a sample feasibility study using a district of Can Tho that previously had no regulated water supply or disposal: the study shows where it would be useful to implement (de)centralised systems.

Verifying transferability

The SANSED project is to be used as a basis to verify whether decentralised wastewater treatment and water supply systems could be used in other regions with poor infrastructure.

The SANSED final report appeared in volume 31 of the “Bonner Agrikulturchemische Reihe” (Bonn agriculture-chemical series, ordered and purchased via www.ipe.uni-bonn.de/publikationen).

Further information can be found on the project website. Project website ➤ www.sansed.uni-bonn.de
Many tourist resorts in southern countries do not have any environmentally friendly means of waste and wastewater disposal or energy supply. The MODULAARE research and demonstration project used a Turkish hotel complex to test a sustainable solution to these problems: the procedure developed combines the fermentation of organic waste with membrane technology for wastewater cleaning. The resulting products: process water, fertiliser and biogas.

Tourist resorts cannot enjoy stable economic development if their environment is not intact. Heavily visited regions, rapidly growing new resorts and ecologically sensitive areas in particular need to orient their tourism toward the guiding principle of sustainability – and ensure that their energy and water supplies and waste and wastewater disposal facilities are environmentally compatible.

Spot checks have determined a daily water consumption of up to 1,200 litres per guest in international holiday hotels (including apportioned consumption for green facilities and swimming pools). By way of comparison: households in Germany currently consume about a tenth of this, an average of 123 litres per resident per day. Waste-water often flows – poorly cleaned – into rivers or directly into the sea because sewage facilities in the hotel complexes are either poorly maintained or lacking altogether; it is often not possible to be connected to the central wastewater disposal system as tourism resorts are often outside built-up areas. Waste disposal causes just as many problems: large hotels produce up to 2.5 kilograms per guest every day, which is often disposed of at unauthorised dumps.

**Integrated concept for tourism regions**

One answer to these problems, particularly in ecologically sensitive regions, are “Integrated modules for high-efficient wastewater treatment, solid waste disposal and regenerative energy production in touristic resorts” (MODULAARE). This is the title of the project combining membrane technology in wastewater treatment and anaerobic fermentation in the treatment of bio-waste to enable targeted nutrient flow management for wastewater and organic waste. This results in a virtually closed nutrient cycle in an almost wastewater-free hotel – and also produces valuable by-products such as process water, fertiliser and energy.

To put this procedure to the test in a practical setting, the international project team set up a test facility at the “Hotel Sarigerme Park” on the Turkish Aegean coast in 2005. Concluded in 2008, the project was managed by the Verband zur Förderung angepasster, sozial- und umweltverträglicher Technologien e.V. (AT-Verband, association for the promotion of adapted, social and environmentally compatible technologies, Stuttgart); the Institute for Sanitary Engineering, Water Quality and Solid Waste Management at the University of Stuttgart was in charge of scientific management, MEMOS Membranes Modules Systems (Pfullingen) produced the membrane technology and Bio-System Selecta GmbH (Konstanz) produced the anaerobic system. The administrative authorities for the island of Mainau on Lake Constance supplied basic data and supported the project’s public relations.

**Membranes cleaning the wastewater**

The procedure used recovers biomasses from the wastewater via membranes – not through final clarification (sedimentation) as usual. Membranes not only remove all solids, but also large amounts of germs and viruses. The membrane bioreactor upstream is a mechanical cleaning process that removes the solids. The membrane filtration enables increased concentrations of biomasses (experts refer to a higher space-time yield): bio-membrane reactors operate with biomass contents of 10 to 15 grams per litre. This value is about three times higher than conventional activated sludge reactors (approx. 4 g/l) because the biomass concentration in the activation no longer depends on the sedimentation behaviour in the secondary settler. The MODULAARE process provides further treatment of excess sludge together with kitchen and garden waste in the fermentation module.
The membrane system offers a number of technical ways to eliminate nutrients. Carbon, nitrogen and/or phosphorus can also be reused to some extent – depending on the intended use of the cleaned wastewater. Phosphorus can be used within garden irrigation as a fertiliser; the process can also provide soil protection, especially in areas with a negative humus balance like the Mediterranean area. The modular nature of the system allows it to adapt to seasonal fluctuations in guest numbers, be it through a different solids content or activated/deactivated membrane modules.

Biogas covers energy requirements

Hotel waste can consist of more than 70% organic material. Due to the nature of the waste, only around a third of it can be treated aerobically (compost) without major technical efforts. The high water content and the structure of the material means there can be sufficient anaerobic areas to result in considerable odour; compost can also easily dry out in Mediterranean and arid zones due to the high air temperatures. Fermentation on the other hand can treat up to 90% of the organic waste, and the fermentation residue can be used in agriculture.

The MODULAARE project has developed a practicable concept that permits optimum use of biogas: used either to provide heat or – converted into electricity – to cover the high amounts of energy required by the membrane bioreactor. Any wastewater (e.g. from drainage) is fed directly back into the membrane bioreactor.

Project website www.modulaare.de

Verband zur Förderung angepasster, sozial- und umweltverträglicher Technologien e.V. (AT-Verband)
Dr. Udo Theilen (Co-ordinator)
Dieter Steinbach, Andrea Schultheis (MODULAARE overall concept)
Waldburgstraße 96
70563 Stuttgart, Germany
Tel.: +49 (0)7 11/35 52 79
Fax: +49 (0)7 11/35 52 80
E-mail: atverband@aol.com
Internet: www.at-verband.de
Funding reference: 02WD0440

University of Stuttgart
Institute for Sanitary Engineering, Water Quality and Solid Waste Management
Departments of Wastewater Technology and Siedlungsabfall (municipal waste)
Prof. Dr.-Ing. Martin Kranert (scientific management)
Bandtäle 2
70569 Stuttgart, Germany
Tel.: +49 (0)7 11/68 56 55 00
Fax: +49 (0)7 11/68 56 54 60
E-mail: martin.kranert@iswa.uni-stuttgart.de
Internet: www.iswa.uni-stuttgart.de
Funding reference: 02WD0441
When it comes to connecting new building developments to the water supply and disposal system, local authorities are faced with a choice: should the existing sewer system be expanded, or should a decentralised solution be implemented? The Fraunhofer Institute for Interfacial Engineering and Biotechnology used a model project in Knittlingen near Pforzheim to demonstrate the benefits of a semi-decentralised concept: as this method uses rainwater, it reduces the level of fresh water consumption. It also produces fertiliser for farmers and its operation is energy-neutral.

Industrial nations generally apply a combined-system principle to wastewater disposal: rainwater is used to dilute the wastewater before it enters the central sewage plant. This process is counter-productive as the sewage plant has the laborious task of extracting the contents from the water. A practical alternative from both an economic and ecological perspective could be to use cycle-oriented, semi-decentralised systems for water supply and wastewater disposal – in emerging and developing countries too.

The Fraunhofer Institute for Interfacial Engineering and Biotechnology (IGB) implemented such a concept as part of the “DEcentralised Urban infrastructure System 21” (DEUS 21) project in 2005, selecting a new business development with 100 buildings in Knittlingen near Pforzheim. The Fraunhofer Institute for Systems and Innovation Research (ISI) is working alongside the project to compare the ecological and economic aspects of the system with those of conventional processes.

Semi-decentralised concept for a new building development – the Knittlingen “water house”

The water house in Knittlingen

A vacuum sewage system sucks the domestic wastewater from transfer chutes in front of the houses; it is then treated in the water house in an anaerobic cleaning reactor with built-in membrane technology. The central vacuum station, commissioned in 2005, produces the vacuum required for this process. The builders can also lay a vacuum pipe in the home, enabling installation of a water-saving vacuum toilet and a shredder for kitchen waste.

Solids separated

Preliminary tests have shown that wastewater cleaning is more effective if the solids are separated beforehand. The output solids are therefore treated separately at 37°C using the high-load digestion process developed by the Fraunhofer IGB with integrated microfiltration. Fermentation of the solids produces up to 5,000 litres of biogas every day. The hydraulic retention time in the reactor is approx. ten days; the solids retention time is freely adjustable to a certain extent but is considerably higher. An unheated, fully mixed bioreactor with a volume of ten cubic metres is used to treat the overflow from the sedimentation tank (approx. 99% of the inflow); the outflow is handled by four parallel rotating disc filters (pore diameter of 0.2 μm).

The anaerobic sewage plant offers reliable functionality even at low temperatures: at reactor temperatures as low as 13°C the outflow values register less than 150 milligrams of the chemical oxygen demand (COD) per litre (limit value for sewage plants serving less than 1,000 residents). The inflow concentrations are between 400 and
1,100 milligrams COD per litre, with the average level of degradation at 85%. The maximum biogas production in the reactor for cleaning the primary treatment overflow is around 3,000 litres a day. The increase in biomass produces around 10% of the expected amount of excess sludge from the activated sludge procedure. Since its commissioning in March 2009, the membrane filtration has been cleaned through automatic filtrate backwashing, with the first chemical clean taking place in April 2010.

**Agricultural benefits**

The water flowing out of the plant was suitable for irrigating and fertilising farmland. The bioreactor breaks down virtually no ammonium or phosphate, both of which occur in relatively high concentrations in the wastewater. The membrane filtration removes the bulk of germs from the water, so it is therefore safe to use as fertiliser. Spot checks in the outflow from the rotating disc filters used in the membrane filtration revealed no traces of Escherichia coli bacteria, although it was present in the reactor sludge at a level of one million per millilitre.

If this cannot be used as fertiliser, one alternative is to recover the ammonium and phosphate: an electrochemical process precipitates the nutrients as struvite (MAP, magnesium ammonium phosphate). Excess ammonium is bound to zeolite by means of an ion exchange process and recovered as ammonium sulphate through air stripping.

**Energy-neutral operation**

The fully anaerobic process technology is able to convert most of the organic materials from the wastewater into biogas: a daily yield of 40 to 60 litres per resident – as opposed to just 25 litres from conventional wastewater cleaning through sludge digestion. The energy in the biogas produced through anaerobic wastewater cleaning is over 100 kilowatt hours per resident each year. Large sewage plants consume around 30 kilowatt hours of electrical energy per resident per year (and around 30 kWh thermal energy): in comparison, anaerobic conditions enable energy-neutral wastewater cleaning at the very least.

---

**Fraunhofer Institute for Interfacial Engineering and Biotechnology (IGB)**

Prof. Dr. Walter Trösch  
Dipl.-Ing. Marius Mohr  
Nobelstraße 12  
70569 Stuttgart, Germany  
Tel.: +49 (0)711/970-42 20  
Fax: +49 (0)711/970-42 00  
E-mail: walter.troesch@igb.fraunhofer.de  
marius.mohr@igb.fraunhofer.de  
Internet: www.igb.fraunhofer.de  
Funding reference: 02WD0457