

**SYSTEMS SOLUTIONS FOR  
WATER SUPPLY, WATER TREATMENT  
AND WASTEWATER PURIFICATION**



# WATER – A PRECIOUS RESOURCE

Water covers three quarters of the earth's surface but only about one percent is available to us as fresh water. Worldwide, 780 million people still have no access to clean water. 1.1 billion live without sanitation and 2.5 billion cannot rely on functioning wastewater disposal units. Even in Central Europe, the wastewater of entire cities still runs unpurified into surface waters. In developed countries, up to 25 percent of valuable drinking water is regularly lost due solely to leakages from water-pipes. This figure can easily cross the 50 percent mark in emerging and developing countries.

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## Water management – a global challenge

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The water infrastructure systems in industrialized countries are now more than 100 years old. Built according to the early technology of that time, they are, by today's standards, inefficient and expensive to run. Moreover, conventional water infrastructure systems in most highly industrialized countries are designed to use water once only. The idea of re-using water is completely foreign to most parties except for a few industrial production site-owners who run an internal system to recycle their water resources. At present, regenerative water supplies are not yet a major concern and could take a long time to catch on.

The value of the installed water infrastructure in Germany exceeds 1500 euros per head and the sewer system alone is valued at over 330 billion euros. Urgently required reconstruction work is currently estimated at 55 billion euros. In addition, relatively clean rainwater flows into the conventional mixed sewer system together with the pollutants it picks up on its way and dilutes the wastewater. Its purification is then not only energy and cost-intensive but also ineffective (mixed water overflow). Mixed sewer systems are faced with a major problem when heavy rainfalls occur and the capacity

of the stormwater tanks in a wastewater treatment plant is inadequate so that the mixed water overload is discharged unpurified into the environment. This type of system certainly does not set a good example for developing and emerging countries.

Water is undeniably the most important single foodstuff and experts fear that scarce supplies of clean water could trigger national and international conflicts during the course of the 21<sup>st</sup> century. Water management, i.e. easy access to clean water, a guaranteed supply of water, the installation of hygienic sanitary systems and efficient, compact wastewater purification, is therefore one of the major global challenges facing this century.

Innovations in all areas of water management are needed to help the world cope effectively with these major challenges. This holds true for both industrialized countries as well as for emerging and developing countries. Geographical and climatic factors such as the (seasonal) shortage of water in arid and semi-arid areas must also be taken into consideration (p. 5).



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### **New approaches, new technologies**

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The technological challenges in connection with water are manifold. Innovative approaches and methods are needed to use existing resources more effectively and to exploit new strategies, such as decentralized and adaptable infrastructure systems for collecting and distributing water or – just as important – finding possibilities for re-using water. It is obvious that rainwater should be treated to open up a new resource. Wastewater can be purified with modern, cost-effective filter technologies and in adapted biological processes. Ideally, the substances recovered from wastewater during the purification process can be recycled almost completely for energy and solids.

Humidity is a further source for the production of both drinking and process water of the highest quality. Our researchers are currently focusing on how to implement concepts to absorb atmospheric humidity in a hygroscopic salt solution and release it as usable water.

Over the past years, the Fraunhofer IGB has developed a comprehensive portfolio of technical innovations for sustainable water management, integrated in a holistic infrastructure concept which includes major aspects of energy supply and waste management. The institute adapts individual developments to the requirements of the region in question and combines various modules to find an optimum tailor-made solution for each specific case.

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### **Sustainable, energy-efficient water management**

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Providing water supplies and disposing of wastewater are not possible without energy, and a large proportion of the energy consumed by industrialized nations goes into the running of their water systems. Many town councils will find that the highest energy bills are run up by their own wastewater treatment plants. The treatment and supply of drinking water on a large number of international markets already requires a considerable amount of energy.

This has encouraged the Fraunhofer IGB to intensify its efforts even further to develop advanced energy-efficient technologies for water treatment. It is our aim to equip innovative electrophysical technologies with flexible process controls to deal with problems concerning the distribution of the electric network load in connection with the current new energy policy.

- 1 *Water is purified and biogas produced in an anaerobic wastewater reactor.*
- 2 *Water house, fully equipped with technology for semi-decentralized water management.*

# WATER MANAGEMENT AND INFRASTRUCTURE SYSTEMS

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## DEUS 21 – A semi-decentralized urban water infrastructure system

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The DEUS 21 water infrastructure system designed by the Fraunhofer IGB comprises technologies for the cost-effective and efficient management of water in urban structures through the semi-decentralized treatment of water and wastewater streams. Systems solutions are available for future-oriented municipal water management in rural regions, for newly developed areas, urban districts in need of modernization and also for holiday resorts, tourist centers and hotel complexes. The DEUS 21 system is especially effective for regions with no previous water infrastructure, lacking sewage networks and central sewage treatment plants. The concept is also ideal for areas where old types of infrastructure can no longer be adapted to cope with new challenges arising from climate changes or population increases/decreases. The DEUS 21 water management concept, already operating on a demonstration scale in Heidelberg-Neurott and Knittlingen, is especially suitable for export to areas suffering from water-shortage as it can be adapted specifically to the requirements of arid and semi-arid regions.

### **Saving water and costs**

Industrialized nations are used to wasting good drinking water although it would be relatively easy for each household to save this precious resource by installing appropriate faucets and toilets. Vacuum and pressure systems are excellent alternatives to conventional hydraulic sewers. Flushing toilets could be replaced by vacuum toilets, already common on airplanes, ships and trains and also in some Scandinavian households.

### **Use of rainwater**

There is no need to use good drinking water for such activities as watering flowers in the garden or flushing a toilet. Especially in regions where water is scarce, it is well worth-while for each household to use rainwater and treated

washing water for personal requirements. The Fraunhofer IGB has developed appropriate technologies to treat rainwater for subsequent use in households.

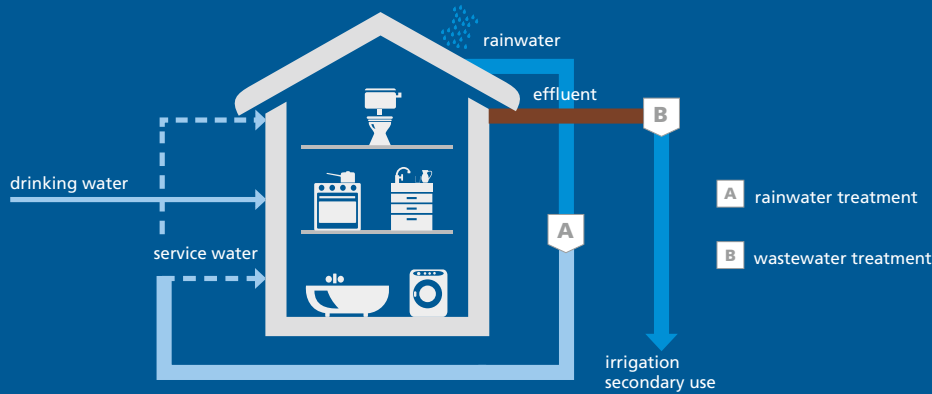
### **Anaerobic wastewater treatment**

Anaerobic biotechnology, where organic carbon compounds are converted into biogas, i.e. a mixture of carbon dioxide and methane, is an attractive alternative to today's common aerobic wastewater purification treatment especially for decentralized or semi-decentralized water infrastructure systems. Biogas can be used as a regenerative energy carrier for running combined heat and power plants or, alternatively, be fed into the existing natural gas network. Just like natural gas, biomethane can also be purified for use as fuel for automobiles.

Nitrogen and phosphorus compounds remain in the purified water and residual solids after anaerobic wastewater purification in enclosed bioreactors, which is not the case in the conventional, aerobic activated sludge process. Microorganisms can be removed by microfiltration with a rotating disk filter. This treatment supplies water that is hygienic and safe to use for irrigating agricultural land, economizing on both clean water and fertilizers. Alternatively, the nutrients can be recovered from the purified water (p. 14) for fertilizing purposes. In this case, the water can then be discharged into the environment or re-used.

In combination with sustainable waste management concepts, energy from regenerative sources and innovative building services engineering, the DEUS 21 concept is a holistic solution for a self-sufficient water supply infrastructure which is completely independent of central water supplies and wastewater disposal networks.

**For detailed information, please visit**  
[www.deus21.de](http://www.deus21.de)



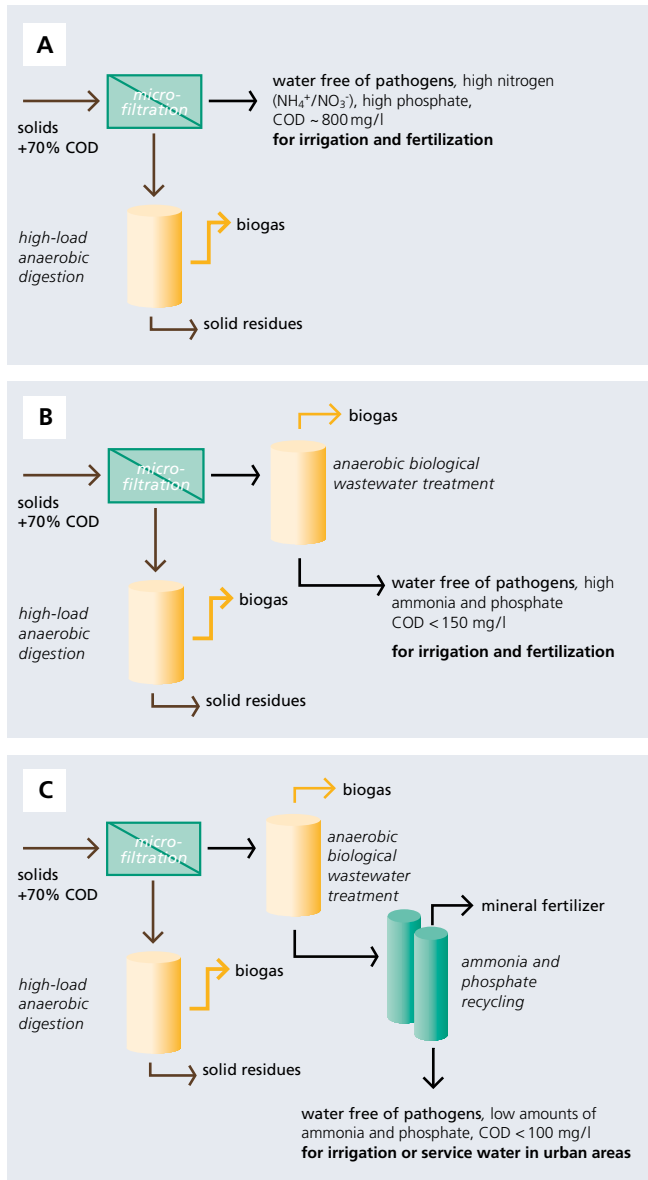
Solutions for arid and semi-arid regions

Obviously, regions with low precipitation characterized by long periods of drought and high insolation need different infrastructure systems for reliable water supplies and wastewater disposal compared to central Europe. The technologies developed at the Fraunhofer IGB are suitable for both arid and semi-arid areas, and can be adapted to the requirements of individual regions.

The rotating disk filter is an innovative microfiltration technology (p. 17) which separates solids from water together with up to 70 percent of the chemical oxygen demand (COD) of the raw effluent. The filtered water no longer contains pathogenic bacteria, but it does contain nitrogen compounds and phosphate, and its COD is below 800 mg/l. The filtered water can be used directly for irrigation and fertilization purposes. The separated solids are anaerobically biodegraded and converted into biogas (Fig. 2 A). Alternatively, once the solids have been removed, the wastewater can be treated in an anaerobic bioreactor where the organic carbon compounds are converted into biogas and the nitrogen compounds into ammonium. This water can then be used for irrigation and fertilization or as process water for low-value industrial purposes (Fig. 2 B).

For higher-quality uses and in urban areas with a greater population density, ammonium and phosphate must be recovered from the water in order to achieve the water quality required for approval by the authorities. They can then be used for the production of mineral fertilizers (Fig. 2 C). The degree of purity and the efforts required to purify wastewater are determined by the subsequent use of the element.

2 Adaptation of various IGB technologies to arid and semi-arid regions



# GENERATION OF DRINKING WATER AND WATER TREATMENT



Many regions of the world are experiencing an alarming shortage of natural drinking water resources due to climate changes, high consumption and increasing populations. In coastal areas, such as in Southern Europe and on many Mediterranean islands, groundwater is already oversalinated due to infiltration from seawater. Precipitation is often on the decline while demands for water continue to increase. Some islands now depend on tankers to supply them with sufficient quantities of drinking water. Pressure from increasing populations and the tourist industry will exacerbate this situation even further in the near future. It is not hard to foresee that it will become more and more difficult to obtain drinking water from constantly renewable fresh water sources.

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## **Solar desalination of seawater in a gravitation-supported vacuum evaporation plant**

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Today, many areas depend entirely on the desalination of brackish or sea water for their drinking water supply. However, established desalination technologies, such as reverse osmosis or conventional thermal processes, are high on energy, and consume, either directly or indirectly, large amounts of fossil energy which cause significant CO<sub>2</sub> emissions.

The Fraunhofer IGB is developing an energy and cost-effective alternative in which thermal energy can be used at comparatively low temperatures for the multi-stage vacuum evaporation of water. In our innovative solution, the vacuum necessary for evaporation is created and maintained solely by means of gravitation. The process is controlled mainly by hydraulic and mechanical components so that electrical measurement, control and regulating equipment can be kept to a minimum. The technology is uncomplicated, robust and modular in construction. Simple thermal solar collectors provide the necessary heat, and a few photovoltaic modules are sufficient to fuel the electrical components making the process independent of fossil energy and the general power supply system. The plant can also work on heat from industrial processes and other sources.

The technology is suitable for small to medium-sized plants for decentralized, sustainable drinking water treatment with a daily capacity of 100 liters to approx. 10 m<sup>3</sup> as well as for small-scale consumers (individual households, farms), hotels and holiday resorts, small housing estates with their own water supplies, and small to medium-sized industrial plants. Moreover, the technology can be used in various other branches of industry to reduce the amount of wastewater for disposal by thickening and recirculating the distillate back into production processes.

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## **Generating drinking water from air humidity**

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In arid and semi-arid regions, it is difficult to provide a reliable drinking water supply due to low precipitation combined with high evaporation rates. Groundwater, if it exists at all, is usually oversalinated and levels are decreasing continuously. Under such conditions, it is well-nigh impossible to obtain sufficient water from surface water or groundwater sources for a reliable supply.

### **New, future-oriented solutions**

An alternative way to produce drinking water which does not involve access to surface or groundwater is the generation of water from air humidity. To this aim, the IGB has developed



a technology based on an absorption process which can be operated exclusively on regenerative energy sources.

To begin with, water vapor is absorbed from air with a highly hygroscopic liquid, a highly concentrated salt solution. This happens in tower-like modules with the salt solution flowing down so-called sorption paths, followed by a distillation process to desorb the absorptively bound water. In this process, the brine – which was circulated and diluted during absorption – has now re-achieved its initial concentration and can be used for a further absorption step. The plant is designed as a vacuum evaporator to run at very low evaporation temperatures. This was achieved by modifying the gravitation-supported vacuum evaporation technology described above. The absorption modules were built as towers, several meters high, to use gravitation in the desired manner.

### **Decentralized and energy self-sufficient**

The process is easy to set up, cost-efficient and suitable for decentralized water generation independent of all kinds of infrastructure. Energy supplies from regenerative sources, e.g. such as thermal solar collectors for the evaporation process, photovoltaics to supply electrical components or wind power for operation regardless of the time of day, ensure sustainable water generation.

- 1 *Even in desert regions, humidity can be extracted from air to produce drinking water.*
- 2 *Plant for desalination of sea-water by means of gravitation-supported evaporation.*





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### Disinfecting water with innovative UV light sources

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A disinfection phase is of the utmost importance to supply a population with safe, high-quality drinking water. In addition to the classical method of chlorination, disinfection by means of UV light and ozone has also been established as a reliable and environmentally-friendly process.

#### **Microwave-induced UV radiation**

A new development of the Fraunhofer IGB uses a microwave energy field to turn the gas filling a variably shaped glass case into plasma. UV light can be emitted in desired wavelengths, depending on the choice of gas or gas mixture in the case. As the shape of the lamp can be user-defined, the process can be put to a multitude of applications.

#### **Disinfection of large volume flows in the discharge of wastewater treatment plants**

Homogeneous radiation from a number of light windows arranged parallel to the direction of flow can emit enough light to disinfect water reliably and economically even at high flow rates.

All elements of the light system submerged in water have a long life as the lamps have no parts, such as ignition electrodes, which are subject to wear and tear. A laminar homogeneous emission of light and the relatively cold lamp surface also reduce the formation of biofilms or surface layers so that less cleaning is required. Maintenance is simplified as the active electro-technical components are located outside those parts of the apparatus submerged in water.

<sup>1</sup> Adsorber particles are immobilized on carriers.



# PROCESS AND WASTEWATER TREATMENT

## PHYSICAL/CHEMICAL PROCESSES



One problem in connection with process and wastewater treatment which still has to be solved is how to remove recalcitrant organic pollutants (so-called micropollutants) which are a recognized hazard for humans and the environment even in very low concentrations. These trace contaminants can be found in the process waters of chemical and pharmaceutical industries and in the outlets of treatment plants. They are also present in a growing number of cases in raw water before treatment to drinking water quality where they arrive over water cycles in the environment. Pollutants such as PAH<sup>1</sup>, PCP<sup>2</sup>, alkylphenoles, polychlorinated biphenyls, chlorinated aromatics, pesticides, drug residues and natural macromolecules such as humic acids are difficult to biodegrade and sometimes even non-biodegradable due to their chemical and physical properties. Some of these pollutants have accumulated in our environment and already contaminate groundwater and surface waters to a certain degree. Experts warn that high concentrations of antibiotics in the environment could be responsible for patients' resistance to these medicines, and that even small quantities of drugs with hormonal effects, present in drinking water, could be harmful to consumers. Micropollutants are especially problematic in those regions of the world which already depend entirely on direct forms of water re-use to ensure sufficient supplies for their populations. At first, trace pollutants can be present in very low concentrations, perhaps even close to the detection limit of modern analytic equipment, but they are extremely dangerous as they accumulate in the environment due to their persistent toxic properties.

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### Filtration and adsorption processes

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It can sometimes be helpful to increase the concentration of weakly concentrated pollutants for subsequent treatment or in order to degrade them more efficiently. Membrane technologies and adsorbers are good methods for binding these substances reliably. Once a relevant load has been reached, it is prepared for the degradation processes described below by means of regeneration.

### Synthetic adsorbents for removing environmental pollutants

Polymer particles are especially suitable as adsorbents for the selective removal of trace substances from water, in particular during the treatment of industrial process water. The Fraunhofer IGB produces tailor-made micro or nanoparticles. In close cooperation with the University of Stuttgart, we were able to demonstrate the specificity and efficiency of polymer adsorbent particles for bisphenol A (BPA), diclofenac (painkiller), pentoxifylline (for vascular disorders) and penicillin G in model solutions. Together we have set up a pilot plant in the Robert Bosch Hospital in Stuttgart to purify the hospital wastewater. BPA, which has an estrogenic action and is used in large quantities in the plastics industry, has already accumulated in the environment to an alarming extent. In a measuring campaign carried out on surface waters across Europe, 1230 samples contained BPA with no traces detected in only 5 of the samples tested.

For use as adsorbents, the polymer particles can be applied to commercial carrier materials or integrated in ultrafiltration membranes which are then integrated into existing procedures. The polymer particles can be adapted to fit various trace substances. The Fraunhofer IGB has a test facility to run corresponding experiments.

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<sup>1</sup> PAH polycyclic aromatic hydrocarbons

<sup>2</sup> PCP pentachlorophenol



## Oxidation processes

### Advanced oxidation processes (AOP)

Pollutants must be degraded or removed effectively and safely in order to reduce negative effects on living beings and their environment. A number of suitable processes has been compiled and called advanced oxidation processes (AOP). Here, pollutants are oxidized in aqueous solutions with the aid of reactive hydroxyl radicals which are formed when ozone or hydrogen peroxide is added or through radiation, catalysis (Fenton reaction) and ultrasonic or electric processes. The Fraunhofer IGB is experienced in oxidation processes for water treatment with ozone, hydrogen peroxide, ultrasound and anodic oxidation. These processes can be adapted to meet our customers' specific requirements and combined to deal with high and low flow rates.

### Improved electrochemical ozone generation

Together with a partner from industry, the IGB has made considerable progress in the field of electrochemical generation of ozone. The ozone concentration of the resulting oxygen/ozone composite is 2 to 3 times above the maximum achieved by conventional electrochemical or gas discharge ozone generators. Less apparatus is involved, and energy demands for the electrochemical generation are lower compared to conventional ozone generator methods.

### Electrolytic oxidation in separate anodes/cathodes

Together with European partners from industry and research, the Fraunhofer IGB has developed an electrochemical process in which ammonium and organic substances in water as well as organically-bound halogens can be removed from landfill leachate through an electrochemical oxidative process by using reactions at the anode of the reactor followed by reduction at its cathode. The electrolytic cell is divided into two

reaction segments for electrochemical reactions by means of an ion exchange membrane. These segments are flooded one after the other but are part of a single electric circuit. This means that the pollutants in the water undergo two simultaneous treatments and that the water is purified without having to add chemicals or additives. The electrochemical process succeeds in degrading the water components completely, which does not hold true for membrane filtration, so that there is no concentrate left over for disposal.

Laboratory and prototype plants are available at the Fraunhofer IGB to adapt the process to other processes and other wastewater streams.

### Open plasma processes for water purification

Ions, highly reactive radicals and short wave radiation are created in a plasma to degrade organic components in wastewater by applying high voltage from ambient air and atmospheric oxygen. In this process, chemicals are no longer necessary so there is no problem with their disposal.

The "open" plasma reactor for purifying water was designed in such a way as to allow the highly reactive species formed in the plasma to be transferred effectively to the polluted water. To reach this goal, the plasma has to be in direct contact with a flowing water film. By gravitation only, the water for purification flows directly down the outer surface of a grounded electrode, a stainless steel cylinder, through the plasma zone. Hydroxyl radicals, among others, are formed in the plasma. They pass into the water and decompose dissolved pollutants until they are mineralized due to their high oxidation potential. Cyanide, for example, is dissolved by 90 percent within 2 minutes. The plasma process is also extremely energy-efficient.



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### Electrophysical precipitation to separate emulsions and suspensions at reduced energy costs

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Numerous industrial processes generate aqueous emulsions and suspensions which are discharged as wastewater. Unstable, temporary emulsions and suspensions can easily be treated in simple processes, such as with coalescence separators, but stable emulsions and suspensions require complex pre-treatment. Demulsifiers are often used to separate stable emulsions, e.g. drilling and cutting oil emulsions or wastewater from washing processes. Separating emulsions with membranes, particularly by ultrafiltration, does create a recyclable permeate but the costs for acquisition and running are high. In thermal processes, the aqueous phase is evaporated and the oil phase is retained as a concentrate but here the energy demands are extremely high. Metallic salts such as  $\text{FeCl}_3$  or organic polymers are used to separate solids from suspensions and are responsible for oversalinating water. It is imperative to dose polymers exactly as overdosing makes them act as emulsifiers.

### Electrophysical precipitation as an alternative to adding chemicals

Electrophysical precipitation is an innovative process for separating stable emulsions and suspensions without having to add chemicals. To start with, iron and aluminium electrodes are placed in the fluid current. When direct current is applied, two processes take place at the same time. On the one hand, electrolytically created iron and aluminium ions are dissolved on the sacrificial anode, forming hydroxides thus facilitating the separation of extremely small solid particles and droplets by means of adsorption, precipitation and flocculation. This solves the problem of how to separate stable emulsions and suspensions efficiently. On the other hand, the water is cleaved on the surface of the electrodes into highly-reactive

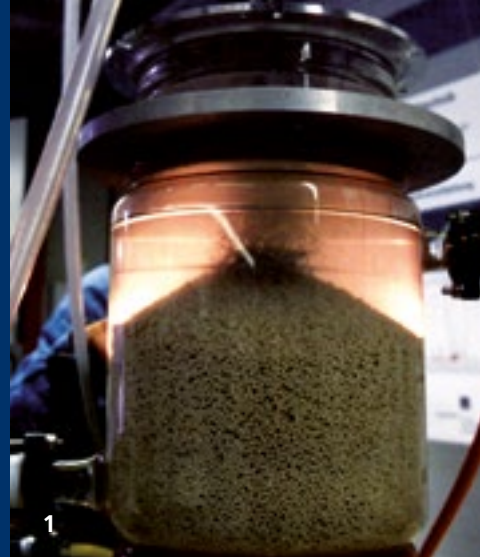
radicals, which create numerous secondary reactions with the suspended matter, leading to a decrease in chemical oxygen demand (COD) or to the destruction of organic complexing agents. For this reason, electrophysical precipitation is also suitable for removing heavy metals from raw water and wastewater.

The process of electrophysical precipitation is governed by surface reactions and its effectiveness depends on the size of the surface area of the electrodes. This is why the latter were designed in the shape of plates. The voltage applied to the electrodes and the current created are kept low to minimize energy consumption. After electrophysical precipitation, the hydroxides and precipitated impurities are separated from the aqueous phase. A wide variety of established processes is available for this purpose and the appropriate one is chosen according to the specific task on hand.

- 1 *Experimental setup of a plasma reactor for water purification.*
- 2 *Pipe reactor during electrophysical precipitation.*
- 3 *Agglomeration of hydroxide flakes.*

# WASTEWATER TREATMENT

## BIOLOGICAL PROCESSES



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### Anaerobic biological purification of highly polluted wastewater

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Anaerobic wastewater purification processes are especially suitable for treating wastewater with a high biological oxygen demand (BOD<sub>5</sub>) found, for example, in the food and beverages industries, in slaughterhouses and also at airports (de-icing agents).

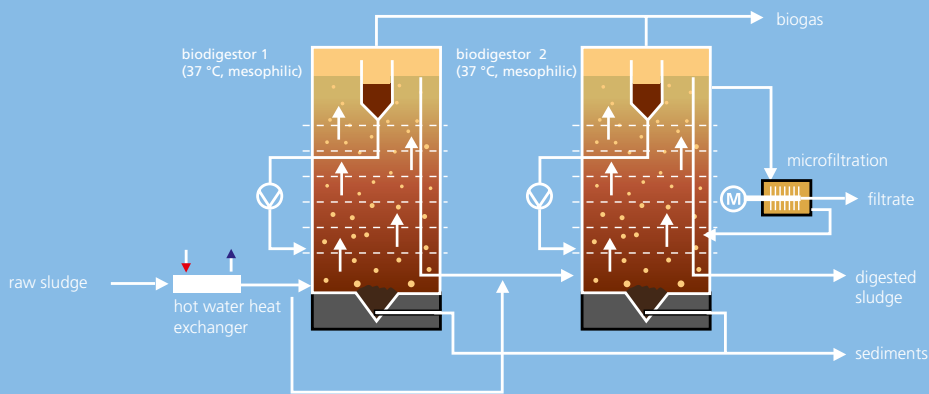
#### Anaerobic technology – an economical alternative

Larger companies often run their own biological treatment plants. These are usually aerobic and have several disadvantages such as high power requirements for aeration and mixing, a common lack of nutrients (N and P) and the generation of large quantities of sewage sludge, whose disposal is expensive. Modern anaerobic technology is a much more economic alternative and has already been tested with several partners. The advantages are that the biogas formed can be used energetically and that the amount of sludge is reduced by a factor of ten.

#### Reactor technology with biomass retention

A small growth of biomass is characteristic for anaerobic conversion as the majority of the energy contained in the wastewater components can pass straight over into the final product i.e. methane. If turnover rates are to be increased, the active biomass must therefore be retained in the reactor for concentration. Two methods are available for this: immobilization of the biomass on a carrier material in a fixed bed reactor (Fig. 1) or mechanical retention in a membrane reactor. The Fraunhofer IGB has various types and sizes of reactors for examining the anaerobic purification of wastewater samples. Once a process has been optimized on a semi-technical scale in our biotechnical pilot plant, the scale-up is carried out on-site for our customers.

- 1 *Fixed-bed circulation reactor.*
- 2 *Schematic diagram of two-stage high-load digestion process with microfiltration.*
- 3 *Sewage treatment plant in Tauberbischofsheim with two-stage high-load digestion and microfiltration.*



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## High-load digestion for less sewage sludge and more energy

Conventional wastewater treatment in communal plants generates huge amounts of sewage sludge as waste. The figure for Germany is an annual high of 2.2 million tons of dry solids. Today, 30–50 percent of the operating costs of a sewage plant are eaten up by the treatment and disposal of its sewage sludge. This is why reducing the costs of sludge treatment is of enormous interest to all involved.

### New high-load process

The Fraunhofer IGB has developed a high-load process for fermenting sewage sludge which was first put into operation in 1994 at the sewage plant in Leonberg (60,000 population equivalents, PE). The records show that high-load digestion converts sludge to biogas much faster, in less space and at less cost compared with conventional digestion towers. Former common problems, such as excessive foam formation, no longer obstruct operation. The main advantages in comparison with conventional digestion processes are shorter residence time (5–7 days instead of 20), higher organic volume loads (8–10 kg/m<sup>3</sup>×d instead of 1–2), an improved degree of degradation (up to 70 percent of organic dry matter) and increases in biogas yields. The high-load process can also be used to treat other organic substrates, such as green waste from farms and organic urban waste.

### Further improvements through microfiltration

Major improvements were achieved by combining high-load digestion with microfiltration using a rotating disk filter (p. 17). This increases the turnover and achievable quantities of biogas even more. Further advantages are improved drainage of residual sludge, smaller amounts of sludge and consequently cost savings for sludge disposal. The filtrate is free of particles but rich in ammonium and phosphorus which can be recovered by stripping (for ammonia), precipitation (for magnesium ammonium phosphate, MAP) or in an electro-chemical process for use as fertilizers.

This high-load process is now being operated successfully in seven communal sewage treatment plants. In 2007, it went into operation for the first time in a smaller treatment plant run by the Wastewater Utility Association Mittleres Wutachtal (10,000 PE) and has proved itself to be an economic alternative to aerobic sludge stabilization for smaller plants as well.

In 2012, the high-load digestion was run successfully for the first time with a gas lift loop reactor instead of the usual mixed phase system in Bad Dürrenberg (26,000 PE). The simplified building design helped save a considerable sum otherwise required for construction purposes.

# RECOVERING NUTRIENTS

Besides organic solids, wastewater also contains large amounts of nutrients such as nitrogen, phosphorus, magnesium, potassium and sulfur. Great efforts and in some cases considerable amounts of energy are being put into eliminating nutrients from wastewater by means of nitrification, denitrification and/or biological phosphorous elimination (so-called bio-p processes), to prevent them from entering and eutrophying surface waters.

At the same time, the world-wide demand for nutrients is increasing continuously and prices are rising. Researchers are therefore concentrating on recovering anorganic nutrients from municipal, industrial and farming wastewater in efforts to connect water protection and fertilizer production. Fertilizers recovered from wastewater could become an alternative to mineral fertilizers generated in the energy-intensive Haber-Bosch process and to phosphate exploited in mines, especially as these reserves will be exhausted within a few decades.

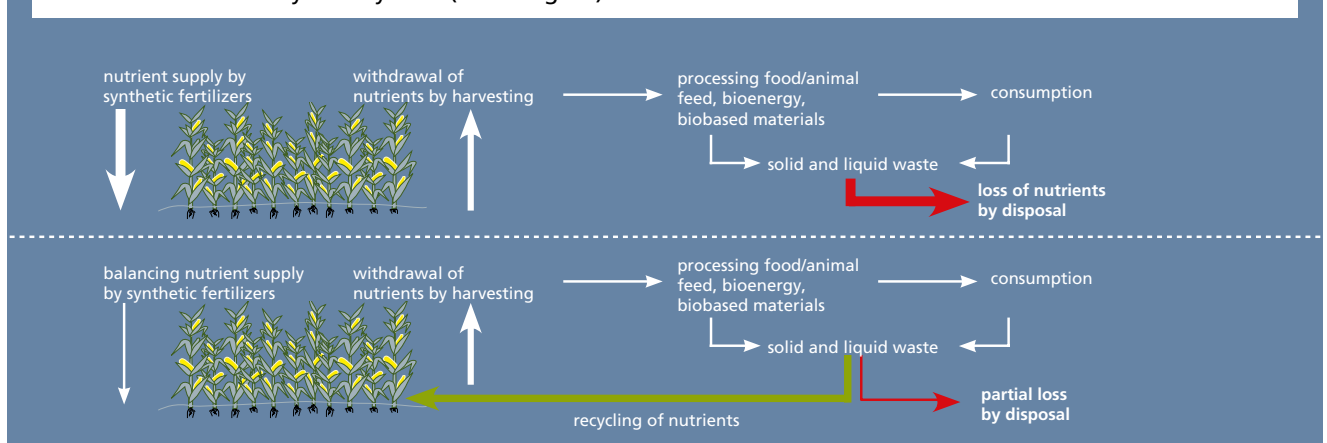
## Patented electrochemical process

The Fraunhofer IGB is working on the development and optimization of methods to extract magnesium ammonium phosphate (MAP, struvite), ammonium salts and potassium salts from wastewater. An electrochemical process has been patented for precipitating nitrogen and phosphorus as struvite without adding salts or bases. In an experimental reactor, it was possible to lower the phosphorus concentrations by 99.7 percent to values under 2 mg/l. The recovered product (struvite) can be used directly in agriculture as a high-quality fertilizer. A mobile pilot plant for in situ testing with a volume flow of 1 m<sup>3</sup>/h wastewater is currently in the test phase.

## Organic fertilizer pellets

Organic fertilizers can be recovered from digested sludge left over from fermentation processes. Nutrients are formed into pellets which can be used directly as fertilizers for agricultural purposes. The fertilizer pellets can be enriched with defined compositions of nitrogen and phosphorus and are a cost-efficient alternative to conventional fertilizers.

General nutrient flow diagram in a non-sustainable system (upper figure), and in a sustainable cyclical system (lower figure)



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# SERVICE PORTFOLIO



## Optimizing wastewater treatment plants

The Fraunhofer IGB has many years of experience in developing and optimizing purification processes for both municipal and industrial wastewater treatment plants. In numerous projects, systematic analysis and detailed measurements were the key to the improvement of processes such as nitrification and denitrification, and to an increase in the production of biogas in several sewage treatment plants. In most cases, it was possible to optimize the entire operation significantly. This method saves funds which would otherwise have to be spent on plant reconstruction and/or alterations.

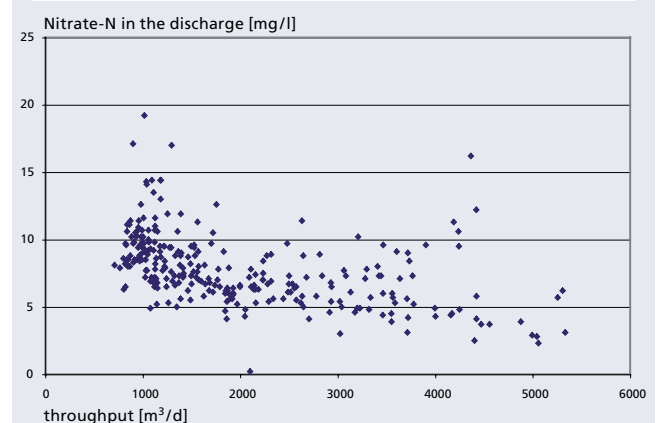
### Improving processes as opposed to expanding plants

The Fraunhofer IGB approach to a solution begins with a careful evaluation of the operational logbooks. In the process, we not only determine all the usual design parameters, but also analyze how well a sewage treatment plant is functioning using process measurement and control measures for each and every section of the plant. In addition, we often carry out a specific measurement program to determine how efficiently the individual purification steps are operating. This results in optimum customized solutions bringing each treatment plant up to state-of-the-art standards in a cost-effective way and helping operators to meet the target values specified by the German and European wastewater directives. Such an approach is always worthwhile because it saves considerable sums otherwise needed for extending existing treatment plants.

### An example

A sewage treatment plant has a pre-positioned denitrification unit, consisting of two basins located in series. When temperatures are low in winter, the second basin is aerated to assist the nitrification process. Occasionally, this results in high discharge values for nitrate nitrogen, leading the operator to suspect that the hydraulic retention time in the remaining basin is no longer sufficient for denitrification. In-depth analysis of the operational log showed, however, that high discharge values for nitrate nitrogen were observed particularly when the throughput was low (see below). This means that the suspected hydraulic overloading of the basin did not actually occur. Nevertheless, the log showed that nitrogen concentrations in the inflow were high in the cold season when low quantities of infiltration water were required. The problem was solved by increasing the amount of circulation water when throughput was low. This saved the operators the costs for constructing a new basin.

Nitrate nitrogen in the discharge of a treatment plant as a function of the throughput







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### Plant, reactor, bioreactor design and process development

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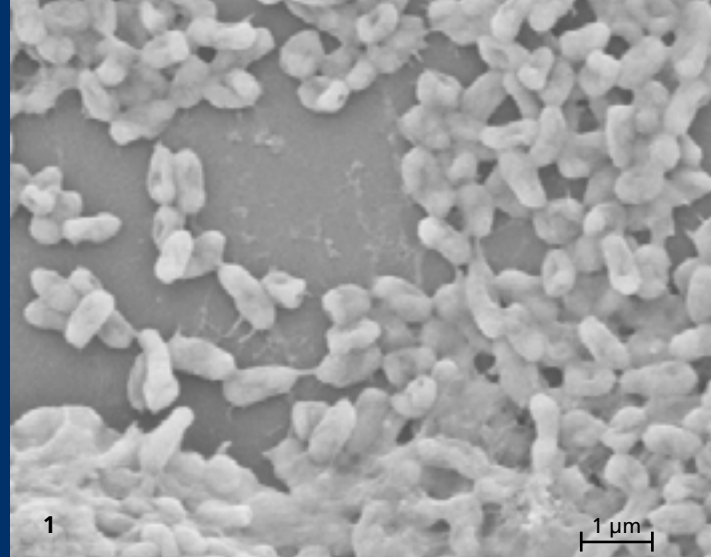
The Fraunhofer IGB has developed various types of bioreactor for wastewater treatment, for example anaerobic and aerobic loop reactors (airlift/gaslift reactors), membrane bioreactors and a fixed-bed circulation reactor, in which the particle bed is periodically circulated. Fixed-bed reactors are used in anaerobic technologies to increase the active biomass immobilized on and between particles. In the Fraunhofer IGB fixed bed circulation reactor, the fixed bed is partially circulated at set times to ensure lasting, trouble-free operations (p. 12, fig. 1).

The IGB team decides in each case which bioreactor is the most suitable and which process concept fits best, depending on specific requirements such as type of wastewater and intended use after wastewater treatment. The solution is then adapted to the prevailing regional, climatic and cultural conditions.

### Innovative filtration technology: rotating disk filter

Thanks to its excellent filtrating performance and low energy consumption, the rotating disk filter developed at Fraunhofer IGB has come to play a major role in our infrastructure concepts for municipal wastewater. The rotating disk filter is a dynamic membrane filter, consisting of a stack of ceramic membrane disks on a rotating hollow shaft. It can be used for sewage sludge digestion and for filtrating activated sludge, digested sludge, raw wastewater and black water. The rotating disk filter requires only a minimum of maintenance and is in operation on a commercial scale in the membrane bioreactor of a municipal treatment plant. Technically speaking, this makes the anaerobic membrane bioreactor a viable alternative to the aerobic activated sludge process.

- 1 *Foam development in the activation basin of a wastewater treatment plant.*
- 2 *Rotating disk filter – micro-filtration technology for communal wastewater treatment.*



### Evaluation of the microbiological quality of water

A high number of infectious diseases can be transmitted via drinking water and according to the World Health Organization, 3.4 million people die every year from illnesses which can be traced back to polluted water. When it comes to introducing new technologies for treating water, the microbiological quality is of major importance not only in Europe but everywhere – for instance, when rainwater is to be treated for use in showers or for washing clothes.

The Fraunhofer IGB tests relevant hygiene parameters for filtration processes under defined conditions and adapts verification procedures for germs to fit all requirements.

### Water check: Chemical analysis of drinking water

Germany's Drinking Water Ordinance ensures that water suppliers distribute water of the highest quality. However, this high quality can be damaged on its last steps to customers i.e. inside bathroom and kitchen pipes or passing through faucets which can be contaminated with lead, copper, iron, nickel, zinc or chrome. If water softening plants are used, they often lead to a rise in sodium levels. Domestic wells can have unacceptable levels of nitrate and phosphate due to fertilizers from farms in the nearby surroundings.

Together with AQA, an Austrian company, the Fraunhofer IGB has developed a water test which enables each household to test its most important foodstuff for chemical pollution. The IGB can analyze 24 relevant chemical parameters to test the quality of water samples with state-of-the-art quality-assured processes. The results are compared with acceptable limits laid down by the Drinking Water Ordinance and provide consumers with information on the mineral composition of their water and on whether it can be used to mix baby food.

**1** *The quality of tested water depends on the number and type of microorganisms present in the sample.*



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## Range of services

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- Market analyses, technological analyses, feasibility studies
- Customized concepts for water management in municipalities and industrial plants focusing on the recovery of resources (master plans)
- Studies on the aerobic and anaerobic biological decomposition of wastewater, determining design parameters, calculation of cost effectiveness
- Studies on the mechanical and chemical-physical elimination of wastewater components, determining design parameters, calculation of cost effectiveness
- Development of biological and chemical-physical processes for water treatment and wastewater purification in industrial plants and municipalities
- Development of reactor systems in modular design, and on biotechnical plant and pilot scale levels (semi-technical), method-supported development of components and processes, modeling and simulations
- Transfer to pilot scale and production scale
- Analysis of sustainability and cost effectiveness

### Contact us

**Dr.-Ing. Marius Mohr**

Head of Innovation Field Water Technologies and Resource Recovery

Phone +49 711 970-4216

[marius.mohr@igb.fraunhofer.de](mailto:marius.mohr@igb.fraunhofer.de)

**Dr.-Ing. Ursula Schließmann**

Coordinator Business Area Environment

Phone +49 711 970-4222

[ursula.schliessmann@igb.fraunhofer.de](mailto:ursula.schliessmann@igb.fraunhofer.de)

## Fraunhofer Institute

for Interfacial Engineering and Biotechnology IGB  
Nobelstrasse 12  
70569 Stuttgart | Germany

Phone +49 711 970-4401  
Fax +49 711 970-4200  
info@igb.fraunhofer.de  
www.igb.fraunhofer.de

### Fraunhofer IGB brief profile

The Fraunhofer Institute for Interfacial Engineering and Biotechnology IGB develops and optimizes processes and products in the fields of health, chemistry and process industry, as well as environment and energy. We combine the highest scientific standards with professional know-how in our competence areas – always with a view to economic efficiency and sustainability. Our strengths are offering complete solutions from the laboratory to the pilot scale. Customers also benefit from the cooperation between our five R&D departments in Stuttgart and the institute branches located in Leuna and Straubing. The constructive interplay of the various disciplines at our institute opens up new approaches in areas such as medical engineering, nanotechnology, industrial biotechnology, and environmental technology. Fraunhofer IGB is one of 69 institutes and independent research units of the Fraunhofer-Gesellschaft, Europe's leading organization for applied research.

### Fraunhofer SysWater Alliance

Fraunhofer IGB manages the Fraunhofer SysWater Alliance in which eleven Fraunhofer Institutes pool their skills to develop innovative water system technologies. Taking into consideration the social, economic and ecological consequences involved, the aim of the Alliance is to transfer sustainable solutions for water production, infrastructure and wastewater purification to practice-oriented, national and international applications in order to develop technologies with which the United Nations' "Millennium Development Goals" can be achieved to greater effect than compared with traditional state-of-the-art methods. A further objective is the systemic cross-linking of the resource water with energy, waste and agriculture.



Member of  
**German Water  
Partnership**

#### *SysWasser Coordination Office:*

*Fraunhofer IGB  
Dr.-Ing. Ursula Schließmann  
Nobelstrasse 12  
70569 Stuttgart | Germany  
Phone +49 711 970-4222  
Fax +49 711 970-4200  
ursula.schliessmann@  
igb.fraunhofer.de  
www.syswasser.de*