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UNLOCKING THE POTENTIAL OF WASTEWATER

Using wastewater as a resource while protecting people and ecosystems

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EXECUTIVE SUMMARY

On a global scale, less than half of all wastewater is collected and less than one fifth is treated. This has led to severe environmental degradation of many inland and sea waters around the world. Increasing water scarcity and population growth underline the importance of treating and understanding the value of wastewater. The United Nations' Sustainable Development Goal 6 aims to halve the proportion of untreated wastewater discharged into our water bodies by 2030. In achieving this goal, it is important also to focus on energy efficiency and energy recovery in the design of new and upgrade of existing wastewater treatment plants.

Energy producing wastewater treatment plants
The water sector accounts for approximately 4% of the world's total electricity consumption and wastewater treatment alone accounts for a quarter of this. In Denmark, the water sector's share of the country's total electricity consumption has fallen to 1.9%. Most Danish wastewater treatment plants have invested in different ways to reduce their energy consumption and are increasingly focusing on energy production. As a next step, some water utilities are also looking into recovering the heat from the wastewater before it is discharged with the additional benefit of reducing the temperature impact on the receiving waters.

Using wastewater as a resource
Considering wastewater as a resource is a relatively new perspective. However, today it is widely recognised that the organic content in the wastewater can be a resource for energy production and phosphorus can be used for fertiliser production with several advantages compared to the application of sewage sludge on agricultural land. Finally, the water itself can be cleaned to such high standards that it can be reused in a number of ways – e.g. for flushing toilets, laundry machines or irrigation for crops.

Centralised vs decentralised solutions
Ensuring the most cost-efficient design of an area's wastewater infrastructure is a great challenge. In areas with dense population, the optimal structure tends to be centralised treatment plants whereas in rural areas, which are not connected to the central sewerage system, decentralised solutions are often more attractive.

Treating industrial wastewater
Municipal wastewater treatment plants are generally designed for domestic wastewater and not necessarily equipped to handle industrial wastewater which often contains hazardous substances that may cause problems for biological processes and sludge disposal. Pre-treatment of industrial wastewater at the source can therefore have several advantages. Specifically, treatment can be tailored to the specific industrial pollutants which typically occur in high concentrations in relatively small volumes of wastewater and therefore requires relatively low investment and operational costs.

Find inspiration for your own wastewater projects
This white paper features lessons learned from different Danish stakeholders within wastewater treatment. It is meant to serve as a tool for inspiration for reaping the benefits of using wastewater as a resource.

We hope you will be inspired.

"When we treat our wastewater, we protect both human health and the aquatic environment as well as increase biodiversity. At the same time, we have technologies that can help reduce greenhouse gas emissions and energy consumption from wastewater treatment."

Lea Wermelin, Minister for Environment, Denmark

We need efficient treatment of our wastewater to protect our health and natural environment. The good news is that with the right methods and technology, wastewater can become a valuable resource. For instance, sludge from treated wastewater can be turned into a useful source of energy.

The Danish Government has set an ambitious goal of reducing the country's greenhouse gas emissions by 70 percent in 2030. To achieve this goal, all sectors must contribute – including the wastewater sector.

The goal for the Danish water sector is to become energy and climate neutral - and perhaps even net producers of energy. It is an ambitious goal which requires cooperation between Danish authorities, water utilities, companies and organisations in order to create more innovative solutions which can lead to added value for both water consumers and society as a whole. This is a great example of how Denmark contributes to finding solutions to some of the world's major water and climate challenges and it follows up on a number of the United Nations Sustainable Development Goals.

This white paper features a series of best practice examples of wastewater treatment – both centralised and decentralised. Although many of these solutions have been created within a Danish context, they are scalable and applicable for a global audience.

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1. EFFLUENT REQUIREMENTS AS A DRIVER FOR INNOVATION

Treating wastewater to the highest standard to protects people and ecosystems

In many countries, decades of uncontrolled wastewater discharge have resulted in severe environmental degradation of both inland and coastal waters. Stricter regulatory standards for both treatment efficiency and effluent quality are important tools for reversing this trend.

Collected but failing to meet standards

Worldwide, it is estimated that only 20% of all wastewater generated from households and industry is adequately collected and treated. The United Nations' Sustainable Development Goal 6 seeks to halve the proportion of untreated wastewater discharged into our water bodies by 2030. In Europe, 97% of the generated wastewater is collected and subjected to treatment beyond the primary level, however only 69% is subjected to tertiary treatment.

Regulation as a driver for development

The environment has been a key focus area in Denmark for a long period and some of the oldest wastewater treatment facilities were established more than 100 years ago and today, 97% of all wastewater is treated. Denmark was among the first to take major steps in minimising the adverse impact from the cities' wastewater discharge to the aquatic environment. The approach has been to use novel technologies and not just move the pollution away from the cities but treat the sewage water from the cities to an appropriate standard. This has enhanced the liveability in the Danish cities and made the surrounding areas more attractive. Geographically, Denmark is challenged by the lack of major water bodies for discharge of pollutants from the cities. As a result, the environmental aspect has been important for a long time and has led to stringent regulation implemented since the 1980s, with the Danish standards for discharge to sensitive waters being further strengthened during the 1990s. Much of the legislation passed in Denmark has been taken up almost in its full content by the European Union and today, Denmark is subject to the EU Water Framework Directive. However, the Danish regulation is in many aspects more stringent than the general EU requirements. From the beginning, the legislative requirements and standards have been based on a specific evaluation of the recipient with the aim of ensuring vast improvements of the water quality in the surrounding water bodies.

"Besides removing nutrients from wastewater to a very high standard, treatment plants in Denmark are being converted into resource recovery facilities. Through advanced control strategies it is possible to lower the energy consumption of the facilities while minimising emissions of methane and nitrous oxide (N_2O) thus reducing the overall carbon footprint of the facilities. The result is not only improved water quality but also an overall more sustainable future"

Lars Schrøder
CEO, Aarhus Water

Polluter pays principle

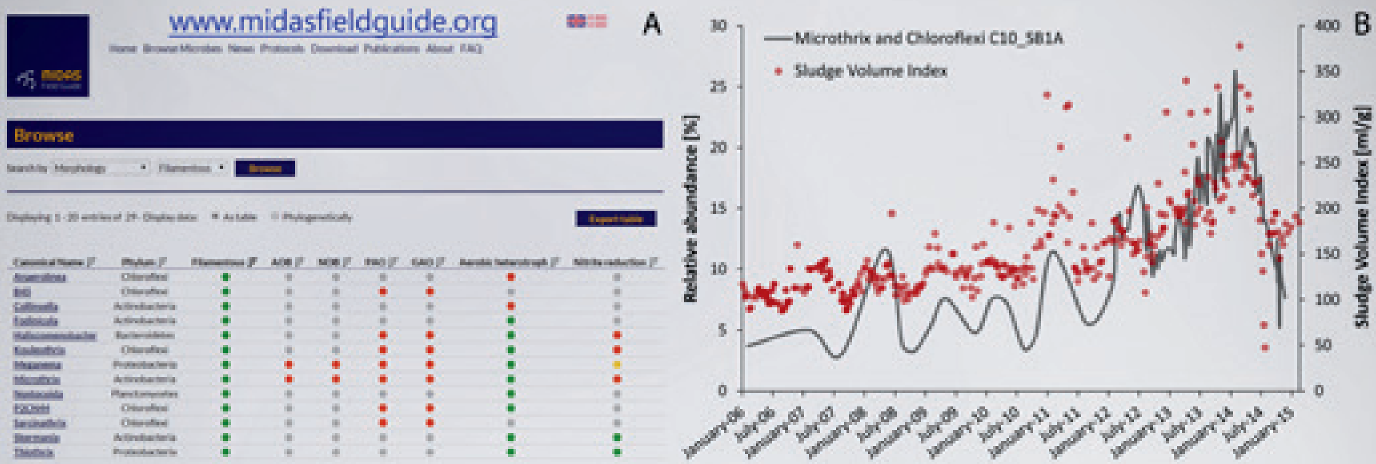
In many countries, water and wastewater services are seen as public goods paid for by the state. However, in Denmark and in other member states of the European Union the 'polluter pays principle' applies to both domestic and industrial users, which means that the cost of wastewater collection and treatment must be covered by the water tariffs. To complement the regulatory framework, a discharge tax has therefore been implemented which means that the polluter (in this case the wastewater treatment facility) has to pay a tax on every kilo of discharge of the three key parameters; organic matter (BOD), total phosphorous (P) and nitrogen (N). The result has been a very innovative and progressive optimisation strategy for the water sector in Denmark.

Operating beyond the discharge requirements

Today, Danish treatment plants of all sizes are generally operated well below the discharge requirement as this has proved to be both economically beneficial to the wastewater utility and to the environment. This shows that regulation can be a productive driver for innovation and excellency. Back in late 1980s and early 1990s, the Danish approach led to the construction of biological WWTPs throughout the entire country – even for very small plants. Since then these plants have been constantly optimised and expanded. The result has been a substantially improved aquatic environment with many cases of water quality enabling salmon breading in rivers and creeks – even in very densely populated areas. The recreational value of the Danish water bodies has also been improved and in many cities, it is now possible to swim in the inner city harbours.

Cost-efficient solutions

Wastewater collection and treatment costs are typically twice the size of the water abstraction and supply costs, which means that cost-efficient solutions are imperative to ensure affordable wastewater treatment for water users and polluters. Despite the high degree of energy recovery and high level of treatment, the cost per household for high quality drinking water and handling of sewage is on the same level as other countries.



Online DNA-analyses - understanding microbial communities in WWTPs for process optimization, Aalborg, Aarhus, Odense and Copenhagen, Denmark

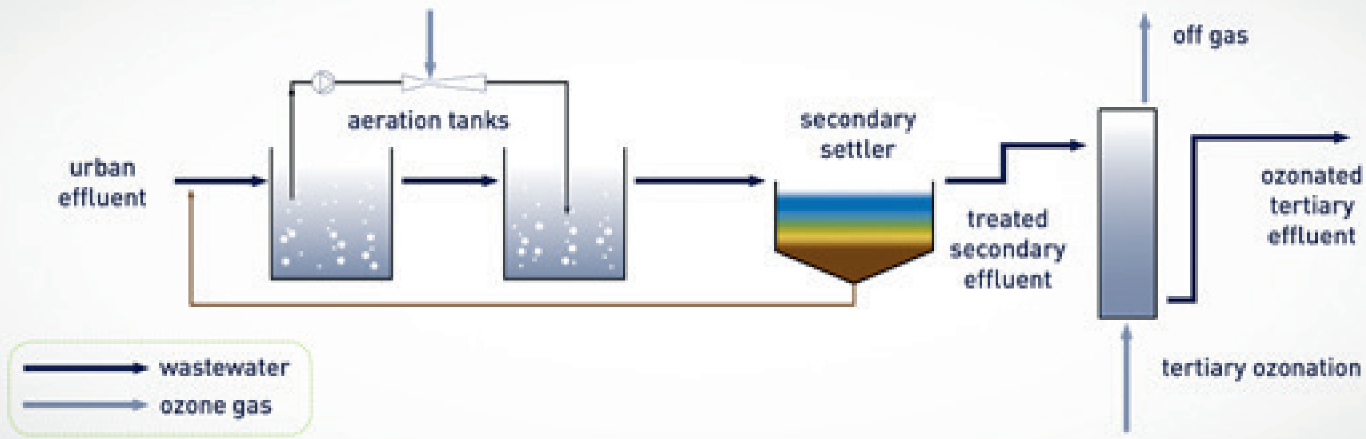
Aalborg University has established the MIDAS database which provides information about function and distribution of most microorganisms in activated sludge in Danish WWTPs. The microbial community composition has been surveyed in 50 WWTPs most years since 2006 by advanced DNA analyses, providing an enormous knowledge bank. Each WWTP now "know its microbes" and can use this information about key species involved in nitrogen removal, phosphorus removal, and settling properties to optimise the operation as changes in community composition are often reflected in plant performance. In order to have day-to-day information, Aalborg University has tested "online DNA analyses", where hand-held DNA sequencers of the size of a smartphone are used for identification of the microbes in a few hours – directly at the WWTP. The results are very promising and day-to-day or week-to-week analyses are soon a reality for surveillance and control of microbes at many Danish WWTPs.

(Courtesy: Center for Microbial Communities - Aalborg University, Aalborg Forsyning A/S, Aarhus Vand, VCS Denmark, BIOFOS and Krüger)

Towards climate neutral wastewater treatment, Odense and Aarhus, Denmark

During the last decade, there has been a strong movement towards reducing the cost and climate impact from wastewater treatment, primarily through energy savings and increased energy production through anaerobic digestion. From a climate perspective, it is also relevant to focus on bringing down greenhouse gas emissions, including minimising N_2O emissions from wastewater treatment as this typically contributes to 20-50% of the total climate impact from wastewater treatment. A unique N_2O sensor technology has therefore been installed at a number of treatment plants around Denmark. The sensor can detect the N_2O concentration online in the process and the emission of N_2O can be calculated real-time through emission models. Furthermore, the online control strategies for reducing N_2O have been developed and tested in control campaigns. As unbalanced energy savings and increased energy production can lead to an increased N_2O emission, this can actually result in a net negative effect on the climate. This new technology enables wastewater treatment plants to move beyond energy neutrality to 'climate neutrality'.

(Courtesy: Unisense Environment, DHI, VCS Denmark, Aarhus Vand with financial support from VTUF and the Danish Eco-Innovation Programme)



Removal of micropollutants in wastewater through innovative use of known technology, Brædstrup, Denmark
Many countries in Europe and throughout the world has increased the focus on removal of micropollutants from wastewater to protect the drinking water and the aquatic environment. At Brædstrup wastewater treatment plant, a development project is using known technologies in a new way to remove micropollutants – incl. pharmaceutical residues – from the wastewater. Ozonation in the main process at the WWTP combined with tertiary treatment (also with ozone) was tested and the results show that every measured micropollutant was removed to below the predicted no effect concentration (PNEC). Through ecotoxicology tests, lower levels of mutagen and hormonal effects were observed and no negative side effects were detected. Ozonation also resulted in better sludge conditions, increased removal of E. coli and antibiotic resistant bacteria as well as antibiotic resistant genomes. The last test of the project will be applying dosages of activated carbon directly in the biological process. This should result in adsorption of micropollutant by the activated carbon and thereby make it possible to remove it together with the sludge. The project is to end in 2020 with a final report.

(Courtesy: SAMN Utility, Aalborg University, KD Maskinfabrik, SUEZ and COWI A/S)

Measurement and mitigation of microplastics in stormwater and wastewater, Denmark
In recent years, the Danish Technological Institute (DTI) has been a principal partner in several R&D projects focusing on characterisation and removal of microplastics and microrubber in wastewater treatment plant influent/effluent, industrial wastewater and stormwater, respectively. Based on chemical sample purification and Raman-spectroscopy, DTI has developed a method enabling identification, characterisation and measurement of both microplastic and microrubber particles obtained from water samples. The method has been continuously applied, improved and further developed over the past five years. Focus has also been on the removal of microplastics from different water sources by developing and successfully demonstrating a variety of wastewater treatment technologies. The close collaboration with Danish universities, water utilities and water technology providers has provided important knowledge in terms of measuring and mitigating microplastic pollution in water environments. The projects have received funding from the Danish Eco-Innovation Programme (MUDP) and the Water Sector Development and Demonstration Programme (VUDP).

(Courtesy: DTI, Aarhus and Aalborg Universities, Berendsen, Aage Vestergaard Larsen A/S, AL-2 Teknik A/S, Grimstrup Maskiner ApS, Dankalk K/S, Techras Miljø Aps and a number of utility companies including Mariagerfjord, Novafos, Ringkøbing-Skjern, Syddjurs, VCS Denmark, Lemvig and Hedensted)

2. WASTEWATER AS A SOURCE OF CLEAN ENERGY

Heading for energy producing wastewater treatment plants and an energy neutral water cycle

Reducing the costs for collection and treatment of wastewater is an important issue for water utilities around the world. In order to achieve this, focus must be on cost efficiency, improvement of the wastewater treatment plants' energy self-sufficiency and possible sale of surplus energy to the grid

Reduction of energy consumption
On a global level, the International Energy Agency (IEA) estimates that the water sector accounts for approximately 4% of the world's total electricity consumption and wastewater treatment alone accounts for a quarter of this. Meeting the UN's target of halving the proportion of untreated wastewater by 2030 could therefore put significant upward pressure on energy demands, unless energy efficiency and recovery technology is applied at the treatment facilities. In Denmark, the water sector's share of the country's total electricity consumption has fallen to 1.9% as more and more utilities have realised the great potential for energy savings and energy recovery in wastewater treatment. Most wastewater treatment plants in Denmark have invested in an assessment of different ways to reduce their energy consumption. These include implementation of online monitoring and energy management systems, replacement of surface aeration by more energy efficient bottom aerators and different operational approaches.

New focus towards energy self-sufficiency
In the recent years, Danish water utilities have moved beyond simply focusing on reducing energy consumption to also focusing on energy production. The first goal is typically to become energy neutral, and the second goal is being able to sell excess electricity and heat to the local electricity and heating companies. Some of the largest water utilities are already well on their way. In Denmark's second largest city, Aarhus, the Marselisborg WWTP produced 30% more electricity than the amount consumed by the plant itself on average between 2015-2019. At the same time the treatment plant produced 75% more heat than it consumed, resulting in a total net energy production of 150%. In Odense, Denmark's third largest city, the Ejby Mølle WWTP achieved similar levels of total net energy production. As a next step, the water utilities in both cities are now looking into recovering the heat from the wastewater before it is discharged with the additional benefit of reducing the temperature impact on the receiving waters.

"Danish water utilities will contribute to Denmark's goal of 70 per cent CO_2 reduction in 2030 through energy recovery and a significant reduction of energy consumption from wastewater treatment. At Aarhus Vand, we have reduced our GHG emissions by nearly 80 per cent since 2008. This shows that there are great benefits to be gained by working systematically with energy optimisation."

Lars Schrøder, CEO, Aarhus Vand and Vice Chairman of the Danish government's Climate Partnership on Waste, Water and Circular Economy

Solutions depend on plant design and context
More and more wastewater treatment plants in Denmark are upgraded with anaerobic digestion of sludge and/or codigestion with organic waste products and they utilise the produced biogas to generate electricity and heat. The optimal solutions depend on the individual plant design and the possibilities for either internal use or external sale of the produced electricity or heat. The tipping point for which the implementation of anaerobic digestion is financially viable depends on the development of new technologies and changes in the price structure for purchase and sale of electricity and heat. In Copenhagen, a technology is currently under implementation which allows for upgrading biogas to a quality which is similar to natural gas or vehicle fuel.

Heading for an energy and climate neutral water cycle
By introducing new technologies to reduce energy consumption and improve energy production, it is the goal that the utility companies can provide an energy neutral water cycle. In this scenario the energy production from the utility's treatment plants is able to cover the energy consumption related to its groundwater extraction, water treatment, water- and wastewater transport as well as wastewater treatment. In 2019, VCS Denmark demonstrated a 100% net energy production for the water cycle in the entire service area for the utility, covering all 8 WWTPs and the production and distribution of water in the City of Odense, Denmark's third largest city with a population of 200,000. The Danish water sector has set a common goal of becoming energy and climate neutral by 2030. In 2020, this goal was implemented in the government's national climate plans.

Benchmarking and innovation lead to lower costs
The innovation of new wastewater treatment optimisation and cost-efficient solutions for both the construction and operation of infrastructure is largely driven by the fact that Danish water utilities are subjected to mandatory benchmarking on operational parameters and cost efficiency across the water sector. Innovation projects are often based on collaboration across governmental bodies, water utilities, consulting companies, technology suppliers, universities and research institutions. The Danish Water and Wastewater Association (DANVA) also carries out its own voluntary benchmarking each year.

Download their latest report here:
www.danva.dk/waterinfigures

Achieving 150% energy self-sufficiency at WWTP, Aarhus, Denmark

Over the past five years, the water utility Aarhus Vand has put great focus on energy savings and energy production. At its Marselisborg WWTP, the utility has implemented energy-saving technologies such as an advanced SCADA control system, a new turbo compressor, sludge liquor treatment based on the anammox process, as well as optimised the fine bubble aeration system. This has resulted in a reduction in power consumption of approximately 1GWh/year which corresponds to about 25% in total savings. During the same time period, the energy production has been improved through implementation of new energy efficient biogas engines (CHP), resulting in an increase in electricity production of approximately 1 GWh/year. Furthermore, a new heat exchanger has been installed with the aim of selling surplus heat to the district heating grid, which represents approx. 2 GWh/year. Between 2015 and 2019, Marselisborg WWTP had an average total energy production of 9.6 MWh/year and an energy consumption of 6.4 MWh/year, equivalent to a net energy production of 150%. Most of the installed technologies have a payback time of less than 5 years.

(Courtesy: Aarhus Vand)

Energy and climate positive wastewater treatment, Copenhagen, Denmark

With a total of 60,000 m^3 digester capacity at its three treatment plants, Denmark's largest wastewater company, BIOFOS, was able to reach a 173% surplus on green energy production in 2019. By increasing the energy surplus, BIOFOS has been able to increase the supply of green energy to the City of Copenhagen's 'city-gas' network as well as the natural gas network, thereby reducing CO_2 emissions produced by traditional methods of gas production. In addition, the surplus of heat from the incineration of digested sludge supplies the district heating network in Greater Copenhagen. With a constant growth in green energy production, BIOFOS' energy balance has been positive since 2014. As a result, BIOFOS aims to become a climate positive treatment company by 2025. In addition to increasing its own green energy production, BIOFOS also focuses on reducing its purchase of fossil fuel based energy from the public grid and as well as reducing emissions of greenhouse gas emissions from the wastewater treatment processes – especially from the potent nitrous oxide (N_2O).

(Courtesy: BIOFOS)

Maximising the value of wastewater at existing treatment plant, Odense, Denmark

The City of Odense is situated inland and the local wastewater utility, VSC Denmark, is operating under stringent requirements for nutrient reduction at its treatment facilities due to a sensitive recipient. In spite of this, the utility's largest wastewater treatment plant – with a capacity of 410,000 person equivalents (PE) – has achieved a degree of electricity self-sufficiency of more than 125% through optimisation of the plant's existing infrastructure. Continuous improvements across all parameters have been achieved through a holistic approach where any improvement counts and new ideas have been consistently pursued and tested. Further optimisation opportunities have been identified in cooperation with a number of consulting companies, which will enhance nutrient reuse and maximise biogas extraction for additional heat and electricity production even further.

(Courtesy: VSC Denmark)

Net-zero energy operations at WWTP, Downers Grove, Illinois, USA

The Downers Grove Sanitary District in Illinois has dedicated significant resources to reduce its energy footprint. Improvements in process efficiency including plant automation, aeration system improvements, upgrades to HVAC and building management systems, and variable frequency drives have resulted in a 30% reduction in electricity usage at its wastewater treatment plant. The remaining electricity used by the facility is produced on-site using a biogas driven combined heat and power system. Biogas is produced by co-digesting hauled food waste and sewage sludge generated on-site. The biogas is used as fuel to drive an engine-driven electric generator. Furthermore, heat recovery in the form of circulating hot water is used for plant process heat. The CHP plant was installed in 2017 with a payback time of 3.5 years. Total Infrastructure investments of roughly USD 5 million are expected to have a 10-year payback period.

(Courtesy: NISSEN energy Inc., Landia and Downers Grove Sanitary District Wastewater Treatment Center)

3. RESOURCE RECOVERY FROM WASTEWATER

Wastewater treatment plants as resource recovery facilities

Traditionally, wastewater has been considered a liability. Meeting increasingly stricter standards for wastewater discharge also increases the costs of treatment. Utilising the resources in the wastewater can prove an important step in the opposite direction.

Considering wastewater as a resource is a relatively new perspective. However, today it is widely recognised that the organic content in the wastewater can be a resource for energy production, the nutrients - especially the phosphate – can be used for fertiliser production, and the water itself can be cleaned to such high standards that it can be reused in a number of ways – e.g. for flushing toilets or laundry machines.

Utilising organic content

As described in the previous chapter, organic material in wastewater can be separated and utilised for biogas. This has been standard procedure in larger wastewater treatment plants for a while, and new water treatment technologies and more efficient equipment for combined power and heat production have increased the potential. Organic content can be saved for energy use in biogas production if new carbon saving processes for nutrient removal are introduced. Denmark has vast experience in optimising the use of carbon and is now also gaining know-how in nutrient recovery.

Phosphorus recovery from wastewater sludge

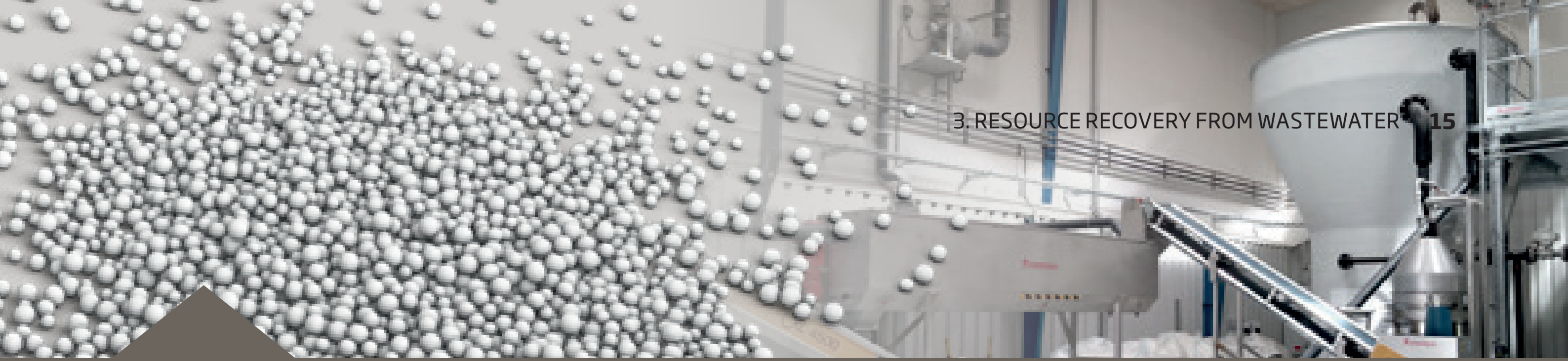
Phosphorus is a scarce resource with great value for the agricultural sector. Phosphorus is accumulated in the wastewater sludge and in internal side streams and if treated properly, it is possible to change this into a controlled harvesting of a pure fertiliser. The recovery of phosphate for fertiliser enables a multitude of possibilities for sludge handling, not wasting the valuable phosphorus to end up in low quality form as ashes or mixed with heavy metals and micro pollutants from wastewater in the sludge. The phosphorus product struvite has been approved in Denmark as a fertiliser product. Two full-scale plants in Aarhus currently forms the background to increase the current P-recycling from approximately 15% to 25%. Once these are completed, the total phosphorus recovery throughout the catchment area is expected to be increased to approximately 22 tonnes P/year or approx. 0.5 tonnes of struvite fertiliser per day.

Benefits of using struvite fertiliser compared to sewage sludge

The solution of recovery of struvite as a pure mineral phosphorus fertiliser offers several advantages in comparison to the application of sewage sludge on agricultural land:

- Environmental benefits: Struvite is significantly cleaner than the sewage sludge in terms of heavy metals. The content of the typical problematic metals such as lead, cadmium, nickel, chromium copper and zinc is a factor of 20-100 times lower in relation to the content of phosphorus.
- Reduced risks of groundwater contamination: Phosphorus from wastewater can be utilised for agriculture without risking a contamination of soil and groundwater with the accumulation of heavy metals and other harmful substances to the environment, which makes it possible to carry out subsequent groundwater exploitation in the same area.
- Greater flexibility in terms of usage and storage: Struvite is much more flexible as a fertiliser as the material is concentrated, comes in a dry form and is possible to store for longer periods of time.
- Economic benefits: Struvite can be sold at a high price (up to EUR 335 per tonne)
- Ready-to-use as fertiliser: There is no need for further processing as the material is ready to use and can be mixed with other mineral fertilisers if there is a need for changing the level of potassium or nitrogen.
- Better suited as dedicated fertiliser: Struvite has shown excellent properties for fertilising specific plants and crops with need for ekstra phosphorus and magnesium. Golf courses and plant nurseries are good examples of this.
- Low solubility: Struvite has a low solubility, making it suitable for depot fertiliser where the phosphorus content is released slowly in line with the needs of the plants. This is an advantage for fertiliser spreading without danger of dissolution into groundwater or surface water.
- Lower cost: Sludge from P-recovering plants, which is low on phosphorus, can be used as a bio-fuel without it resulting in a loss of phosphorus to ashes. The cost of regaining phosphorus from ash is much higher than extraction as struvite from wastewater.

Struvite based P-recovery is the state-of-the-art for phosphorus recovery from wastewater. The technology is still under development and Danish wastewater utilities and companies are working on developing even more efficient process solutions.



Phosphorus recovery from wastewater, Herning and Aarhus, Denmark

In 2015, the water utility Herning Vand Ltd. opened the second P-recovery plant in Denmark, which recovers phosphorus from a concentrated side stream in the wastewater treatment plant. For several years, the WWTP suffered from struvite scale buildup in its sludge and wastewater pipes, causing problems for the dewatering process of sludge and biogas production. In addition to solving the problem, Herning Water wanted to exploit the potential of recycling the struvite into agricultural fertiliser. A solution based on controlled precipitation of struvite was therefore designed, and a full-scale recovery plant of the phosphorus compound struvite was built based on previous test results from Aarhus Vand at its plant Aaby WWTP. At both plants, the struvite is precipitated as a 'ready-to-use fertiliser' and sold to a fertiliser company. An official approval of the product as commercial fertiliser has been obtained for the struvite produced at both the Herning and Aarhus plants under the name PhosphorCare™. The operational savings at the treatment plants and the expected revenue from sale of struvite is expected to result in a payback time of 10-12 years.

(Courtesy: Herning Vand, Aarhus Vand, Stjernholm, Grundfos, Norconsult, Suez and SEGES)

Resource recovery for the future, Billund, Denmark

Billund BioRefinery (BBR) is a resource recovery plant that integrates waste management and wastewater treatment. BBR produces clean water, energy for the local public district heating and power grids, as well as high quality natural fertiliser for the surrounding agricultural areas. The wastewater catchment areas consist of combined and separate sewer systems and the waste comprises of sorted organic waste from households and local industries. BBR integrates wastewater treatment with anaerobic digestion and other innovative processes like Exelys™ (thermal hydrolysis)and AnitaMox™ (Anammox process). These, along with STAR™ advanced online monitoring and control system, minimises energy usage and maximises energy production and effluent quality. As a result, effluent nutrient concentrations (N, P and COD) have been reduced to a quarter of the level required by Danish legislation and the plant operates with a 200% energy surplus relative to the plant's own consumption. BBR is a public private partnership with a payback time of 9 years and was financially supported by the Danish Eco-Innovation Programme (MUDP) and the Danish Water Sector Foundation (VTUF).

(Courtesy: Billund Vand og Energi A/S and Krüger Veolia A/S)

ReCoverP: Improved Recovery of phosphate from wastewater, Aalborg, Aarhus, Herning and Odense, Denmark

Almost 80% of phosphate (P) in Danish wastewater is reused as fertiliser in agriculture from biosolids produced in wastewater treatment plants. Recovery of high-value P-products also holds great potential. A project supported by Innovation Fund Denmark has evaluated this. Aalborg University and University of Southern Denmark – together with water utilities and consultants – tested and optimised novel methods and approaches for improved recovery of high-value P-products from wastewater treatment plants of which most had biological P-removal and anaerobic digesters. New methods for speciation and quantification of polyphosphate accumulating microorganisms and chemical P-containing components were developed, allowing detailed P-mass-balances. Development of crystallization of high-purity CaP from digester digestate by the OxyCrysPTM technology was very successful. LDHs as filter and ion exchange material as well as application of membranes were very promising to recover or crystallize P-products.

(Courtesy: Aalborg University, University of Southern Denmark, Aarhus Vand, Aalborg Forsyning, VCS Denmark, Herning Vand and Krüger AS)

4. CENTRALISED WASTEWATER TREATMENT

Ensuring effective and cost-efficient treatment through centralisation

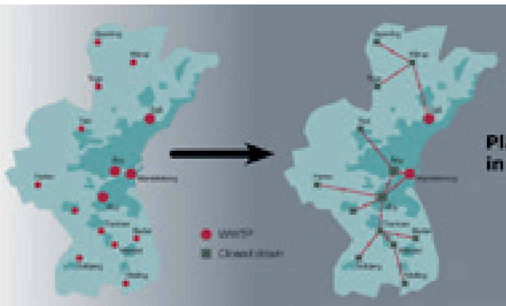
Stronger environmental legislation and increased public awareness of the importance of proper wastewater treatment have led to centralised and more efficient treatment in many regions. Other factors driving the centralisation of wastewater treatment include consolidation of the water sector with bigger water utilities and an increased demand for cost-efficient treatment and resource recovery.

Building a cost-efficient infrastructure
In some regions, sewerage networks and treatment facilities have reached a coverage of almost 100%. However, in many other regions there is still a massive need for further expansion of sewer networks and for construction of new or upgrading of existing treatment plants. Ensuring the most cost-efficient design of an area's wastewater infrastructure is a great challenge. In areas with dense population, the optimal structure seems to be mainly large centralised treatment facilities as increased demands of energy self-sufficiency and resource recovery requires larger units. In rural or semi-rural areas, the most cost-efficient structure tends to be decentralised with smaller local treatment plants and low-technology solutions. This general model, however, is being challenged from many sides. Rapid urban growth, especially in developing countries, may require a cluster approach to maintain sewer networks of manageable size. Furthermore, water scarcity calls for increasing reuse of wastewater in local areas. New technologies, such as compact treatment units or different membrane technologies, are rapidly becoming competitive for households, buildings and industrial districts. In Denmark and other countries, centralised wastewater treatment, where wastewater is pumped from minor towns and villages to the nearest bigger town, have become very common over the past 10-15 years. The main driver for the development is an increased demand for cost-efficient solutions with focus on reduced operational costs, especially related to reduced labour and maintenance costs and more energy efficient plants.

"Centralised treatment is currently more efficient and it is more feasible to apply solutions that recover energy, phosphorus and other valuable resources from wastewater. At smaller plants, this is too costly and too complex."

Ole Godsk Dalgaard, Project Director, Water and Environment, COWI A/S

Advanced treatment opportunities
In Denmark, the centralised treatment plants initially used simple biological treatment to decompose the organic components in the wastewater. Although the biological treatment was developed and optimised to provide almost complete breakdown of organic substances, the end products and other pollutants still caused severe environmental degradation to the receiving water bodies. This led to the development of new tertiary treatment technologies for removal of substances like nitrogen and phosphorus by biological or chemical methods. The latest development includes very energy efficient wastewater treatment and more plants are in fact becoming net producers of both electricity and heat. Furthermore, some WWTPs have been designed for phosphorus recovery. At present, it is only feasible to apply solutions that recover energy, phosphorus and other valuable resources from wastewater at larger, centralised wastewater treatment plants. At smaller plants, these processes are too costly and too complex.



Structural analysis of wastewater infrastructure, Aarhus, Denmark
To develop the most cost-efficient wastewater infrastructure, Denmark's second largest city Aarhus conducted a thorough analysis of the current treatment system. Initially, treatment took place at 17 small and large treatment plants. However, an analysis revealed that a more centralised structure where wastewater treatment is carried out at just two large treatment plants would be more economically and environmentally advantageous in the future. Implementation of the new structure is now gradually taking place and the initial focus is on phasing out smaller treatment plants where operational costs are relatively high and the possibilities for utilising the wastewater as a resource are not financially viable. The analysis pointed out two wastewater treatment plants to be permanent: Egå WWTP, which has already been extended and reconstructed, and the new Aarhus Rewater (wastewater and resource plant), which is expected to be finalised in 2030.

(Courtesy: Aarhus Vand and COWI A/S)

Lower specific energy and reliable flow estimates in wastewater networks, Haderslev, Denmark

Following a network restructuring project, wastewater in the municipality of Haderslev in Southern Denmark is now being transported up to 60 kilometres for centralised treatment. Large amounts of infiltrating water swell the water volume in the pipes to around 10 million m^3 a year. As the local water and wastewater utility, Provas, only gets paid for handling 2 million m^3, this is bad for business. Solving the problem required a detailed overview of flow patterns at every single pumping station. To resolve this issue, Provas and Grundfos tested the Grundfos Dedicated Controls pump controller using the energy optimisation feature and the flow estimation feature. After three months of testing, flow estimation was correct to +/-5% and specific energy was reduced by 36% at one of the test pumping stations. Monitoring energy consumption over time showed potential energy savings at Provas' 150+ network pumping stations. Provas benefitted from operational savings, a better system overview and project plans now based on actual operating data and flow estimates.

(Courtesy: Provas and Grundfos)

Economic and environmental benefits of centralisation, Mariagerfjord, Denmark

The water utility in Mariagerfjord in Northwestern Denmark wanted to improve both economic and environmental benefits of its wastewater treatment and decided to build a new state-of-the-art treatment plant. The new plant will initially handle 75,000 PE but is constructed for 110,000 PE to accommodate the expected population growth over the next 25 years. The new plant is replacing 10 smaller plants, which have treated a total of 5-6 million m^3 of wastewater annually. A 2,000 m^3 digestion tank reduces the amount of sludge and has made biogas production possible. The new WWTP complies with the stricter requirements for discharging into a fjord, even though the cleaned wastewater is actually led nearly 4 km out into the sea. In fact, discharge of organic materials, nitrogen, and phosphorus from the new plant is significantly lower than the total discharge of all the 10 old WWTPs. As the new plant is placed 27 metres above sea level, the cleaned wastewater is discharged primarily by gravity through a pressure gravitational network. Finally, a two-string pipeline with separated sewers has been constructed to avoid the costly and unnecessary treatment of rainwater, which made up more than 50% of the total volume of sewerage water sent to the old plants.

(Courtesy: Mariagerfjord Vand A/S, Jakobsen & Blindkilde A/S, Strøm Hansen A/S, EnviDan A/S and AVK)

5. DECENTRALISED WASTEWATER TREATMENT SOLUTIONS

Protecting the environment while keeping water resources in the area

There are many economies of scale to be achieved from centralised treatment. However, in areas which are not connected to the central sewerage system, decentralised solutions are often more attractive. In areas suffering from water scarcity, local treatment and reuse of wastewater can also contribute to a more stable water balance.

The term 'decentralised wastewater treatment' is often used to describe treatment of wastewater that is not discharged to a municipal treatment plant but takes place onsite and/or in cluster systems for treatment and disposal of wastewater from dwellings and businesses. Decentral wastewater treatment takes place at widely different scales, from clusters within a mega-city to scattered individual households in rural areas.

Strengthening treatment in rural areas

Decentralised treatment solutions are mainly applied in rural areas or other areas, which are not connected to the municipal sewerage system, such as university campuses, industrial parks or resorts. Since 2004, the Danish wastewater treatment strategy has strengthened its focus on villages and scattered households in rural areas. The need to protect groundwater aquifers or surface waters, which are important drinking water sources and sensitive to nutrient pollution, has led to development of a range of new solutions for decentralised treatment. At the high-tech end of this range are prefabricated mini-treatment units for households or small villages. They are typically compact purification systems based on biological processes, mostly confined in tanks and reactors that are covered to prevent spreading of unpleasant odours. At the other end of the range are low-tech biological sand and gravel filters designed for discharge to surface water or for infiltration of treated wastewater into the soil.

Reusing water resources in the area

Ensuring sufficient availability and sustainable management of water and sanitation for all is part of the United Nations' Sustainable Development Goal 6. Reuse of wastewater is one option which can contribute to achieving this goal. Planning for water supply and considering wastewater as a resource rather than a problem may postpone costly investments and give greater flexibility when water shortages occur. Today, treating wastewater to a level of drinking water quality is possible with advanced oxidation processes (AOP) and different membrane technologies. However, treated wastewater is typically used for purposes in which a lower quality is sufficient such as street cleaning, watering of parks and irrigation for crops.

In agriculture, low-technology or partial treatment, for instance in constructed wetlands or reed beds, may be adequate for a range of uses, including irrigation of cereals or tree crops that do not go from farm to fork. If the wastewater is to be reused, the cost will be lower if the recipient is located in close proximity of the treatment facility. This could e.g. be local farmers with greenhouses which require continuous use of water. Or a hotel which reuses its own treated wastewater to water the lawns. Or a golf course where lakes on the golf course can be used as 'storage facilities' for the reclaimed water, which increases flexibility.

Decentralised versus centralised treatment in cities

As ever-expanding cities around the globe have to serve more and more people, there is a risk that multiple sewer systems will grow to unmanageable sizes or require huge pumping costs. A number of existing wastewater treatment plants are already close to reaching their full capacity. In areas with rapid urban growth, decentralised treatment can serve as an attractive temporary solution until an optimal design for a centralised infrastructure is established. A cluster approach with decentralised treatment facilities is for instance attractive in cities with large differences in service levels between the urban centre and surrounding shanty towns or satellite cities as part of a gradual upgrading of the water infrastructure.

Despite the benefits of decentralised solutions, it is also important to be aware that wastewater treatment plants located within cities can be difficult to manage due to risk of foul smell from treatment basins and heavy transport required for disposal of sludge. In addition, the increasing value of land often makes it financially attractive to relocate treatment plants outside the city. Nevertheless, if available space for a wastewater treatment plant becomes a limitation, decentralised plants are attractive solutions to sustain urban progress.

Reclaimed wastewater for irrigation takes pressure off drinking water supply, Harare, Zimbabwe

In Harere, the capital of Zimbabwe, water scarcity was a big problem during the dry season. At the same time, a golf course located in a prestigious area near the former president Mugabe's palace was using large amounts of water for irrigation. As it became politically unacceptable that the local population lacked access to drinking water while the golf course remained lush and green, it was decided to instead use reclaimed wastewater from the local community to irrigate the golf course. In order to reuse wastewater, though, it was essential to have some sort of 'storage facilities' for the treated water to balance the flow and optimise usage. The solution was to build a cost-efficient decentralised wastewater treatment system from Biokube to treat the wastewater from the surrounding community. The treated water is discharged to the lakes on the golf course and later used to water its fairways and greens. As all harmful bacteria are removed and there is no smell from the plant, the result was a sustainable source of water for irrigation that made it possible for the golf course to keep its prestigious image while relieving some of the pressure on the community's water resources.

(Courtesy: Biokube)

Decentralised wastewater system under a public restaurant, Nonthaburi, Thailand

A wastewater system under a public restaurant? Yes, it is possible if the technology is odour free. In 2008, the municipality of Nonthaburi outside Bangkok installed their first own sewage treatment plant. The decentralised system treats the wastewater from the local town hall and discharges the treated wastewater to the neighbouring park, where it contributes to keeping a constant water level in a scenic lake. Since the treatment system is both noise and odour free, the city hall placed its outdoor restaurant on top of the treatment plant - so far without any complaints from the guests. This demonstrates very well, the low level of odour and noise of the BioKube wastewater treatment process.

(Courtesy: Biokube)

6. INDUSTRIAL WASTEWATER TREATMENT

Treatment at the source is often more efficient for industrial wastewater

Municipal wastewater treatment plants are mainly designed to remove easily degradable organic substances and nutrients which are the major constituents of domestic wastewater. However, in many countries the sewer network and treatment plants often also receive wastewater from industrial production.

Industrial wastewater differs a lot
Wastewater from food processing companies is generally well suited for centralised treatment since it is often rich in easily degradable organic compounds, which provide nutrients for the growth of microorganisms and thereby enhance the biological processes. In fact, some treatment plants actively encourage discharge of waste from food processing industries because it is a carbon source and enables them to increase the biogas production and thereby generate more energy, as well as improve the biological removal of nitrogen and phosphorous.

"Municipal wastewater treatment plants are designed for domestic wastewater and not necessarily for industrial wastewater, which not only pollutes but may even cause problems for biological processes and sludge disposal. Treatment of industrial wastewater at the source can have several advantages."

Ulf Nielsen, Chief Planner, DHI

Wastewater from manufacturing industry, on the other hand, has a much more complex composition and often includes substances that do not respond to biological treatment or which may hamper the growth of microorganisms and therefore interferes with the biological treatment processes or makes the sludge unsuitable for use in agricultural fertilisers. In addition, some toxic compounds may jeopardise the occupational health and safety of the utility's staff while corrosive compounds may damage the sewers and pumping equipment. In these cases, it may be advantageous or even mandatory to pre-treat the industrial wastewater at the source before discharging it to the municipal sewerage system or to have full treatment before discharging it directly to the water recipient.

More efficient to treat at the source
Treatment of industrial wastewater at the source has several advantages. First and foremost, treatment can be tailored to the specific industrial pollutants which typically occur in high concentrations in relatively small volumes of wastewater and therefore requires relatively low investment and operational costs. More importantly, it may be possible to recycle or reuse wastewater internally in the production after partial treatment or to recover and reuse raw materials or chemicals. Prime examples are the recycling of dyes used in textile production or metals used in metal plating, where up to 90% of the used water, dyes and metals may be recovered, thereby reducing the discharge of wastewater accordingly. In many countries where wastewater discharge fees are graduated according to pollution load, investment in decentralised wastewater treatment may have a very short payback time.

Methods for decentralised treatment
Industrial pollutants, which require specialised treatment processes, include non-degradable or slowly degradable organic compounds, fat, grease, oil, heavy metals and toxic organic compounds such as pesticides and pharmaceuticals. A number of specialised processes for removal of industrial pollutants can be applied at the source, including neutralisation, heavy metal precipitation, membrane filtration, forward/reverse osmosis, activated carbon filtration, chemical oxidation, ultra-violet disinfection, evaporation, crystallisation and more.

Hospital wastewater and water reuse
In recent years, special attention has been paid to the discharge of hospital wastewater to the public sewerage network. This type of wastewater contains a complex mixture of pharmaceutical residues and other substances that are hazardous to both human health and the environment. Nevertheless, hospital discharge to the public sewer network is seldom regulated. In a number of European countries, including Denmark, there is an increasing focus on Contaminants of Emerging Concerns - incl. pharmaceuticals and microplastics - and on how new treatment technologies can be applied to protect the aquatic environment against them. Removal of the critical pollutants from hospital wastewater will usually require extensive and advanced treatment methods resulting in high-quality effluent. If the treatment is carried out at the source, the treated wastewater can be reused for other purposes at the hospital, which again can reduce the hydraulic load on the sewerage network and treatment plants.

Advance treatment of hospital wastewater, Herlev, Denmark

Hospital wastewater is a complex mixture of disease bearing pathogens, medicine residues and other hazardous substances which present a risk to utility staff, public health and the environment. Technology suppliers have collaborated with one of Denmark's largest hospitals, Herlev Hospital, to implement a full-scale innovative wastewater treatment solution. The full-scale plant has been in operation since May 2014 and has non-stop and robustly treated the wastewater to date (July 2020). The plant is based on an innovative combination of the following technologies: A membrane bio reactor (MBR), ozonation, granulated activated carbon (GAC) and UV treatment. Hazardous pharmaceuticals, estrogenic activity and pathogens – both bacteria and virus - are efficiently removed, resulting in an effluent which is discharged directly to the local stream (Kagså). The cost evaluation shows significant sewer tax savings.

(Courtesy: DHI and UltraAqua)

Reuse of industrial wastewater at a low cost, Alberta, Canada

As a result of water scarcity, many industries today are under increasing pressure from consumers, regulators and investors to shift towards a more sustainable use of water. One of the strategies is Zero Liquid Discharge (ZLD), in which all wastewater is cleaned and reused within a factory. ZLD strategies for minimising waste streams are already possible but extremely resource consuming. By using forward osmosis, a very high quality of extracted water can be obtained, while energy use, capital costs, and waste streams are kept at a low. The company Forward Water Technologies has developed an industrial wastewater treatment pilot plant, which uses Aquaporin Inside® forward osmosis membranes to clean and recycle water. And they have experienced a reduction in waste output of 60-70% with this system. The pilot plant is currently operating with streams from oil & gas production. However, the learnings from this application can be transferred to other industries – e.g. the textile industry which is one of the most water consuming and polluting industries.

(Courtesy: Forward Water Technologies and Aquaporin A/S)

PFAS-concentrate from Swedish airfield	PFOS ug/L	PFOA ug/L
Before treatment	679	34
After SCWO treatment	<0.1	<0.01

Removal of 99.9 % of PFAS from airfield, Sweden
Large quantities of groundwater and soil are currently contaminated with PFAS (per- and polyfluoroalkyl substances). This is problematic as these are found to be persistent, bio accumulative and toxic. PFAS are extremely difficult to remove with conventional remediation technologies but they are widely used around the world - for example in fire extinguishing agents used regularly at airfields. An airfield in Sweden had identified PFAS as a pollutant in their soil and water environment and therefore engaged Aquarden Technologies to remove these compounds through its SCWO treatment technology. The result was a 99.9% drop in PFAS-concentration levels. The SCWO technology can also be customised to treat wastewater from a range of other industries including solvents, detergents, medicinal waste, leachate, phenols, and others. It is designed to handle the most problematic and contaminated wastewater onsite and is particularly suited to treat wastewater containing hardly-degradable organic compounds like PFAS.

(Courtesy: Aquarden)

Zero Liquide Discharge of industrial process water, Monroe, NC, USA
IMET Alloys is a strategic materials management company and an industry leader in recycling super alloys and titanium for the aerospace industry. In 2018 IMET Alloys USA was looking to replace their maintenance intensive evaporator. To evaluate which technology and supplier to go with, the company invited leading evaporator suppliers to make presentations based on the following key performance parameters: energy consumption, cleaning frequency, concentration rate, capacity, distillate quality, up-time, technical support, and response to service issues. The choice fell on Envotherm's ET 1250 evaporator with additional equipment. The solution makes it possible to reuse 95% of IMET Alloy's process water with an energy consumption of less than 35 kWh per treated m^3 process water and zero liquid discharge. IMET Alloy has been impressed with the installation, technology, performance of the equipment and the technical support, which is available online 24/7. The expected payback time for the investment is 1.5-3 years.

(Courtesy: Envotherm)

7. THE TRUE VALUE OF WATER

A Danish perspective on how we can shape our water future

In Denmark, we value our water. We care for how we extract it, use it and release it back to nature. We consider water a valuable resource in the circular economy and a contribution to reaching our green energy and climate goals. Above all, we value water for its potential to improve lives.

Let's protect our drinking water
Everyone deserves water that is clean and safe to drink. In Denmark, our drinking water origins entirely from groundwater. Our strategy is to protect our groundwater resources and in return, our drinking water only receives minimal treatment. Most waterworks simply pump, filtrate and distribute it to the consumers. We monitor it carefully and work to secure clean groundwater for future generations as well.

Let's care for every drop
Water is a scarce resource – and every drop counts. We must make the most of the water we have. In Denmark, we have a low water consumption. The average Dane consumes just over 100 liters a day, our water loss is around 8% and our industries are increasingly focusing on water efficiency and reuse in their production. The price is based on full cost recovery, which ensures a reliable and efficient water supply 24 hours a day. Now let's fight to make every drop count worldwide.

Let's use our wastewater as a resource
Wastewater should no longer be thought of as a problem. Instead, let's turn our wastewater treatment plants into energy and resource recovery facilities where we can extract phosphorous and produce organic fertilizer and biogas. In Denmark, we also aim to utilise wastewater even further up the value chain to produce products such as biofuels and bioplastics.

Let's move towards an energy and climate neutral water cycle
Water plays a key role in creating a sustainable world. It is important to make sure our water management is sustainable as well. In Denmark, we use a minimum of energy to pump and treat water. We continuously work to be energy efficient and we contribute to a greener and more flexible energy system by producing energy from wastewater. In fact, some facilities are now producing more electricity than they consume. By 2030, the Danish water sector aims to be energy and climate neutral across the entire water cycle.

Let's use rainwater to create resilient and liveable cities
Rainwater can improve urban life if it is managed wisely. In Denmark, we store and delay rainwater and stormwater in parks, streets and football fields to create both resilient and liveable cities for a growing population. By doing so, we adapt to the changing climate and weather patterns as well as increase our biodiversity. So, while we may not be fans of rainy days, we appreciate what rainwater can do for us.

Let's swim in our city harbours
Water can be used actively in urban development. Waterfront areas and blue-green infrastructure can transform neighbourhoods and create economic growth. By treating our wastewater and managing our stormwater in underground basins, we have transformed polluted inner-city harbours into urban oases. So when the weather permits, you can go fishing or swimming in the harbour in Danish cities.

Let's collaborate and solve the global water challenges
We want to connect, inspire and learn from each other in global partnerships – and work together to contribute to a sustainable world. Water is one of our most valuable resources and it plays into many other agendas like adapting to and mitigating climate change and increasing biodiversity. Through national and global partnerships across sectors, we can deliver on the UN Sustainable Development Goals on water and sanitation, affordable and clean energy, sustainable cities and communities and life on land and under water.

Water is **life**. And with the right care for water, we can make better lives.

The partners behind Water Vision Denmark aim to further innovation in the Danish water sector, increase Danish export of necessary water technologies to the world and contribute to job creation across the water sector.

WATER VISION DENMARK
INNOVATION | EXPORT | REGULATION

Ministry of Environment and Food of Denmark

DANVA

Danish Environmental Technology Association
Association for Danish Environmental Technology Companies

DI | Water

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