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Wastewater & Circular Economy with focus on Third World

MUDP report

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1. Abstract English

The project covered by this report started in December 2015 as a MUDP research project sponsored and partially funded by the Ministry of the Environment / Danish Environmental Protection Agency.

The original purpose of the project was to develop a high-efficiency container-based wastewater treatment plant that could be deployed urgently in refugee cities and disaster areas. The goal was to develop the plant's biological purification function so that it can function efficiently even after long storage in storage buildings, and the purification solution should ensure that the wastewater is free of pathogenic organisms with the possibility of recycling or seepage of the purified wastewater. The wastewater treatment plant should be developed with a special user-friendly functionality that would make it easy to operate and service in emergency situations. The construction should also be developed in a special version for use in temporary camps for rescue personnel in emergency situations. For this purpose, the plant should be designed in compact module-based units so that it can be deployed quickly in disaster areas by aircraft and / or helicopter.

During the initial detailed planning of the various solutions and including discussions with The Red Cross and NGOs it became apparent that the concept of container-based wastewater treatment plants for emergency use in refugee camps and disaster areas was too narrow. There was a much broader perspective in expanding the concept to include wastewater and Circular Economy not only in refugee camps, but in the Third World in general. It is the same issues that needed to be addressed but the perspective is much broader.
Of course, this recognition was further apparent by the United Nations Sustainable Development Goals, adopted at the UN in September 2015, in particular SDGs 6 and 7.

With the acceptance of the Danish Environmental Protection Agency, the project was therefore expanded to deal with Wastewater & Circular Economy with a focus on the Third World. This is also where the largest refugee camps are and where recycling of both the purified sewage water and sludge has immediate potential.

At the same time, it was decided that the final report should contain descriptions of immediately practical solutions in the Third World, so that the report also could act as a manual. These descriptions of operational solutions developed by others will be updated on an ongoing basis via BioKube's website at www.biokube.com/biokube-technical.library. There will be links to operational descriptions and videos developed by others

The report has the following main chapters:

Wastewater – From a problem to an asset.
Treatment of wastewater on a general large scale started in Europe in the middle of the 19th century with the aim of protecting public health. Wastewater treatment was mainly done in large cities.

After the 1950s wastewater treatment also moved to the rural regions, now also with focus on the environment. The aim was now also to protect the natural waterways from being polluted.

At the same time there was a focus on drought and water shortage in many areas. Consequently, treated wastewater was seen as a resource to increase access to water, mainly for irrigation.

With the general implementation of United Nations' Sustainable Development Goals, here, especially SDG 6, the reuse of treated wastewater has become widely accepted, and almost mainstream.

Reuse of treated wastewater.
With the wish to reuse treated wastewater, the quality of the wastewater treatment systems become very important.
You cannot safely reuse treated wastewater if the quality of the preceding wastewater treatment system is in doubt. And since many of the systems are small, it is very important, that they can operate unattended and not be negatively affected by fluctuations in the incoming water.

The chapter describes the different technologies used and the use of SAF (Submerged Aerated Filter) technology such as BioKube is recommended for small systems. See more om www.biokube.com.

Reuse of sludge.
The chapter describes how sludge can be converted from a problem to an asset.
The two main ways of reusing sludge are either as fertilizer or as energy.

Sludge is a significant hassle and expense when treating wastewater. Using simple technologies, sludge can be reused.
Sewage sludge is a carbon-neutral biomass and could be an effective resource for reduction of CO_2 emission and contribute in the reduction of global warming.
Among the many types of biomass, sewage sludge has an advantage that the generated amount and quality is almost constant throughout the year, so it is also a stable energy source.

The chapter describes in detail a system installed in Ghana where sludge from wastewater collected from storage tanks in Accra, Ghana, is converted to charcoal. See video here of the system in operation.
The system installed in Ghana was also a research project in which BioKube participated partly financed by the Danish Foreign Ministry.

Drinking water from poor-quality water.
With water shortage comes naturally the lack of access to good-quality drinking water.
The chapter describes a cheap, but still efficient system for treating poor-quality water to drinking water, using BioKubes ultrafiltration system ULTRA/Clean.

Changing focus and technologies during the project.
The chapter describes the considerations behind some major changes during the course of the project.
The major changes were

- Moving from a containerized solution to a permanent in ground solution
- Moving from after treatment with drum filter and UV lighting to Ultra Filtration

2. Abstract Danish

Det projekt, der er omfattet af denne rapport, startede i december 2015 som et MUDP-forskningsprojekt sponsoreret og delvis finansieret af Miljøministeriet / Miljøstyrelsen.

Projektets oprindelige formål var at udvikle et højeffektivt container baseret spildevandsrenseanlæg, som kunne indsættes akut i flygtningebyer og katastrofeområder. Målet var at udvikle anlæggets biologiske rensefunktion, så den hurtigt kan fungere effektivt selv efter lang tids opbevaring i lagerbygninger, og renseløsningen skal sikre, at spildevandet er fri for patogene organismer med mulighed for genbrug eller nedsivning af det rensede spildevand. Renseanlægget skulle udvikles med en særlig brugervenlig funktionalitet, som ville gøre det enkelt at betjene og servicere i indsatssituationer. Anlægskonceptet skal desuden udvikles i en særlig udgave til brug i midlertidige lejre for redningspersonale i katastrofesituationer. Til dette formål skal anlægget udformes i kompakte modulbaserede enheder, så det kan indsættes hurtigt i katastrofeområder med fly og/eller helikopter

Under de indledende detailbeskrivelser af de forskellige løsningsmuligheder og herunder samtaler med bl.a. Røde Kors og NGO'er blev vi klar over, at konceptet med containerbaserede renseanlæg til akuthjælp i flygtningelejre og katastrofeområder var for smalt. Der var et meget bredere perspektiv i at udvide konceptet til at omfatte spildevand og Cirkulær Økonomi ikke kun i flygtningelejre, men i Tredje Verden Generelt. Det er helt de samme problemer, der skulle håndteres men perspektivet er meget bredere.
Denne erkendelse blev selvfølgelig yderligere bestyrket af De Forenede Nationers Sustainable Development Goals, der blev vedtaget i FN i september 2015, især SDG 6 og 7.

Med tiltrædelse af Miljøstyrelsen blev projektet derfor udvidet til at omhandle Spildevand & Cirkulær økonomi med fokus på Tredje Verden. Det er også her de største flygtningelejre er og hvor genanvendelse af både det rensede spildevand og slam umiddelbart har størst potentiale.

Med det udgangspunkt blev det samtidig besluttet, at den endelige rapport skulle indeholde beskrivelser af umiddelbart praktisk anvendelige løsninger netop i Tredje Verden, så rapporten samtidig kunne fungere som en håndbog. Disse beskrivelser af operationelle løsninger udviklet af andre vil løbende blive opdateret via BioKubes hjemmeside på www.biokube.com/biokube-technical.library. Der vil også være link til operationelle beskrivelser og videoer udviklet af andre.

Rapporten har følgende hovedkapitler:

Spildevand - fra et problem til et aktiv.
Behandling af spildevand i stor skala startede i Europa i midten af det 19. århundrede med det formål at beskytte folkesundheden. Spildevandsbehandling blev i begyndelsen kun udført i de store byer.
Efter 1950'erne er spildevandsrensning også flyttet til landdistrikterne, nu også med fokus på miljø. Målet var nu også at beskytte det naturlige vandmiljø mod at blive forurenet.

På samme tid begyndte der at være fokus på tørke og vandmangel i mange områder. Derfor begyndte renset spildevand nu også at blive betragtet som en ressource, der kunne øge adgangen til vand, hovedsageligt til kunstvanding.

Med den generelle implementering af FN's mål for bæredygtig udvikling, her især SDG 6, er genbrug af behandlet spildevand blevet bredt accepteret og næsten mainstream.

Genbrug af renset spildevand.

Med ønsket om at genbruge renset spildevand bliver kvaliteten af renseanlæggene meget vigtig.
Man kan ikke sikkert genbruge renset spildevand, hvis der er tvivl om kvaliteten og stabiliteten af det forudgående renseanlæg. Og da mange af systemerne er små, er det yderligere meget vigtigt, at de kan fungere uden opsyn og ikke påvirkes negativt af udsving i det indkommende spildevand.

Kapitlet beskriver og vurderer de forskellige teknologier, der bruges og anbefaler brugen af SAF (Submerged Aerated Filter) - teknologi, som BioKube benytter.
Se mere om www.biokube.com.

Genbrug af slam.

Kapitlet beskriver, hvordan slam kan konverteres fra et problem til et aktiv.
De to vigtigste måder at udnytte og genbruge slam på er enten som gødning eller til energi.

Slam er en ressourcekrævende og en betydelig bekostning ved behandling af spildevand. Ved hjælp af enkle teknologier kan slam genbruges typisk som gødning eller energi.

Spildevandsslam er en CO_2 neutral biomasse og kunne være en effektiv ressource til reduktion af CO_2 og dermed bidrage forebyggelse af global opvarmning.
Blandt de forskellige former for biomasse har spildevandsslam bl.a. den fordel, at den genererede mængde og kvalitet er næsten konstant hele året, så det er også en stabil energiform.

Kapitlet beskriver detaljeret et system installeret i Ghana, hvor slam fra spildevand opsamlet fra lagertanke i Accra, Ghana, omdannes til trækul.
Systemet installeret i Ghana var også et forskningsprojekt, hvori BioKube medvirkede, der delvis blev finansieret af Udenrigsministeriet og Miljøministeriet / Miljøstyrelsen.
Se her video om systemet i drift.

Drikkevand fra vand af dårlig kvalitet

Med vandmangel kommer naturligvis også mangel på adgang til drikkevand.

Kapitlet beskriver et billigt, men stadig effektivt system til behandling af vand af dårlig kvalitet til drikkevand ved hjælp af ultrafiltrering med BioKube ULTRA/Clean løsning.

Skift i fokus og teknologier under projektforløbet.

Kapitlet beskriver overvejelserne bag de større ændringer der blev besluttet under projektforløbet.
De større ændringer var

- Ændring fra renseanlæg i containere til permanent nedgravet renseanlæg
- Ændring fra efterbehandling med tromlefilter og UV til ultra filtrering

3. Introduction

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Most of the systems and technologies described in the document are developed and/or sold by BioKube, and the pictures and illustrations hereof belong to BioKube[1] [2].
Some of the systems shown are in the public domain or developed by different other manufacturers. The technology and pictures of these systems belong to the individual manufacturers.

The project is focused on household wastewater, and only sporadically covers the reuse of industrial wastewater.

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[1] See link to BioKube Company Presentation illustrating the different solutions.

[2] See the general description of all BioKube solutions and products at www.biokube.com.

3.1 Original project focused on refugee camps.

The original project was focused only on the treatment of wastewater and reuse of sludge in refugee camps.
The aim was to design a simple system where you could improve the living conditions of people in a camp, and at the same time, develop a low cost and efficient system allowing for safe reuse of the treated water expectedly for irrigation outside of the camp.
It was also an aim in the project that sludge should be reused as fertilizer or energy.

The system should be based on a simple technology that would run for long periods of time without maintenance.
Also, any required maintenance should be able to be performed by people with only basic mechanical training.
It was foreseen that the systems would quite likely be for temporary use and then relocated.
The systems were therefore expected to be containerized for easy relocation.

3.2 Scope of project widened to general Third Country use.

During the initial work with the project, we realized, that the potential demand for such a system was much broader than “only” refugee camps.
The foreseen market for such a system was found to be Third World Countries in general. i.e., people living under fairly poor conditions, often in arid areas with little water and poor sanitation.

Also, we found that people living in these areas could be expected to live there for long periods of time. The systems could, therefore, be made permanent and not based in containers.
This would also significantly reduce the cost of each system.

This change in the focus of the project was approved by the Danish Ministry of Environment in January 2017.
This change in focus and general widening of the scope of the whole project has meant some delay in the completion of the project.

4. Wastewater - from a problem to an asset

4.1 Historic overview[3]

Historical Background. Direct discharge of sewage

Many ancient cities had drainage systems, but they were primarily intended to carry rainwater away from roofs and pavements. A notable example is the drainage system of ancient Rome. It included many surface conduits that were connected to a large vaulted channel called the Cloaca Maxima ("Great Sewer"), which carried drainage water to the Tiber River. Built of stone and on a grand scale, the Cloaca Maxima is one of the oldest existing monuments of Roman engineering. Construction of Cloaca Maxima began 600 BC and parts of is still in operation.

There was little progress in urban drainage or sewerage during the Middle Ages. Privy vaults and cesspools were used, but most wastes were simply dumped into gutters to be flushed through the drains by floods.

Toilets (water closets) were installed in houses in the early 19th century, but they were usually connected to cesspools, not sewers. In densely populated areas, local conditions soon became intolerable because the cesspools were seldom emptied and frequently overflowed. The threat to public health became apparent.

In England, in the middle of the 19th century, outbreaks of cholera were traced directly to well water supplies contaminated with human waste from privy vaults and cesspools. It soon became necessary for all water closets in the larger towns to be connected directly to the storm sewers. This transferred sewage from the ground near houses to nearby bodies of water. Thus, a new problem emerged: surface water pollution.

Developments in sewage treatment

It used to be said that "the solution to pollution is dilution."

When small amounts of sewage are discharged into a flowing body of water, a natural process of stream self-purification occurs. Densely populated communities however generate such large quantities of sewage, that dilution alone does not prevent pollution. This makes it necessary to treat or purify wastewater to some degree before disposal.

The construction of centralized sewage treatment plants began in the late 19th and early 20th centuries, principally in the United Kingdom and the United States.

Instead of discharging sewage directly into a nearby body of water, it was first passed through a combination of physical, biological, and chemical processes that removed some or most of the pollutants. Also beginning in the 1900s, new sewage-collection systems were designed to separate stormwater from domestic wastewater, so that treatment plants did not become overloaded during periods of wet weather.

After the middle of the 20th century, increasing public concern for environmental quality led to broader and more stringent regulation of wastewater disposal practices. Higher levels of treatment were required. For example, pre-treatment of industrial wastewater, with the aim of preventing toxic chemicals from interfering with the biological processes used at sewage treatment plants, often became a necessity. In fact, wastewater treatment technology advanced to

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[3] See link to Encyclopedia Britannica, Online version

the point where it became possible to remove virtually all pollutants from sewage. This was so expensive, however, that such high levels of treatment were not usually justified.
In high-income countries with water shortage, total reuse of water, even including the reuse of wastewater as drinking water is practiced. This is, for instance the case in Singapore.

Wastewater treatment plants became large, complex facilities that required considerable amounts of energy for their operation. After the rise of oil prices in the 1970s, concern for energy conservation became a more important factor in the design of new pollution-control systems. Consequently, land disposal and subsurface disposal of sewage began to receive increased attention, where feasible. Such “low-tech” pollution control methods not only might help to conserve energy but will also serve to recycle nutrients and replenish groundwater supplies.

Also, mainly to preserve the natural waterways, in recent years wastewater treatment has included small cities and even individual dwellings in the open country.

Local, on-site wastewater treatment.
As described above, the treatment of wastewater has historically been done only in larger cities. This partly because for small cities nature could “treat” the smaller amount of discharged sewage water without the recipient becoming too polluted.
See in this respect also the European Water Framework Directive[4].

This is changing, and since the late 1970s there has been an increased focus on treating all wastewater before it is discharged to the natural waterways.
In Europe, the Clean Water Directive has meant that even individual houses in the open country outside the areas with sewer lines must treat their wastewater.
This is currently being implemented in all EU countries.

The historical reasons for treating wastewater can, therefore be summarized into, at present, two considerations and two upcoming.
a) To secure public health by removing harmful bacteria.
b) To protect the natural waterways.
c) And upcoming, primarily due to general water shortage, reuse of treated wastewater, and
d) Even more in the future using sludge to generate energy, used as fertilizer or asset retrieval.

4.2 What can be reused in the wastewater?

Reuse of the treated wastewater.
Reuse of treated wastewater is in the infant beginning, but there is general agreement that the demand will grow, primarily due to increased drought and shortage of water in many countries. In the EU, the European Commission proposed on May 2018 new rules to stimulate and facilitate water reuse, especially for agricultural irrigation.[5]

Why reuse treated wastewater?
Water over-abstraction is a major cause of water stress. Main pressures from water consumption are concentrated on irrigation and domestic demand, including tourism, where there are high seasonal variations in demand and the demand for water is highest in dry periods.
It should be noted that the tourists themselves generate wastewater that can be reused and thereby help to relieve pressure on the local limited water sources.

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[4] See link to EU Water Framework Directive.

[5] See link to EU Proposal for a regulation on minimum requirements for water reuse

The 2007 EU Communication on Water scarcity and Droughts[6] made clear that water scarcity and drought events are likely to be more severe and more frequent in the future due to climate change and increasing population.
Over the past thirty years, droughts have dramatically increased in number and intensity in the EU and at least 11% of the European population and 17% of its territory have been affected by water scarcity.

The potential role of treated wastewater reuse as an alternative source of water supply is now well acknowledged and embedded within international, European, and national strategies.
UN Sustainable Development Goal on Water (SDG 6[7]) specifically targets a substantial increase in recycling and safe reuse globally by 2030.

Water reuse is a top priority area in the Strategic Implementation Plan of the European Innovation Partnership on Water[8], and maximization of water reuse is a specific objective in the Communication "Blueprint to safeguard Europe's water resources"[9].

Reuse of treated wastewater can provide significant environmental, social, and economic benefits. According to the Blueprint, water reuse can improve the status of the environment, both quantitatively, alleviating pressure by substituting abstraction, and qualitatively, relieving the pressure of discharge from wastewater treatment plants to sensitive areas.

Moreover, when compared to alternative sources of water supply such as desalination or water transfer, water reuse often turns out to require lower investment costs and energy, also contributing to reducing greenhouse gas emissions.

Reuse of treated wastewater can be considered a reliable water supply, quite independent from seasonal drought and weather variability, and able to cover peaks of water demand. This can be very beneficial to farming activities that can rely on the continuity of water supply during the irrigation period, consequently reducing the risk of crop failure and income losses. A simple example of this is a BioKube system installed in Zimbabwe where the treated wastewater is used to water greens and fairway on the adjacent golf course.

Appropriate consideration for nutrients in treated wastewater could also reduce the use of additional fertilizers resulting in savings for the environment, farmers and wastewater treatment.

Water reuse contributes to the broader water sector which is a key component of the EU eco-industrial landscape.
The world water market is growing rapidly, and it is estimated to reach 1 trillion € by 2020. For this reason, water reuse also encompasses significant potential in terms of the creation of green jobs in the water-related industry, and it is estimated that a 1% increase in the rate of growth of the water industry in Europe could create up to 20.000 new jobs.

So, it is evident that in the future you will see a substantial movement towards the reuse of treated wastewater.
This will naturally involve better treatment techniques to ensure the reuse of treated water does not collide with public health.

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[6] Se link to EU strategy on Water scarcity & Drought.

[7] Se link to UN SDG 6 “Ensure availability and sustainable management of water and sanitation for all”

[8] See link to The European Innovation Partnership on Water

[9] See link to Blueprint to Safeguard Europe's Water Resources

Here continuous treatment of the wastewater to the required quality standard is important. It is not sufficient a wastewater treatment in a test situation is able to fulfill the requirements. It must do so in real life on a daily basis.

Reuse of Sludge

Sludge is the residue that accumulates in sewage treatment.
This residue is commonly classified as primary and secondary sludge.
Primary sludge is mainly particles in the incoming raw wastewater. In many wastewater treatment systems this is collected in the primary treatment zone (septic tank), but also particles generated from chemical precipitation, sedimentation, and other primary processes.
Secondary sludge is the activated waste biomass resulting from biological treatments.
Quite often the sludges are combined together for further treatment and disposal.

Treatment and disposal of sewage sludge are major factors in the design and operation of all wastewater treatment plants.
The two basic goals of treating sludge before final disposal are to

1. Reduce its volume and
2. Stabilize the organic materials.

Stabilized sludge does not have an offensive odor and can be handled without causing a nuisance or health hazard.
Smaller sludge volume reduces the costs of pumping and storage.

Sludge treatment methods

Treatment of sewage sludge will include a combination of thickening, digestion, and dewatering processes

Thickening

Thickening is usually the first step in sludge treatment because it is impractical to handle thin sludge, a slurry of solids suspended in water. The solid content before thickening will typically be less than 2%.

Thickening is usually accomplished in a tank called a gravity thickener.
A thickener can reduce the total volume of sludge to less than half the original volume, i.e., increasing the solid content to up to 5%.

An alternative to gravity thickening is dissolved air flotation (DAF technology).
In this method, air bubbles carry the solids to the surface where a layer of thickened sludge forms and is continuously removed by scrapers[10].

Digestion

Sludge digestion is a biological process in which organic solids are decomposed into stable substances.[11]
Digestion reduces the total mass of solids, destroys pathogens, and makes it easier to dewater or dry the sludge.
Digested sludge is inoffensive, having the appearance and characteristics of rich potting soil.

Dewatering

Digested sewage sludge is usually dewatered before disposal.

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[10] See link to Wikipedia on Dissolved air Flotation technology

[11] See link to Wikipedia on Anaerobic digestion

Dewatered sludge still contains a significant amount of water - often as much as 70 percent - but, even with that moisture content, sludge no longer behaves like a liquid and can be handled as a solid material.
Sludge-drying beds provide the simplest method of dewatering.

Disposal of sludge
The final destination of treated sewage sludge usually is the land.
Dewatered sludge can be buried underground in a sanitary landfill.
It also may be spread on agricultural land in order to make use of its value as a soil conditioner and fertilizer.
Since sludge may contain toxic industrial chemicals, it is not spread on land where crops are grown for human consumption.

Where a suitable site for land disposal is not available, as in urban areas, sludge may be incinerated.
Incineration completely evaporates the moisture and converts the organic solids into inert ash. The ash must be disposed of, but the reduced volume makes disposal more economical. Air pollution control is a very important consideration when sewage sludge is incinerated. Appropriate air-cleaning devices such as scrubbers and filters must be used.

Dumping sludge in the ocean, once an economical disposal method for many coastal communities, is no longer considered a viable option. It is now prohibited in many coastal countries.

5. Reuse of the treated wastewater

5.1 Cleaning technologies for primary treatment

5.1.1 Introduction

The quality of the treated water depends, to a large degree, on the wastewater treatment technology used. This despite the fact that all wastewater treatment is done using the same natural bacteria.
Some systems give better living conditions to the bacteria. And consequently, they will perform better.

In the following pages, there is a short description of the most commonly used wastewater treatment technologies.
Focus is on small and medium sized systems as these are the sizes you will typically meet if the aim is to reuse the treated wastewater.

There are for each technology short pros and cons. Here the focus is on the different systems' ability to

- ➢ With stability treat the water to the desired standard.
- ➢ Require little maintenance.
- ➢ Be able to operate with no constant operator intervention i.e., the system should run with automatic adjustments to handle any fluctuations.

The main factors in respect to giving good living conditions to the bacteria are

- ✓ Amount of nourishment for the bacteria and the consistency of the incoming nourishment.
  The incoming nourishment to the bacteria is the organic material we want removed from the wastewater before discharge.
  Too much nourishment and the bacteria will not have enough oxygen, and the system will develop Hydrogen Sulphide (H_2S), which is poisonous to the bacteria; too much H_2S, and they will die.
  Not enough nourishment or large fluctuations in incoming load and the bacteria will also die unless there is taken special care of this issue in the system design.
- ✓ Sufficient Oxygen for the bacteria to thrive.
- ✓ No incoming inhibiting agents that will poison or hamper the growth of bacteria

5.1.2 SAF (Submerged Aerated Filters)

SAF is BioKube's preferred technology, especially if the requirement is for the reduction of organic material in the water (BOD and COD reduction) or if the requirement is for the reduction of Ammonium (NH_4).

BioKube's SAF systems are characterized by[12]

- ✓ Very stable cleaning process with low requirement for maintenance.

[12] See link to detailed theoretical documentation for BioKube patented treatment technology

- ✓ Tolerant towards fluctuations in the incoming water.
  Especially in connection with BioKube's patented technology[13]. Compared to other technologies, the process will "self-adjust" to variations in the incoming load to be treated by changes in the thickness of the biofilm on the filter media increasing or decreasing depending on the amount of nourishment.
- ✓ Low energy consumption.
  Energy consumption is +/- ½ kWh energy used per m^3 water treated.
  The energy consumption will vary slightly depending on the treatment demand. Higher treatment demand will require higher energy consumption primarily due to longer retention time.
- ✓ The very efficient treatment process, give smaller footprint.

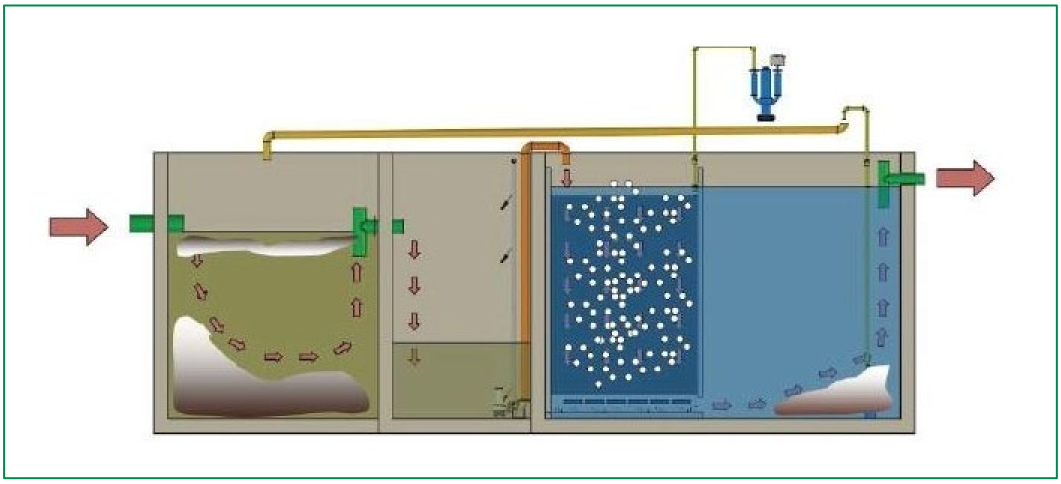


FIGURE 1: BioKube's One-Chamber system,
Schematic illustration of BioKube patented cleaning technology with one treatment chamber
First step, the septic tank to remove solids.
Second step, a buffer tank to enable timed inflow of nourishment to the bacteria.
Third step, an aerated treatment chamber.
Fourth step, settling zone to retain all SS, ensuring clean outgoing water free from particles.
Final step, recirculation to the septic tank of biological sludge from the settling zone.

BioKube's patented treatment technology.
With standard household wastewater containing BOD 400 mg/l, a BioKube one chamber system will treat the water to BOD < 25 mg/l.
<u>The one chamber system consists of</u>:

- Preceding septic tank to retain solids.
- Buffer tank to allow for the timed inflow of the water to be treated (BioKube patent).
- Aerated zone with the bacteria living on the submerged aerated filters. The one step system will reduce BOD to below 5 mg/l.
- Settling zone to remove suspended solids.
- Recirculation from the settling zone to the septic tank. This sends all solids to the septic tank.
  It eliminates Hydrogen Sulphide (H_2S) – and thereby smell – from the system, because aerated water containing oxygen is sent back to the septic tank.
- If removal of Phosphate is required PAX will be dosed in the recirculation to the septic tank to have the phosphorous settle here.

[13] See link to BioKube patent

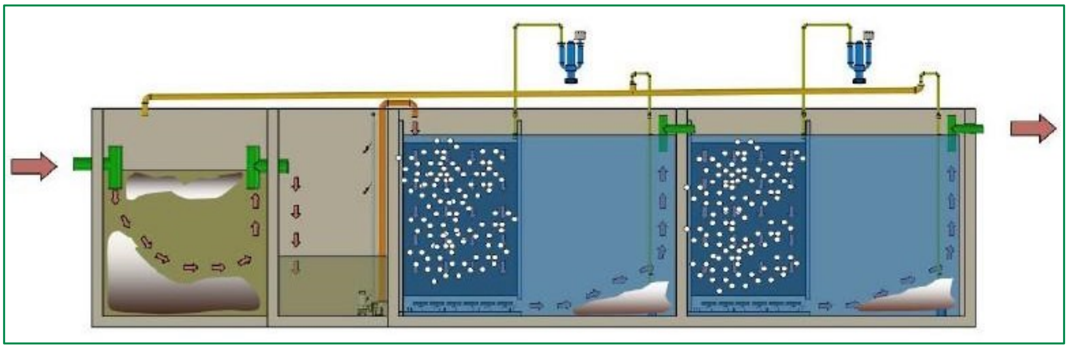


FIGURE 2: BioKube's Two-chamber system
Schematic illustration of BioKube patented cleaning technology with two treatment chambers
You see the second treatment step enabling both nitrification and denitrification.

The two-chamber system consists of:

- In a two-step system, the second treatment zone will reduce BOD outgoing to below 10 mg/l.
  This compares to the 25 mg/l incoming from the first treatment step.
- With BOD reduced to below 10mg/l, the second step will also perform nitrification reducing NH_4 (ammonium) to below 5 mg/l
- The recirculation of treated wastewater with low NH_4 (but high NO_3) will make the system also perform denitrification eliminating Total Nitrogen by over 50 %.
  Typical outgoing value of N_{tot} < 25 mg/l or Total N reduction of over 50 %.

FIGURE 3. Biokube system for 2.000 m^3 / day.
You can clearly see the aerated treatment zone and the subsequent settling zone

5.1.3 Activated sludge

The process is based on aerobic micro-organisms that can digest organic matter in sewage, and clump together (by flocculation) as they do so. It thereby produces a liquid that is relatively free from suspended solids and organic material and flocculated particles that will readily settle out and can be removed.[14]

The general arrangement of an activated sludge process for removing BOD / COD includes the following steps:

Aeration tank where air (or oxygen) is injected in the mixed liquor (the activated sludge).
Settling tank (usually referred to as "final clarifier" or "secondary settling tank") to allow the biological flocs (the sludge blanket) to settle, thus separating the biological sludge from the clear treated water.
Treatment of nitrogenous matter or phosphate involves additional steps where the mixed liquor is left in anoxic condition (denitrification to reduce N_{tot}).

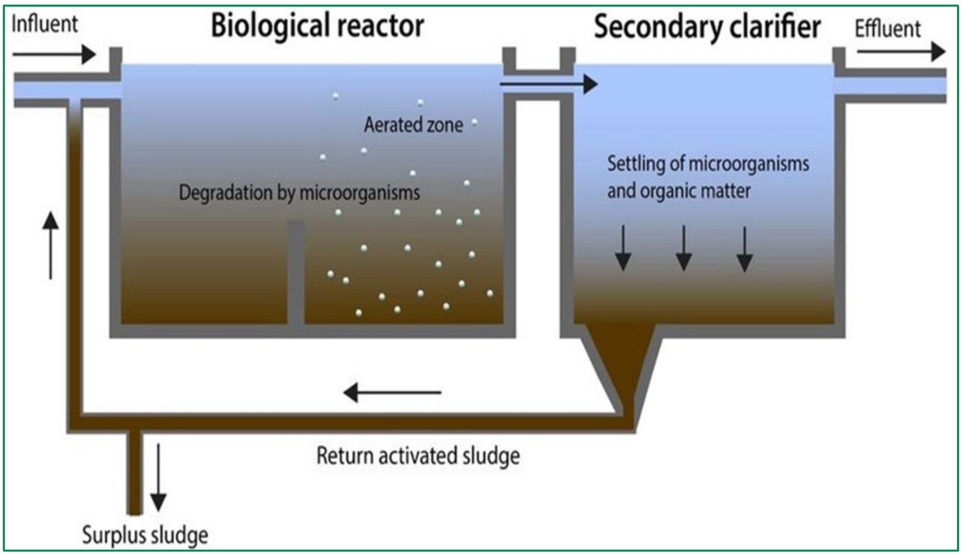


FIGURE 4. Illustration of the treatment process in an activated sludge system.

The process involves air or oxygen being introduced into a mixture of screened and primary treated wastewater combined with organisms to develop a biological floc, which reduces the organic content of the sewage. This material, which in healthy sludge is a brown floc, is largely composed of saprotrophic bacteria.

In all activated sludge plants, once the wastewater has received sufficient treatment, excess activated sludge is discharged into settling tanks to undergo treatment before discharge.
See here also chapter 6 on the reuse of sludge.

Part of the settled material, the activated sludge, is returned to the head of the aeration system to re-seed the new wastewater entering the tank. This fraction of the floc is called return activated sludge (R.A.S.). The aim is to keep a sufficient sludge age.
In small systems with variations in the incoming load, this problem of keeping a correct sludge age is an operational hassle with these systems. There is no self-adjusting; it must be done by operator intervention.
This means in practice, that an activated sludge system requires continuous or at least frequent monitoring.

Many sewage treatment plants use axial flow pumps to transfer nitrified mixed sludge from the aeration zone to the anoxic zone for denitrification. The raw sewage, the RAS, and the nitrified

[14] See link to Wikipedia describing activated sludge

mixed sludge are mixed by submersible mixers in the anoxic zones in order to achieve denitrification.

Activated sludge is as also mentioned the name given to the active biological material produced by activated sludge plants.
Excess sludge is called "surplus activated sludge" or "waste activated sludge" and is removed from the treatment process to keep the ratio of biomass to food supplied in the wastewater in balance. This sewage sludge is usually mixed with primary sludge from the primary clarifiers and undergoes further sludge treatment, for example, by anaerobic digestion, followed by thickening, dewatering, composting and land application.
See here also chapter 6 regarding reuse of sludge.

The amount of sewage sludge produced from the activated sludge process is directly proportional to the amount of wastewater treated. The total sludge production consists of the sum of primary sludge from the primary sedimentation tanks as well as waste activated sludge from the bioreactors. The activated sludge process produces about 70–100 kg/ML of waste activated sludge (that is kg of dry solids produced per ML of wastewater treated).

FIGURE 5. Treatment chamber in an activated sludge system.

Especially small activated sludge systems will often have problems if there are large variations in the incoming load.
If there is no nourishment coming to the system for a long period (for instance a summerhouse or vacation hotel with off-seasons), the bacteria will simply die of lack of nourishment.
If there are other substantial variations in the incoming load, the operator has to take special consideration into maintaining a correct sludge age. This will be an ongoing operational hassle.

5.1.4 SBR (Sequential Batch Reactor)

Sequencing batch reactors (SBR) are a special type of activated sludge process.
In the SBR reactors, oxygen is bubbled through the mixture of wastewater and activated sludge to reduce the organic matter.

The treated effluent may be suitable for discharge to surface waters or possibly for use on land

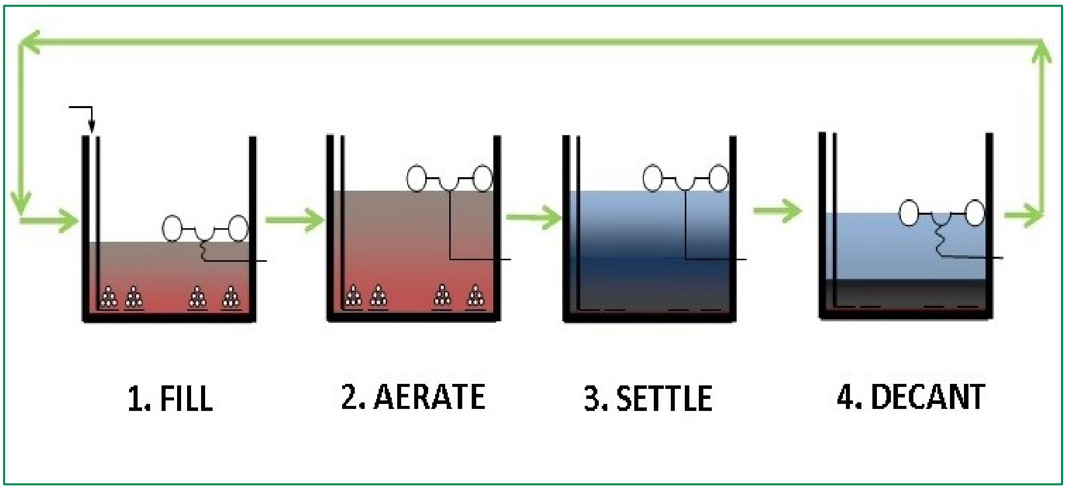


FIGURE 6. Illustration of the treatment process in an SBR system.
There are five stages in the treatment process, they are:
Fill
Aerate / React
Settle
Decant
Idle

The treatment processes.
The inlet valve opens, and the tank is being filled in, while mixing is provided by mechanical means (no air). This stage is also called the anoxic stage.

Aeration of the mixed liquor is performed during the second stage by the use of fixed or floating mechanical pumps or by transferring air into fine bubble diffusers fixed to the floor of the tank.

No aeration or mixing is provided in the third stage, so here, the solids will settle.

During the fourth stage, the outlet valve opens, and the water treated to the required values is discharged.

Especially small SBR systems will often have problems if there are large variations in the incoming load.
If there is no nourishment coming to the system for a long period of time (for instance, a summerhouse or vacation hotel with off-seasons), the bacteria will simply die of lack of nourishment.
If there are other substantial variations in the incoming load, the operator has to take special consideration into maintaining a correct sludge age.
This will be an ongoing operational hassle.

FIGURE 7. Picture of an operational SBR system.
You can see both an aerated chamber and an idle chamber.

5.1.5 MBR (Membrane Bio Reactor)

Membrane bioreactor (MBR) is the combination of a membrane process like microfiltration with a biological wastewater treatment process based on an activated sludge process.
When used with domestic wastewater, MBR processes can produce effluent of high quality.

Two MBR configurations exist:

- Internal/submerged, where the membranes are immersed in and integral to the biological reactor; and
- External/side-stream, where membranes are a separate unit process requiring an intermediate pumping step.

Recent technical innovation and significant membrane cost reduction have enabled MBRs to become an established process option to treat wastewaters. As a result, the MBR process has now become an attractive option for the treatment and reuse of industrial and municipal wastewaters, as evidenced by their constantly rising numbers and capacity.

As with other systems based on activated sludge, especially small MBR systems will often have problems if there are large variations in the incoming load.
If there is no nourishment coming to the system for a long period of time (for instance a summerhouse or vacation hotel with off-seasons), the bacteria will simply die of lack of nourishment.
If there are other substantial variations in the incoming load, the operator has to take special consideration into maintaining a correct sludge age.
This will be an ongoing operational hassle.

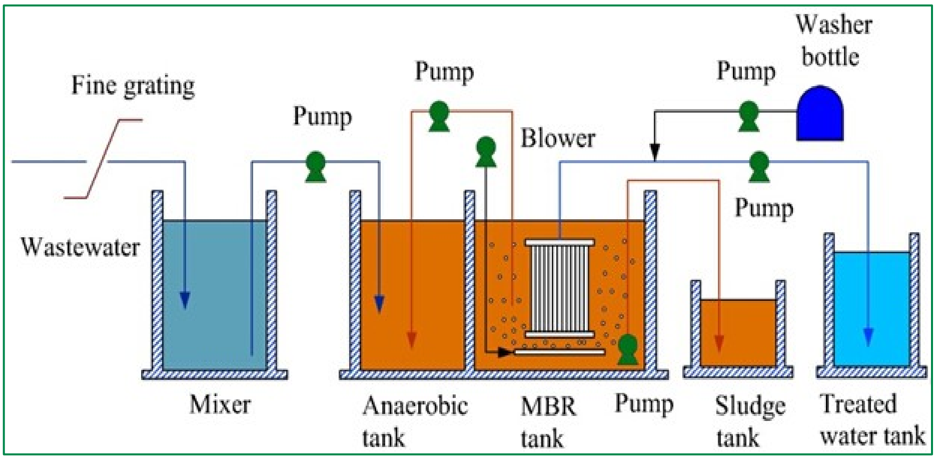


FIGURE 8. Illustration of MBR wastewater system.

FIGURE 9. MBR system in operation.
In the small picture, you can see the sheet membranes that in operation are submerged in the
treatment tank.

5.1.6 MBBR (Moving Bed Bio Reactor)

An MBBR system consists of an aeration tank (similar to an activated sludge tank) with special plastic carriers that provide a surface where a biofilm can grow. In this respect, it is similar to a SAF system.
There can be one or two treatment steps, see illustration below.

The carriers are made of a material with a density close to the density of water (1 g/cm^3). An example is high-density polyethylene (HDPE), which has a density close to 0.95 g/cm^3. The carriers will be mixed in the tank by the aeration system and thus will have good contact between the substrate in the influent wastewater and the biomass on the carriers.

To prevent the plastic carriers from escaping the aeration chamber(s), it is necessary to have a sieve on the outlet of the tank. To achieve a higher concentration of biomass in the bioreactors, hybrid MBBR systems have also been used where suspended and attached biomass co-exist contributing, to both biological processes.

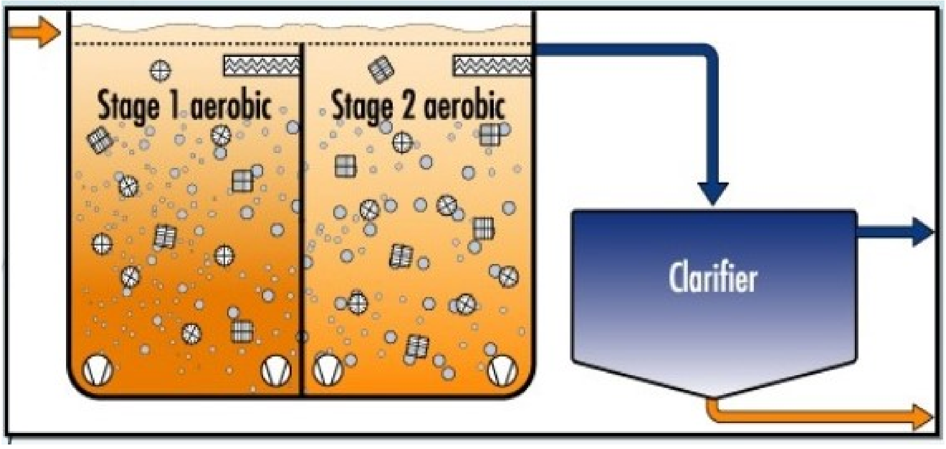


FIGURE 10. An MBBR system with two aerobic chambers

FIGURE 11. An MBBR system in operation. You can see the floating media

5.1.7 Special issues / Fluctuations (Summerhouses & Hotels)

As described earlier, most wastewater treatment systems will have problems if there are fluctuations in the incoming water.
This is especially the case for systems based on activated sludge technology (basic activated sludge systems, SBR (Sequential Batch Reactor systems) and MBR (Membrane Bioreactor systems).

In all activated sludge systems, there will be a tendency for the bacteria to die, if for a long period of time there is no incoming nourishment.
The situation is naturally especially critical in summerhouses and vacation hotels with long periods of no incoming nourishment.

ETV (Environmental Technology Verification) for wastewater systems in summer-houses.

In the EU there is a system of verification of the functionality of technologies involving the environment.
You can apply for the functionality of a new technology to be verified if there is no harmonized standard according to which a technology can be certified.
This is the case for wastewater systems in summerhouses.

Small wastewater systems are certified according to a harmonized standard CEN 12566-3[15]. But the certification only requires a vacation period of two weeks. This is not nearly enough to simulate a summerhouse situation where the house is typically vacant for a 6-month winter period.
The reason for this is, naturally, that systems based on activated sludge cannot function after a several months long vacation period.

FIGURE 12. Typical BioKube summerhouse location.
System installed near the water where the houseowner and his children will swim and fish.

BioKube's ETV verification for summerhouse use[16]

BioKube has ETV (Environmental Technology Verification) for the use of BioKube wastewater systems in summerhouses.

How does summerhouse mode work?

[15] See link to the standard CEN 12566-3 Small wastewater treatment systems for up to 50 PT - Part 3: Packaged and/or site assembled domestic wastewater treatment plants

[16] See link to BioKube ETV Verification

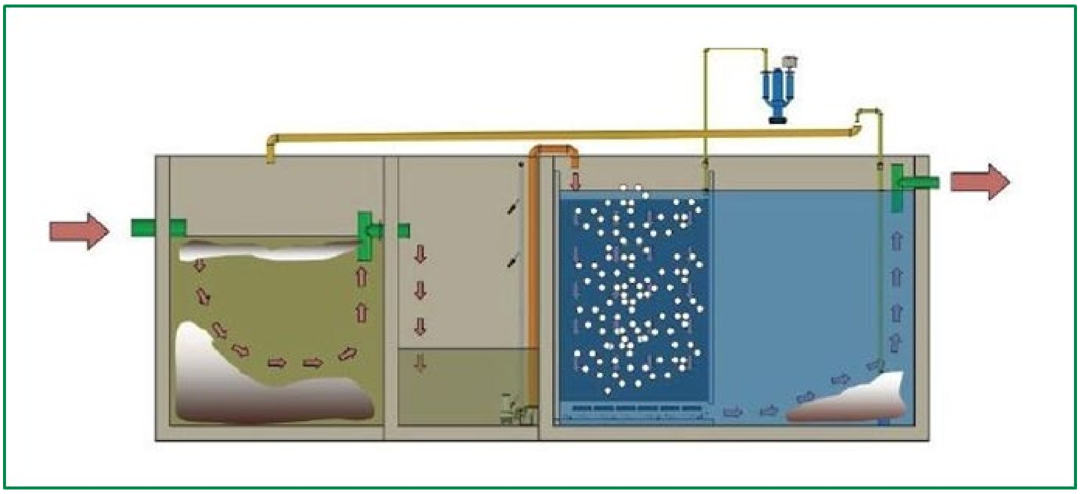


FIGURE 13: BioKube's One-chamber system,
Schematic illustration of BioKube patented cleaning technology with one treatment chamber
First step, the septic tank to remove solids
Second step, a buffer tank to enable timed inflow of nourishment to the bacteria
Third step, aerated treatment chamber
Fourth step, settling zone to retain all SS, ensuring clean outgoing water free from particles.
Final step, recirculation to the septic tank of biological sludge from the settling zone

The ability for the bacteria to receive nourishment regardless of no occupancy in the house, is based on the recirculation from the final settling zone to the septic tank. When treated water is recirculated to the septic tank, it will naturally overflow into the buffer tank; but now, it will contain nourishment from the septic tank.
If there is no occupancy in the house, you do not need as frequent recirculation to remove solids from the settling zone; only enough to give nourishment to keep the bacteria alive. In this situation, recirculation is only done six times per day as compared to every 15 minutes in standard configuration.
The system automatically registers no occupancy (no incoming water for over 48 hours) and goes to summerhouse mode.
When incoming water is again registered by the system, it automatically swifts back to standard mode.
This is done automatically by the system's built-in control box.

The ETV verification.
With the ETV, it is verified that a BioKube system will fulfill the outlet requirements even if there has been no incoming sewage water (i.e. no nourishment to the bacteria) in the preceding six months with no occupancy.
Energy saving mode.
In the winter (or other periods with no occupancy in the house), the system as described automatically registers that there is no incoming water and automatically goes to "summerhouse mode".

The system at the same time goes into "Save Energy Mode", where there is a reduction of power consumption by 80 %.
This reduction is mainly done by letting the blowers run for a limited time each day. With no incoming water, the bacteria need less oxygen. Consequently, it is sufficient to let the blowers run six times ½ hour per 24-hour full day cycle.

FIGURE 14. BioKube systems are also installed in a number of hotels that have the same issue as
summerhouses. Low occupancy in the off-season and consequently low inflow of nourishment
to the bacteria. Also, here, BioKube technology keeps the bacteria alive during the off-season.

5.2 How clean should the treated water be?

Requirements are almost always set by the authorities.
In practically all countries, there are national requirements on how clean the treated water should be.
The requirements will typically reflect

- ✓ To where the wastewater is discharged.
  In this respect there will often be different requirements depending on the situation in the recipient receiving the treated water. How much incoming nourishment can the recipient receive and still fulfill the requirements for the specific recipient?
- ✓ Will the water be reused, and if so, will the treated wastewater come in contact with people?

Typical treatment requirements, what is measured?

The typical parameters measured to fulfill national requirements will be one or more of the following:
BOD_5 / BOD_7: (Biological Oxygen demand) measured in mg/l
COD (Chemical Oxygen Demand) measured in mg/l
NH_4 (ammonium) measured in mg/l
N_{Tot} (Total Nitrogen) measured in mg/l
P (Phosphate) measured in mg/l
SS (Suspended Solids) measured in mg/l
E.coli (measured in no / 100 ml

Nematode: measured in no / 100 ml

It should be noted, that to fulfill some of the requirements, the systems will often be equipped with different kinds of "ad-on equipment", such as UV lighting to remove bacteria or Polly Aluminum Chloride (PAX) dosing to remove phosphate.

Divided into typically used groups, the treatment requirements are:

Standard European cleaning requirements[17]
BOD: 25 mg/l
COD: 125 mg/l
NH_4 N/A
N_{Tot}: N/A
P: N/A
SS: N/A
E.coli N/A
This is the standard European treatment requirements for small and medium wastewater systems. It is also followed in many other countries.
The requirements are often stricter for larger systems.

Countries with ammonium requirements
BOD: 10 mg/l
COD: 75 mg/l
NH_4: 5 mg/l
N_{Tot}: N/A
P: 1,5 mg / l
SS: N/A
E.coli N/A
This is the requirement in Denmark and some areas with sensitive environment in Europe[18]
Countries with Total N requirements
BOD: 10 mg/l
COD: 75 mg/l
NH_4: 5 mg/l
N_{Tot}: 20 mg/l (requirement sometimes given as reduction requirement for instance 50 % reduction)
P: 1,5 mg/l
SS: N/A
E.coli N/A
This is the requirement in England[19] and some areas in Sweden[20].

Countries with bacteriological requirements.
These requirements are typically set where water is reused.
The requirements will often be identical to one of the above plus additional on bacteria.
Typical values will be
Nematode nil
E.coli < 100 / 100 ml[21]

---

[17] See link to EU Water Framework Directive

[18] See link to Danish legislation

[19] See link to UK legislation

[20] See link to Swedish legislation

[21] See link to requirements in Kuwait

It should be noted that the above standards for how clean the treated water should be are set regarding what the values needed be to protect the waterways or groundwater.
In some cases, what is unwanted in surface water to protect life there is desirable if the water is used for irrigation. Both nitrogen and phosphate are desirable if the water is used for irrigation, but unwanted in excess amounts in the waterways.

General Verification of ability to fulfill requirements.
For small wastewater treatment systems, often up to 50 PE / 6 m^3/ day there is in many countries a certification system. Certification normally involves that the system undergoes a test for a full year covering all cycles of a family's normal life.
In the EU this certification is after a standard CEN 12566-3[22]. In the US certification is done by NSF[23].

Certification after one of these standards means that there is certified documentation performed by an independent authorized body of the system's performance.
From the performance numbers achieved you can see if the system will fulfill the relevant local or national demands.

Before using any small wastewater treatment system for reuse, it is recommended that it is verified that the system is certified after one of the above-mentioned standards (or another recognized standard) as this in practice is the only way of checking if the technology actually performs as claimed by the manufacturer.

You should, if possible, also verify that the system functions in "real life" and not just in a test environment.
Ask for validated cleaning results over a long period of time. Not many suppliers supply these numbers, partly because the local authorities do not test actual performances.

One country that does certify the treatment results of all installed small wastewater treatment systems is Denmark. One company, BioKube, makes all their cleaning results for all 4.000 systems in Denmark public[24].

The documented cleaning results for the systems were:

COD	29,9 mg/l	Requirement 75,0 mg/l
BOD	4,8 mg/l	Requirement 10,0 mg/l
NH4-N	3,1 mg/l	Requirement 5,0 mg/l
P total	1,2 mg/l	Requirementm1,5 mg/l

These are cleaning results better than required in practically all countries.
The shown results are from small systems up to 50 PE. For larger systems with individual outlet requirements set by the authorities, the treatment results are often better, simply because the outlet requirements are stricter.

For removal of E.coli the systems can be equipped with UV lighting.

22 See link to CEN 12566-3 Small wastewater treatment systems for up to 50 PT - Part 3: Packaged and/or site assembled domestic wastewater treatment plants

23 See link to NSF/ANSI 40: Residential Onsite Systems from NSF (The Public Health and Safety Organization

24 See link to BioKube treatment results from all 4000 small systems installed in Denmark

5.2.1 After primary treatment

As described in section 5.1, there are different treatment technologies you can use to treat the incoming wastewater. After primary treatment, the treated water should as minimum, fulfill one of the above-mentioned standards.

Again, it should be noted, that the standards are set to protect the waterways from being harmed by discharged wastewater. Here, protection of both plants and fish means that the water should remain clear (no excessive algae growth) and low nitrogen, which is poisonous to fish.
This means low BOD (high BOD will derive the water from oxygen to and lead to degradation in the waterway), low P (which is necessary for water plants to grow).

However, both BOD, P and Nitrogen are desirable if the water is used for irrigation. Here, wastewater with only BOD reduction to bod < 25 mg/l would be desirable.

5.2.2 Removal of Suspended Solids.

A well-functioning wastewater treatment system like BioKube will reduce SS to below 20 mg/l. This will be done by simply settling in a chamber after the primary treatment

This is technically extremely simple; it is only a question of the retention time in the settling tank to be long enough for the particles to settle in the bottom and be removed from here.

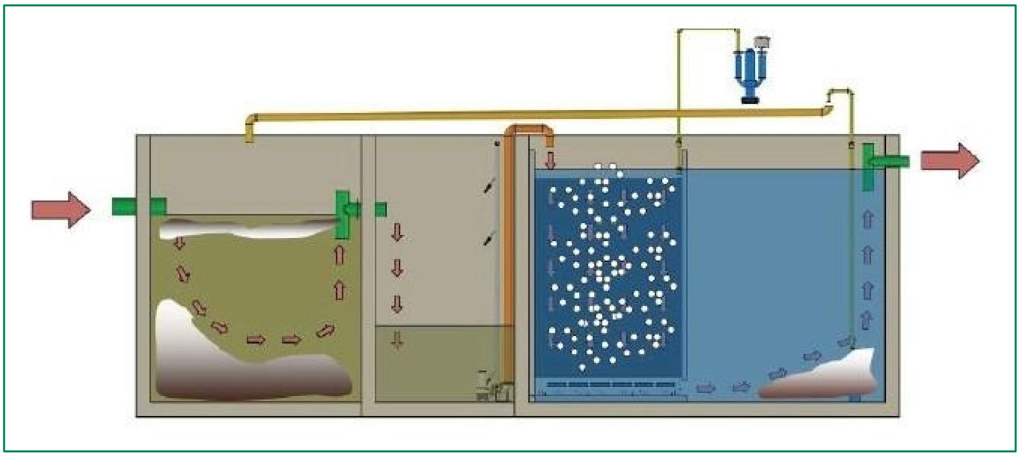


FIGURE 15. BioKube single chamber system. You see

a) Septic tank
b) Buffer tank
c) Aerated treatment zone
d) Settling zone
e) Recirculation to septic tank.
This system will treat wastewater to below BOD 25 mg/l

Sand filters or filtration.

If the treated water is to be completely free from SS you will often use sand filters or filtration. The issue in this respect is typically optical. If you want to reuse the treated wastewater even for something as simple as toilet flushing you will want the water to optically look clean with no color, no suspended solids (particles), and no smell.

Ultra Filtration or MBR system.

A well-functioning solution to remove all SS is Ultra Filtration.

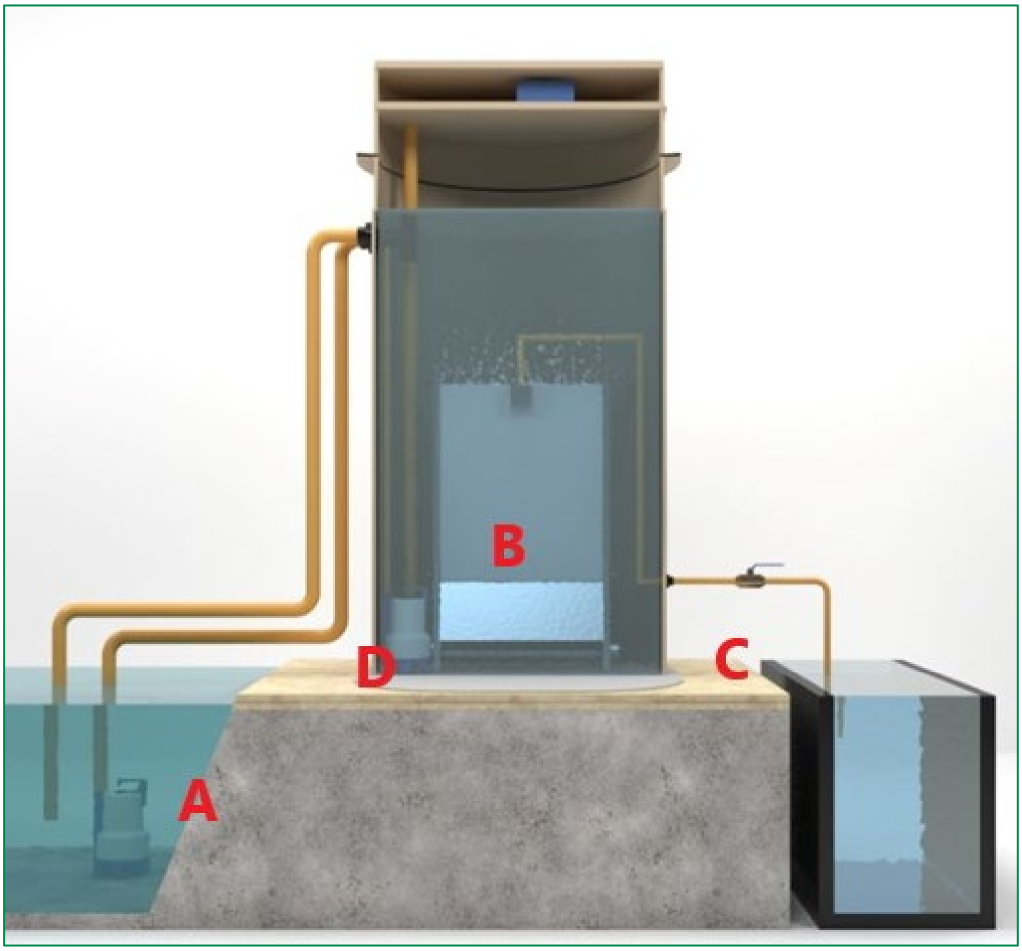


FIGURE 16. BioKube ULTRA/Clean. You see

a) The incoming water pump
b) ULTRA/Clean membrane
c) Outlet (water throughput based only on gravitation)
d) Pump for discharge sludge to water source.

The treated water before discharge passes through the Ultra Filtration membrane. The holes in the membrane are so small that all suspended matter (SS, bacteria, and nematode) remain outside the membrane[25].

Measurements for e.coli removal ULTRA/Clean

Location	Country	Date	water type	E.Coli before cfu /100 ml	E.Coli after cfu / 100 ml	Coliform before cfu / 100 ml	Coliform after cfu / 100 ml	removal rate
Dysted	Denmark	24-07-2019	Wastewater	500	< 1	< 2000	4	99.8 %
Mariatta	Denmark	17-07-2019	Wastewater	> 2000	< 1	< 2000	4	99,95
Gainswille, Florida	USA	12-04-2017	Wastewater	< 1.100.000	< 0,45			99.99
Gainswille, Florida	USA	19-05-2017	Wastewater	< 6.100.000	< 0,45			99,99
KAIPTC	Ghana	29.11-2018	Wastewater	558	< 1	1.302	< 1	99,99
Exodus	Zimbawe	02-08-2019	flood water	46	< 1	120	< 1	99,99
Creek	PNG	07-09-2019	river water	52	0	< 2000	15	99.99
Purari	PNG	08-09-2019	lake water	45	0	< 2000	0	99.99

[25] See link to description of BioKube ULTRA/Clean

FIGURE 17. Cleaning results for BioKube ULTRA/Clean. You can see the retention rate for E.coli is
better than 99,9 %. This makes the treated water safe for reuse.

A wastewater treatment system based on MBR (Membrane Bio Reactor) technology functions much the same way. The difference is that in an MBR system, the cleaning membrane is submerged into the last chamber in the wastewater system and the treated water is discharged through the membrane.

5.2.3 Post treatment - Removal of E.coli, pathogen and nematode

If the treated wastewater is to be discharged to waterways, there are normally no general standard requirements for the removal of bacteria, pathogen and nematode.
There are, however standards for the amount of E.coli in surface water, especially if it is to be used for bathing water[26].

In warm countries, especially in The Middle East, there are requirements for the amount of Nematode in treated wastewater. The requirement is often nil / 0 per 100 ml.

5.3 Examples of reuse of wastewater

There is a general awareness of increasing problems with water scarcity in many countries. In the EU there is a general directive covering water scarcity and the possibilities of reducing this problem by reusing wastewater[27].

The requirements are stricter if the treated wastewater is used to water plants used for direct human consumption

5.3.1 Irrigation

The most common way to reuse wastewater is for irrigation.
Here, it is easier to reuse wastewater from small systems than water from large a large "big city" system.
The reason is practical.
In a "large city" system, you have large underground pipes to bring raw wastewater to the system. To reuse the water, you need large pipes to bring it back.

So, the initial recommendation is to reuse wastewater based on smaller distributed systems.

[26] See link to EU Bathing water directive.

[27] See link to Water Scarcity and Drought in the European Union

FIGURE 18 Illustration of system setup for reuse for irrigation. You see

a) The on-site built septic tank

b) BioKube's Venus treatment unit

c) Below ground storage tank equipped with a pump with timer to use drip irrigation at night.

FIGURE 19. BioKube system under installation at golf course in Harare, Zimbabwe. The treated water will be used for irrigation on the golf course's greens and fairways. You can see the golf course in the picture

FIGURE 20. Drip irrigation from a BioKube system installed at office belonging to Environmental Protection
Agency in Al Hassa, Saudi Arabia

5.3.2 Toilet flushing

Another common reuse of the treated wastewater is for toilet flushing.

One technical issue here is that it involves putting in dual piping. One string for clean drinking water and one for cleaned wastewater for the toilets.
Also, if the water comes from, for instance, a hotel, in the hotel there is much more water produced than there is subsequent demand for toilet flushing. i.e. you have more water available than used for toilet flushing, so there is water also for cleaning or irrigation around the hotel.

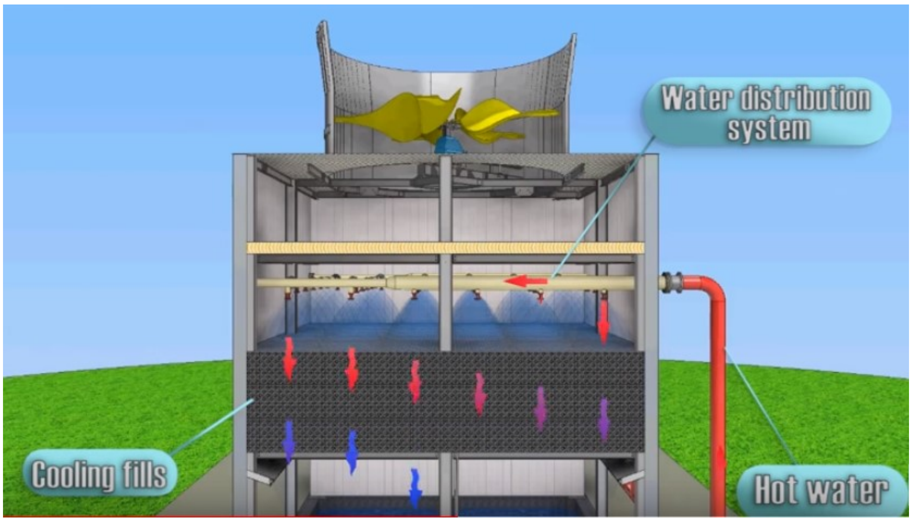
FIGURE 21. BioKube system installed at a luxury hotel in Tanzania. The treated water is used for toilet
Flushing, and the excess water is used for watering the green areas around the hotel

FIGURE 22. BioKube system installed in the basement of a luxury hotel in Mombasa, Kenya. The wastewater treatment is the white boxes. Treated water is stored in the steel tanks and the water reused for toilet flushing and watering the green areas around the hotel.

5.3.3 Cooling Towers

A cooling tower is a heat rejection device that rejects waste heat to the atmosphere through the cooling of a water stream to a lower temperature.
Cooling towers can use the evaporation of water to remove process heat and cool the working fluid to near the wet-bulb air temperature.[28]

If treated wastewater is to be used in a cooling tower it must be low on SS and low on residue BOD[29].
We therefore recommend using ULTRA/Clean before sending the water to the cooling tower.



[28] See link to Wikipedia description of Cooling Towers

[29] See link to Reclamation of wastewater for cooling tower operations

FIGURE 23. The functionality of a cooling tower.

5.3.4 Other secondary usage

If the treated wastewater is used in such a manner, that it comes in contact with people, consideration must be taken towards removing all bacteria.
We therefore recommend the use of ULTRA/Clean.

FIGURE 24. Reuse of water in Africa.

FIGURE 25. Reuse of water. Important to be sure there are no harmful bacteria in the water if it comes
in contact with people

FIGURE 26. There is a wide spectrum of reuse of water. If there is water scarcity, there is no reason
to use drinking water for these secondary purposes.

6. Reuse of sludge

6.1 Handling of sludge is a major cost in wastewater treatment

Handling of sludge is a major expense in wastewater treatment.

Although sludge represents only 1% to 2% of the treated wastewater volume, its management is highly complex and has a cost usually ranging from 20% to 60% of the total operating costs of the wastewater treatment plant.
Besides its economic importance, the final sludge destination is a complex operation, because it is frequently undertaken outside the boundaries of the treatment plant[30].

See BioKube's description of Sludge treatment technologies[31]
Utilizing sludge as a resource is of fairly new date[32] [33]

The description below regarding different technologies for sludge treatment should be seen as the first step of reusing the sludge.

6.2 Traditional ways of sludge disposal and not reuse

Dry weight per capita production of sewage sludge resulting from primary and secondary treatment is about 90 grams per day per person. This is more or less the same in all EU countries where municipal communities are served by two stage physical, mechanical, and biological processing plants.
This is equivalent to the generation of about 10.7 million tons (dry weight) of sewage sludge every year.

Information on the methods and approaches used by different EU member states for the final disposal of sewage sludge is uncertain. In some European countries the main practice is landfilling (50 to 75%), while the rest is disposed in agricultural fields as soil conditioner/fertilizer (25 to 35%) or other recycling outlets (e.g. parks, land restoration, and landscaping).

Agricultural use of raw sludge or other composting practices is the traditional way of reusing sludge, and it is encouraged by national authorities in many EU countries as the best way for recycling, while incineration is considered the worst.
Directive 86/278/EEC on Sewage Sludge in Agriculture[34] requires, however, that no-one may permit the use of sewage sludge on agricultural land unless specific requirements are fulfilled.

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[30] See link to IWA sludge handling solutions

[31] See link to BioKube sludge disposal technologies

[32] See link to Wastewater sludge as a resource: Sludge disposal strategies and corresponding treatment technologies aimed at sustainable handling of wastewater sludge

[33] See link to Sewage sludge treatment on Wikipedia

[34] See link to EU Introduction to sewage sludge

The Directive aims at avoiding the accumulation of toxic substances, especially heavy metals, that might enter the food chain from the use of sludge as fertilizer[35].

6.2.1 Simple dumping and disposal

The traditional way of sludge disposal has historically been to deposit it.
This is no longer considered sustainable.
Sludge is now increasingly seen as an asset and should be reused.

6.2.2 Drying bed

Sludge drying bed is the most widely used method for sludge dewatering.
Sludge drying involves simple-to-use and implement natural ways of drying the sludge compared to mechanical ways of removing the water content.

A sludge drying bed is generally used for small and medium sized communities.
The selection of the technology will depend upon land availability, climatic factors, the quantity and composition of the sludge.

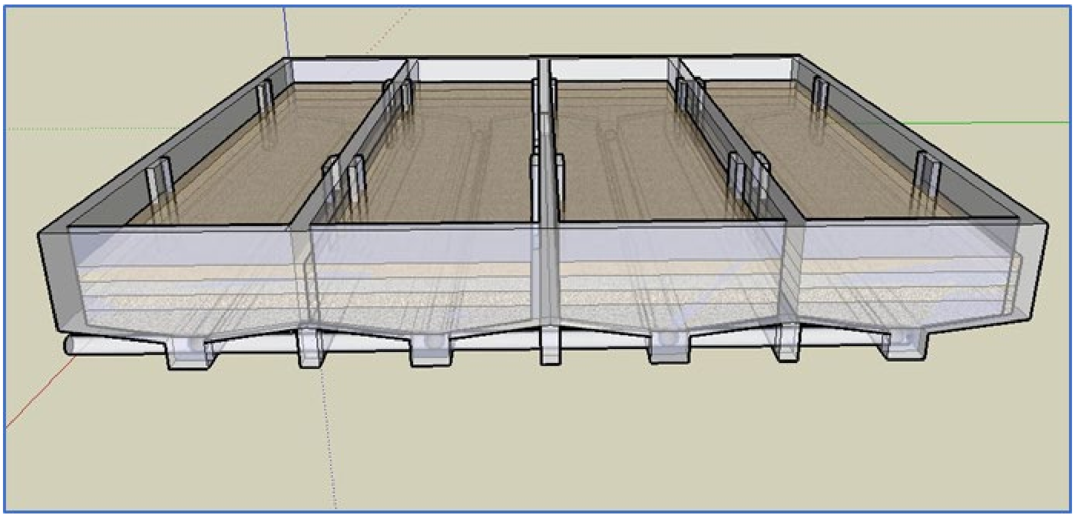

FIGURE 27 Construction of sludge drying bed

[35] See link to Directive 86/278/EEC on the protection of the environment, and in particular of the soil, when sewage sludge is used in agriculture

FIGURE 28. Sludge drying bed in operation in Oman by a BioKube system. It uses simple evaporation to
dry the sludge. You can see the sludge frying bed consists in this case of two chambers used
alternatively. The area is so dry the system only relies on simple evaporation.

A sludge drying bed is a common method utilized to dewater sludge via filtration and evaporation. Perforated pipes situated at the bottom of the bed are used to drain sewage water or filtrate. A reduction of about 70% in moisture content is expected after drying.
In dry areas you will use simple evaporation only.

Each normal sized sludge bed will be 3x6 m2 (18 m2), a small size sludge bed will be 2x4 m2 (8m2).

Daily Capacity of STP	50 m³/day	250 m³/day	500 m³/day	1.000 m³/day
Number of sludge beds required	2	2 - 3	3 - 4	6 - 8
Size of drying bed in warm country	50 m^2	250 m^2	500 m^2	1.000 m^2
Weekly expected amount of sludge and water to be lead to drying bed	10 m^3	30 m^3	100 m^3	200 m^3

6.2.3 Reed bed / Rootzone system

Treatment of sludge in a Reed Bed system is a low energy and low-cost solution that uses nature's own methods to reduce production of sludge through dewatering and through breaking down organic material (see graphics below), including hazardous organic material.[36]

[36] See link to Danish RootZone technology for sludge disposal

Because Sludge Treatment Reed Bed Systems are built on a principle of using nature's own ways, the method has many environment friendly advantages:

- ✓ No use of chemicals, and minimal use of energy
- ✓ Good work environment
- ✓ Reduction of hazardous and pathogenic materials
- ✓ Improvement of sludge quality and possibilities for recycling and reuse.
- ✓ Sustainable treatment of sludge
- ✓ Sludge is reduced in the Reed Bed since a large part is processed by the plants

A Reed Bed has low treatment costs compared to other treatment methods.
- Reduction of expenses for transport and spreading of the sludge.
- You can expect at least 30 years of use.
- Very low operation and maintenance costs

How does the Sludge Treatment Reed Bed System work?
A Sludge Treatment Reed Bed System is designed to dewater and mineralize sludge from wastewater treatment plants and waterworks.
The sludge passively dewaters by drainage through a filter and through subsequent evaporation.
Plants and the microbial activity contribute to the dewatering, ventilation and mineralization.
The environmental sustainable treatment leaves a residue of treated sludge – which results in a product of high quality, "bio-soil", as the final product.
The bio-soil is reusable and can be used as a fertilizer to improve the quality of the soil.
The natural processes in the treatment and the dewatering of the sludge represent a sustainable, energy effective and affordable method of Sludge Treatment in a Reed Bed System, compared to a more conventional mechanical dewatering of sludge.

The Sludge Treatment Reed Bed System contains a number of basins built as either concrete or soil basins with a waterproof membrane at the bottom.
In the basins, there is a filter containing a system for the sludge supply line and for drainage.
In the filter, reed vegetation is planted. The function of the drain system is partly to drain the reject water from the sludge dewatering before it is pumped into the inlet at the wastewater treatment plant and partly to ventilate the filter and sludge.

See the graphics below for a visualization of the process in a Sludge Treatment Reed Bed System.
The majority of the knowledge about Sludge Treatment Reed Bed System of sludge is developed in Danish and northern European sludge treatment facilities[37]

[37] See link to Danish consulting company Orbicon description of treatment (dewatering and mineralization) of sludge in Sludge Treatment Reed Beds (STRB) or Sludge Treatment Wetlands (STW

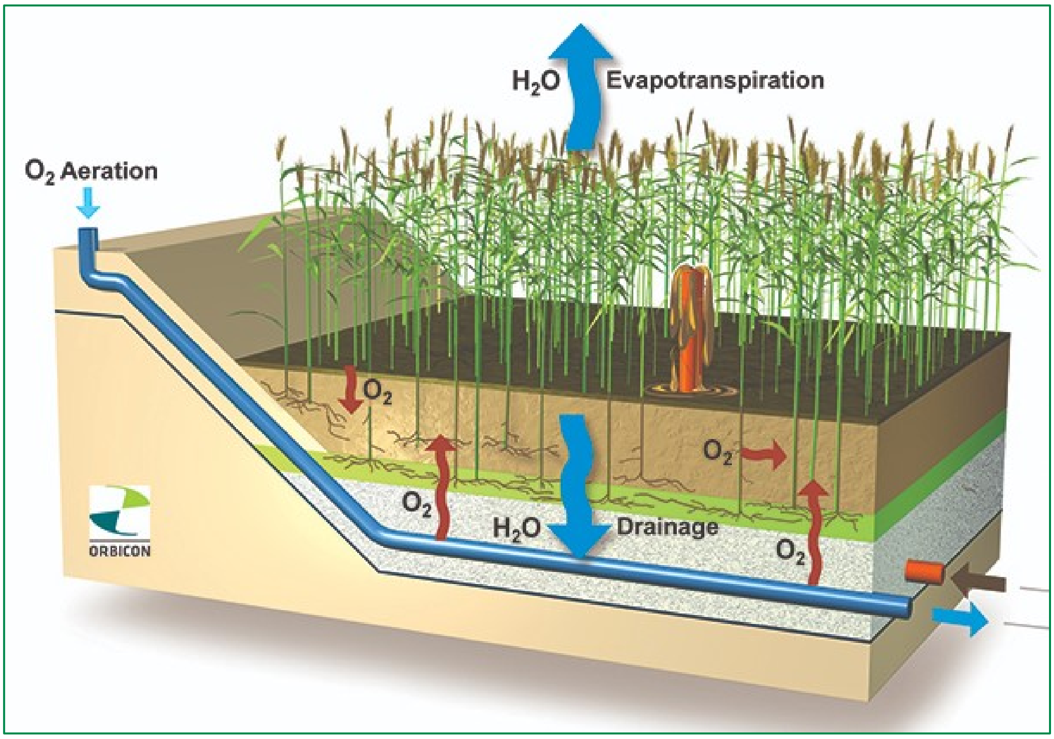

FIGURE 29. Design of Rootzone system

Treatment and disposal of sludge are major factors in the design and operation of all sludge treatment plants.
The two basic goals of treating sludge before final disposal are to reduce its volume and stabilize the organic materials.
Organic substances in waste are degraded with the application of air, whereby an effective decomposition is achieved.

When mineralizing organic matter in the sludge, 60-70 percent of the dry matter is transferred into CO2, oxygen, free nitrogen and partly dewatered soil particles.
The sludge is dewatered, depending on the local climate, to a dry matter content of 35% to 60% within two to three weeks.

In the long term, the sludge will be reduced to 2-4% of the originally applied volume. This reduces operational costs. such as handling, transport, final deposition etc.

Experience has shown that sludge mineralization plants under temperate climate will metabolize 6-8 m3/m2/year at a high dry matter level and 20-40 m3/m2/year at a low dry matter level. Under a hot climate capacity is up to double.

How big is a rootzone system?

Daily Capacity of STP	50 m³/day	250 m³/day	500 m³/day	1.000 m³/day
Number of sludge beds required	2	2 - 3	3 - 4	6 - 8
Total size Reed beds Europe / Africa & Middle East	Europe 50 m^2 Bed Africa 45 m^2 Bed	Europe 250 m^2 Bed Africa 210 m^2 Bed	Europe 500 m^2 Bed Africa 400 m^2 Bed	Europe 1.000 m^2 Bed Africa 800 m^2 Bed
Weekly expected amount of sludge and water to be lead to drying bed	10 m^3	30 m^3	100 m^3	200 m^3

FIGURE 30. Rootzone system in operation

FIGURE 31. Rootzone system in operation.

6.2.4 Screw Press

A dewatering Screw Press has a role in several industry sectors and is not just concerned with processing sewage.

A dewatering screw press minimizes the amount of solid volume that requires disposal too, which ensures landfill and other waste systems are optimized.

If a dewatering screw press has been installed, it eliminates the need for the cost of sedimentation tanks, as the secondary sludge is thickened by the equipment after the process.

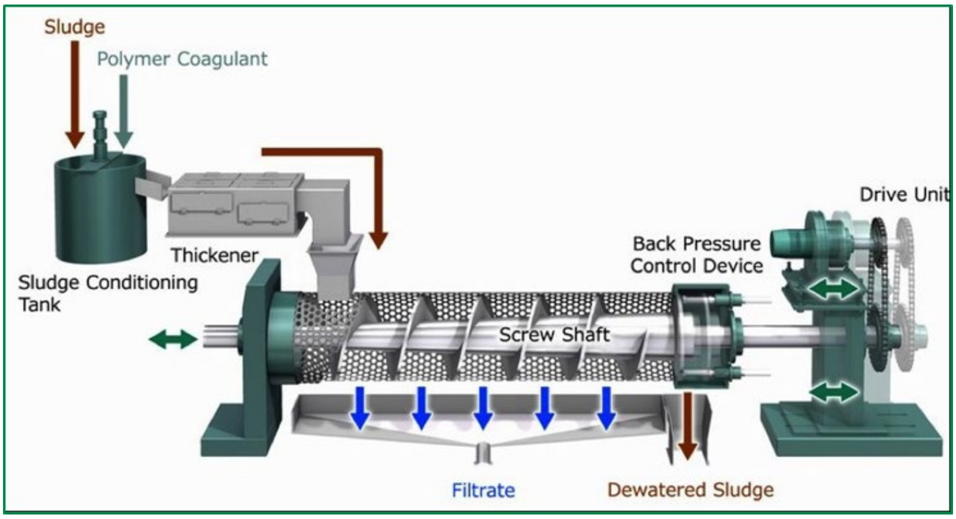

FIGURE 32. Design and construction of Screw Press

Dewater Screw Press design
A feed pump transfers sludge to the dewatering screw press. Sludge water is pumped to the first inlet chamber. It is here that the flow to the other section of the screw press is optimized using an overflow.

As the sludge water enters the mixing chamber from the inlet chamber, a flocculant is added, which helps solid particles aggregate into a product known as flocks. The sludge water is mixed with the flocculant by a slow-moving blade in the mixing chamber. The flocks, together with the treated sludge water, flows towards the screw press.

The helix of the screw has plates that are a self-cleaning filter. The moving plates ensure that continuous self-cleaning of the filter takes place while the fixed plates act as a filter.

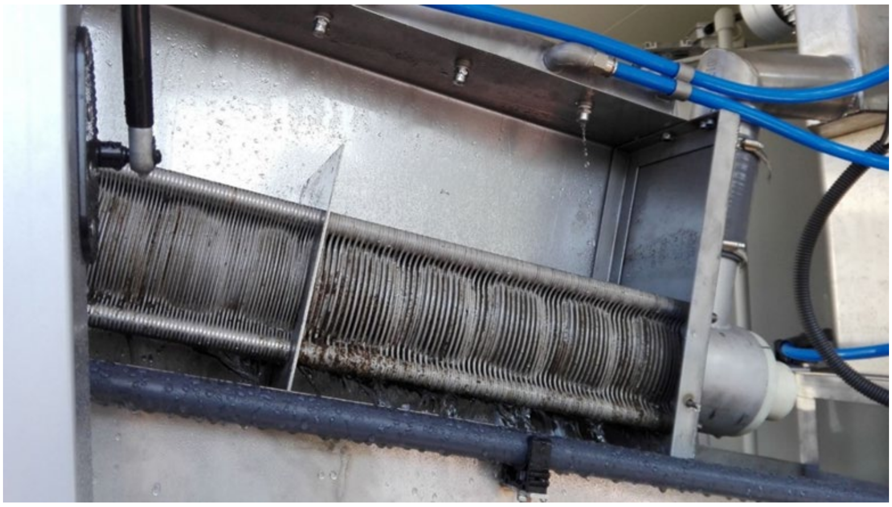

FIGURE 33. The screw press in operation. You see the moving plates.

FIGURE 34. Sludge press in operation. You can see the sludge coming out of the system as dry matter
with a dry matter content of over 18 %

6.2.5 GeoTube

How does a GeoTube work?
GeoTube dewatering containers are an effective dewatering technology fabricated from a specially engineered textile, which will retain the fine solids inside the bag, while allowing water to permeate through the engineered textile.
Over 99% of solids are captured[38].

The water drained from the GeoTube bag is sent back to the wastewater plant to remove BOD.

[38] See link to GeoTube operation manual

FIGURE 35. GeoTube in operation. The GeoTube bag is in the picture installed in a 20 foot garbage container for easy disposal.

FIGURE 36. After a few weeks the sludge in the GeoTube will have a dry content of over 70% giving the possibility of easy reuse or disposal.

6.2.6 Filter bags

A filter bag is basically the same as a GeoTube but for smaller amounts of wastewater.

FIGURE 37. Filter bag system in operation

6.3 Reuse of sludge as fertilizer[39] [40]

Composted organic waste from households, businesses, yards and parks, food processing, and agricultural waste, as well as sewage sludge from sewage treatment plants, contains a host of valuable plant nutrients. Rich in nitrogen, phosphorus, potassium and trace elements such as copper and zinc. This type of compost is used as an organic fertilizer by farmers.

Apart from providing plant nutrition, the organic substances contained in compost stabilizes and/or improves soil humus content. Compost can also be used as a substitute for horticultural peat, as well as for mineral fertilizers, whose production process is energy intensive. This also helps to reduce greenhouse gases. Using phosphorus recovered from wastewater and waste is also beneficial in light of the finite nature of this resource.

But apart from nutrients, compost and all sewage sludge also contain some unwanted inorganic pollutants: toxic heavy metals such as lead, mercury, cadmium, copper, and uranium; organic toxins such as dioxin, PCB , PFT, pharmaceutical residues, pathogens and so on. When compost is used as fertilizer, the pollutants in the compost can accumulate in the soil and enter the food chain via crop plants.
This can also be hazardous to groundwater and surface waters if the pollutants end up in waterbodies as the result of run-off or percolation.
The environmental and health hazards posed by compost fertilizer are difficult to determine because the interactions and transformation processes of compost pollutants are often unknown.
For these reasons it is often required that sludge only is used as fertilizer on fields with crops that are not for direct human consumption nor on fields with grazing animals[41].

[39] See link to the United States Environmental Protection Agency, “Frequent Questions about Biosolids”

[40] See link to Wikipedia regarding reuse of human waste, including sludge

[41] See link to FAO “Agricultural use of sewage sludge”

Before it can be used as a fertilizer, the sludge is dried and often subsequently mixed with agricultural waste before distribution on land. Sludge will be dried in one of the ways described above.

FIGURE 38. Preparation of sludge being mixed with plant residue to make fertilizer

FIGURE 39. Sludge being distributed on a field

6.4 Reuse of sludge as energy

It's no secret that the world's need for energy is increasing - but what many don't realize is that a promising potential energy source is being flushed down our toilets every day. Increasingly, this wastewater - as well as other organic waste from sources like gardens and kitchens - is being used to heat homes, provide electricity, and even power cars.

In 2017 the WHO World Water Day[42] focused on the problems and possibilities posed by wastewater. Below is a short version of the document.
Wastewater is water contaminated with human, agricultural, or industrial wastes. While typically seen as a nuisance, the organic matter contained in wastewater from our sewage systems as sludge can become a valuable resource with sludge-to-energy systems.

[42] See link to 2017 WHO World Water Day

How does wastewater sludge become energy?

When organic waste decomposes in an oxygen-free environment - such as in a deep landfill - it releases methane gas. This methane can be captured and used to produce energy, instead of being released into the atmosphere.
Sewage treatment systems begin treating wastewater by collecting the solid sludge. In a sludge-to-energy system, this sludge then undergoes a pre-treatment process called thermal hydrolysis to maximize the amount of methane it can produce. Next, the treated waste enters an anaerobic digester, which finishes breaking it down. The resulting product is a methane-rich gas, or biogas, that can be used for on-site energy needs, or processed further and used in place of natural gas.
In addition, the solid remnants of the waste create a nutrient-rich "digestate" that can be added to soil to boost plant growth.

What Are the Benefits of Using Wastewater for Energy?

Sludge-to-energy systems tackle many of the world's most pressing environmental and economic issues simultaneously. This is just a short list:

✓ **Energy production:**
The world needs more energy to support growing populations and expanding cities. Using waste for energy is a cheap, renewable and readily available form of energy for many cities. Since sewage treatment plants can use biogas generated from their own sludge to power their operations, it allows them to be energy self-sufficient. This ensures that a sewage plant's primary function - removing pollutants and disease-causing pathogens - is not interrupted by surrounding power outages.
In Denmark many of the large wastewater treatment plants produce more energy than they consume by producing biogas[43].

✓ **Emissions reductions:**
Methane makes up 16 % of the global greenhouse gas emissions[44], and it's extremely potent - about 30 times more powerful a greenhouse gas than carbon dioxide.
Sludge-to-energy systems harness this methane for energy instead of letting it escape into the atmosphere, where it would fuel climate change. Although methane releases carbon dioxide when harnessed for energy, the net emissions are negligible if methane-rich biogas is being used in place of fossil fuels.

✓ **Waste management:**
Many developing countries lack the infrastructure needed to properly manage solid waste and sludge.
In these areas, this toxic, foul-smelling waste is often dumped directly onto land or nearby waters, where it can endanger public health. In many African countries much of the municipal solid waste and sludge is landfilled or dumped - sometimes illegally.
A sludge-to-energy approach provides a solution.
See below the BioKube solution installed in Ghana where sludge is reused as charcoal, and the water is treated so it can be safely discharged[45]. Other similar installations are partly as research projects in operation in Kenya[46] and Uganda[47].

✓ **Economic benefits:**
Sludge-to-energy systems reduce the need for more costly and polluting forms of power,

[43] See link to production of energy from sludge at Copenhagen largest wastewater treatment plant

[44] See link to USA EPA Report on Global Greenhouse Gas Emission.

[45] See link to BBC documentary from COP21 regarding production of charcoal from sludge in Ghana. It is a BioKube developed solution that has received international recognition

[46] See link to YouTube of Charcoal Made from Human Poop in Kenya. It ss Great for BBQ Grilling. Article in New York Post

[47] See link to "Fuel from faeces, a solution to Kampala's charcoal crisis"

such as fossil fuels. In addition, those who operate waste-to-energy operations can directly benefit financially from selling the gas and solid digestate.

- ✓ **Carbon neutral**
  Like other forms of Biomass, getting energy from burning sludge as energy is carbon neutral.
  Sewage sludge is in other words a carbon-neutral biomass and an effective resource for prevention of global warming. Among lots of biomass, sewage sludge has an advantage that the generated amount and quality is almost constant throughout the year, so in business field which lots of fossil fuel is used, sewage sludge has been considered as an effective new energy resource for prevention of global warming.[48]

Where Is This Happening?

While sludge-to-energy systems are not yet commonplace, they're spreading throughout the world.
The United States, China, Brazil, Argentina, Denmark and Norway are just a few examples of countries turning wastewater into power.
Since waste management usually occurs on a local scale, it is up to municipalities in these countries to advocate for and adopt this technology. However, when waste is managed improperly, methane emissions make this local issue a problem of global importance.

6.4.1 Charcoal

Billions of people around the world don't have access to basic sanitation facilities, which is the root of many dire problems.
One solution to the world's poop problem could be turning that waste into charcoal briquettes. This will at the same time help solve the problem of the large amount of wastewater and at the same time generate income to help finance the operation. And these systems can operate on a small scale making them suited also for smaller cities.

In 2015, 39 percent of the global population (2.9 billion people) used a safely managed sanitation service, according to the World Health Organization (WHO). Close to that same number of people (2.3 billion) completely lack any form of toilet or latrine. With such a staggering percentage of the world without safe and sanitary options, big problems arise.

When fecal matter seeps into the water supply, everything goes downhill, fast: Poor sanitation leads to the transmission of diseases like cholera, diarrhea, dysentery, hepatitis A, typhoid, and polio. But water affects more than what you're drinking. WHO reports that at least 10 percent of the world's population is thought to consume food irrigated by wastewater?

Instead of finding better ways to dispose of waste, why not put the sludge to work? That train of thought is how human poop charcoal came about in some parts of Africa. Groups in Uganda, Kenya, and Ghana are looking at poop as a resource, turning feces into fuel.

According to a 2015 report from the United Nations' University Institute for Water, Environment, and Health[49], if all the openly defecated human waste were collected in latrines and turned into briquettes, it would yield up to 8.5 million tons of charcoal. This charcoal isn't just passable, it's exceptional. This charcoal burns longer than firewood or traditional charcoal, is cheaper to both produce and purchase, and creates less smoke.

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[48] See link to burning Charcoal from sludge and other Biomass as being carbon neutral.

[49] See link to UN report "Safe, systematic collection of human waste in low-resource countries could yield valuable fuels, invaluable health and environmental benefits"

Practical example, BioKube system installed in Ghana

The system is installed partly funded by the Danish Foreign Aid and The Danish Ministry of Environment as proof of concept for the project described in this report.

Before the system from BioKube was installed in Ghana, wastewater was collected with sludge trucks from public toilets and collection tanks in Accra city.

FIGURE 40. With very little of the wastewater treated at central plants in Accra, most wastewater is collected in storage tanks. The picture shows a storage tank at a facility with public toilets.

FIGURE 41. Sludge has historically been collected with sewage trucks.
With no central treatment facility, raw untreated sewage is dumped directly in the sea
And this in the sea in Accra, Ghana.

FIGURE 42. Treatment system installed in Accra, Ghana. Sewage from the sludge trucks is deposited in
the large concrete tank (H = 5 m / Ø = 22 m) from where it is processed. The system can handle
140 sludge trucks per day. Equivalent to wastewater from over 70.000 PE.

FIGURE 43 The sludge is dewatered and subsequently dried.

The dried sludge is then ready to be converted to Charcoal. Or it could be reused as fertilizer.

FIGURE 44. Charcoal produced from fecal sludge being used for household cooking

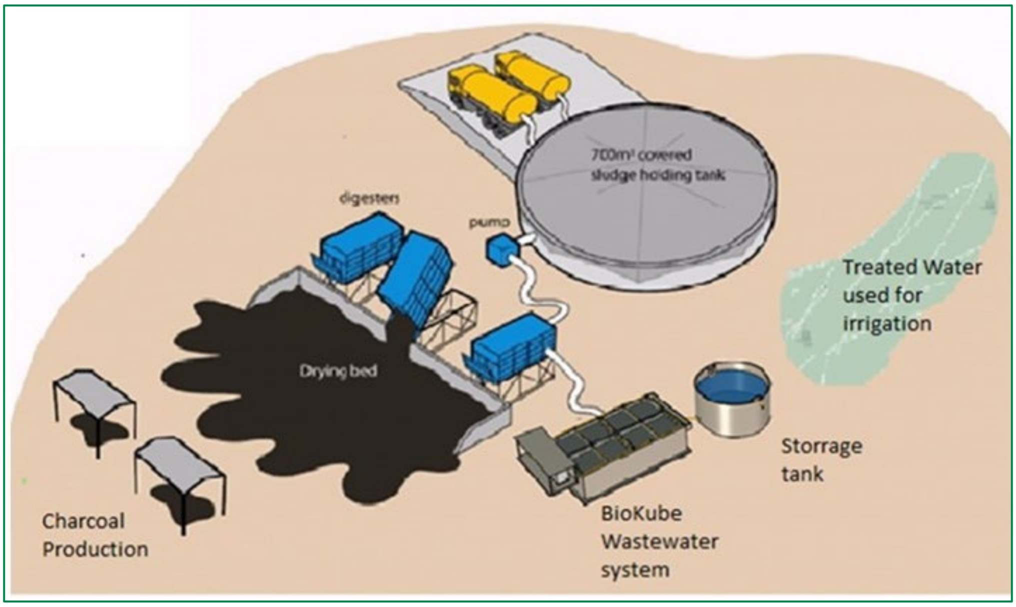

FIGURE 45. Illustration of the BioKube system installed in Ghana
Raw dried sludge is reused for the production of charcoal or fertilizer

How does the system installed in Ghana work?[50]

1) Sewage water is collected by sludge trucks and taken to the treatment facility outside the city
   Ca 60 % come from collection tanks in the city and 40 % from public toilets.
2) The water is from the trucks discharged in the collection tank (H = 5m / Ø = 22m)
3) With the addition of flocculent (natural starch), the sludge is dewatered in dewatering containers.
4) After two days the sludge now containing over 20 % solids is emptied from the drying containers onto a concrete drying slab.
5) After two weeks it is dry and can be made into charcoal.
6) The runoff water from the containers is treated in a BioKube system. The water is treated to the same standards as required in EU, and consequently the treated water as in Europe can safely be discharged.

Practical Charcoal production[51]

On the internet, there are many descriptions of how-to with simple means make charcoal locally[52].

Once the initial test for local feasibility has been established, you can start charcoal production on a larger scale[53].

[50] See link to video showing how the system works.

[51] See link to Wikipedia regarding also small-scale local production of charcoal

[52] See links to making charcoal here – here – here - here

[53] See link to Charcoal production

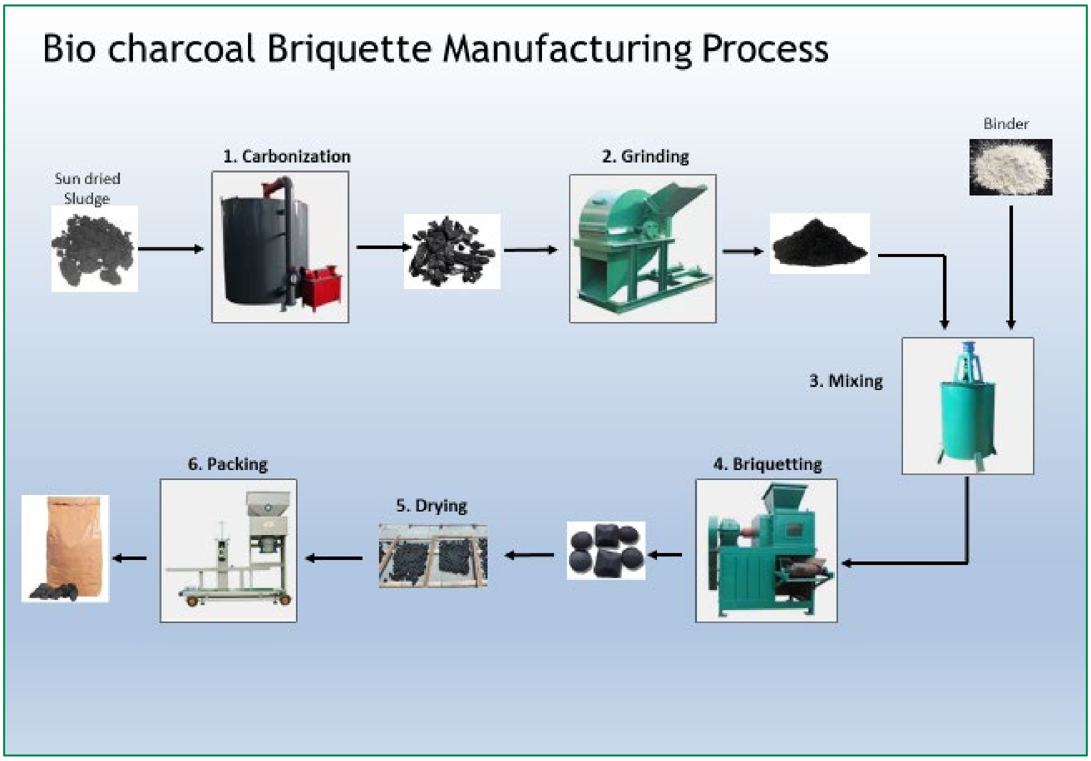

FIGURE 46. Illustration of charcoal production on a large scale.

6.4.2 Biogas

Biogas is produced by anaerobic (oxygen-free) digestion of organic materials such as sewage sludge, animal waste, and municipal solid wastes.

As sustainable clean energy carrier biogas is an important source of energy in heat and electricity generation. It is one of the most promising renewable energy sources in the world.
Biogas is produced from the anaerobic digestion of organic matter, such as manure, sewage sludge, biodegradable wastes, and agricultural slurry, under anaerobic conditions with the help of microorganism.
Biogas is composed of methane (55–75%), carbon dioxide (25–45%), nitrogen (0–5%), hydrogen (0–1%), hydrogen sulfide (0–1%), and oxygen (0–2%).

Production of biogas will typically take place in large systems.
It should be noted, that several of the large wastewater treated systems in Denmark are 100% energy neutral.
Several even produce more energy that they consume[54]

6.4.3 Reuse of material and chemicals in the sludge

There is a number of chemicals in wastewater that with advance can be retracted from sludge; most noticeably Phosphate.[55]

Phosphorus is essential to human life and vital for food production. It is the critical building block of DNA, cell membrane and bones and plays a crucial role in cellular energy metabolism. Today, P is mostly obtained from mined phosphate (Pi) rock, but natural reserves of Pi rock are concentrated in a limited number of countries such as Morocco, China, and the US.

[54] See link to very large biogas system installed at Copenhagen main wastewater treatment plant

[55] See link to IWA “Phosphorus recovery and reuse from wastewater”

On the other hand, an inefficient use of P and the leakage of phosphate-containing fertilizers, detergents and sewage into water bodies are causing irreversible eutrophication problems. Moreover, mined Pi rock is largely contaminated with toxic heavy metals such as cadmium and radioactive uranium. From health and environmental perspectives, there are increasing concerns about the long-term application of chemical fertilizer to farmland.

Increasing attention has been paid to the development of P refinery technology that can recover P from waste streams and reuse recovered P products for agricultural and industrial purposes.

In the wastewater treatment sector, P is removed from wastewater using chemical or bio-based technologies. Removed P ends up in the sewage sludge which is then subjected to anaerobic digestion, dewatering, and disposal. From here, the phosphate can be retracted.

See also illustration below of Billund BioRefinery. An operational large wastewater treatment facility in Denmark focused on total circular economy including recovery of Phosphate[56]

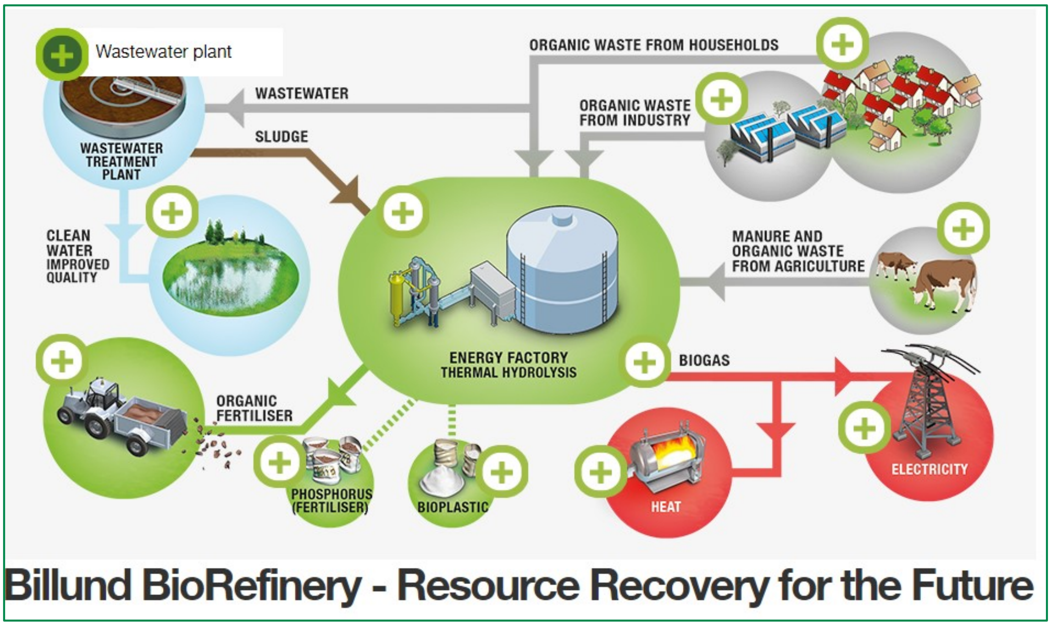

FIGURE 47. Illustration of Billund BioRefinery in Denmark

[56] See link to Billund BioRefinery

7. Drinking water from poor quality water

1 in 3 people globally do not have access to safe drinking water[57].
This can be due to lack of water (drought) or the available water is polluted and not safe for drinking water.

On a small scale, BioKube has developed a product that can create drinking water from a poor-quality source, for instance a polluted river.

BioKube's UltraClean system is an advanced water treatment device designed for removing all particles including bacteria and Nematodes, from river water and other natural water sources.

The treated water as the final step before discharge passes through the Ultra Filtration membrane.
The holes in the membrane are so small that all suspended matter (SS, bacteria, and nematode) remain outside the membrane. The holes in the membrane are only 0,04 µm

The water is treated by means of an extremely durable and efficient, third generation ultra-filtration membrane placed in an aerated chamber.

The functionality of an ULTRA/Clean system is as follows[58]

- ✓ All functions and timers are controlled by the built-in control box
- ✓ From the water source (typically a river or a bad well) the water is pumped into the treatment chamber.
- ✓ The water is led through the ULTRA/Clean membrane by simple gravitation.
  This is done by the water pressure having 150 cm water above the outlet. This water level is maintained by the control box.
  When the water level falls to 140 cm, more water is pumped into the system until the level reaches 150 cm.
- ✓ The membrane is kept clean by rising air from diffusers below the membranes, acting as air scrubbers.
- ✓ A few times per day, particles removed by the membranes are pumped back to the source.
- ✓ A few times per year, the system is cleaned by putting a few litters of bleach into the membrane.
- ✓ The system requires so little energy and it can even run on solar power.

[57] See link to WHO & UNICEF document "1 in 3 people globally do not have access to safe drinking water"

[58] See link to BioKube ULTRA/Clean brochure

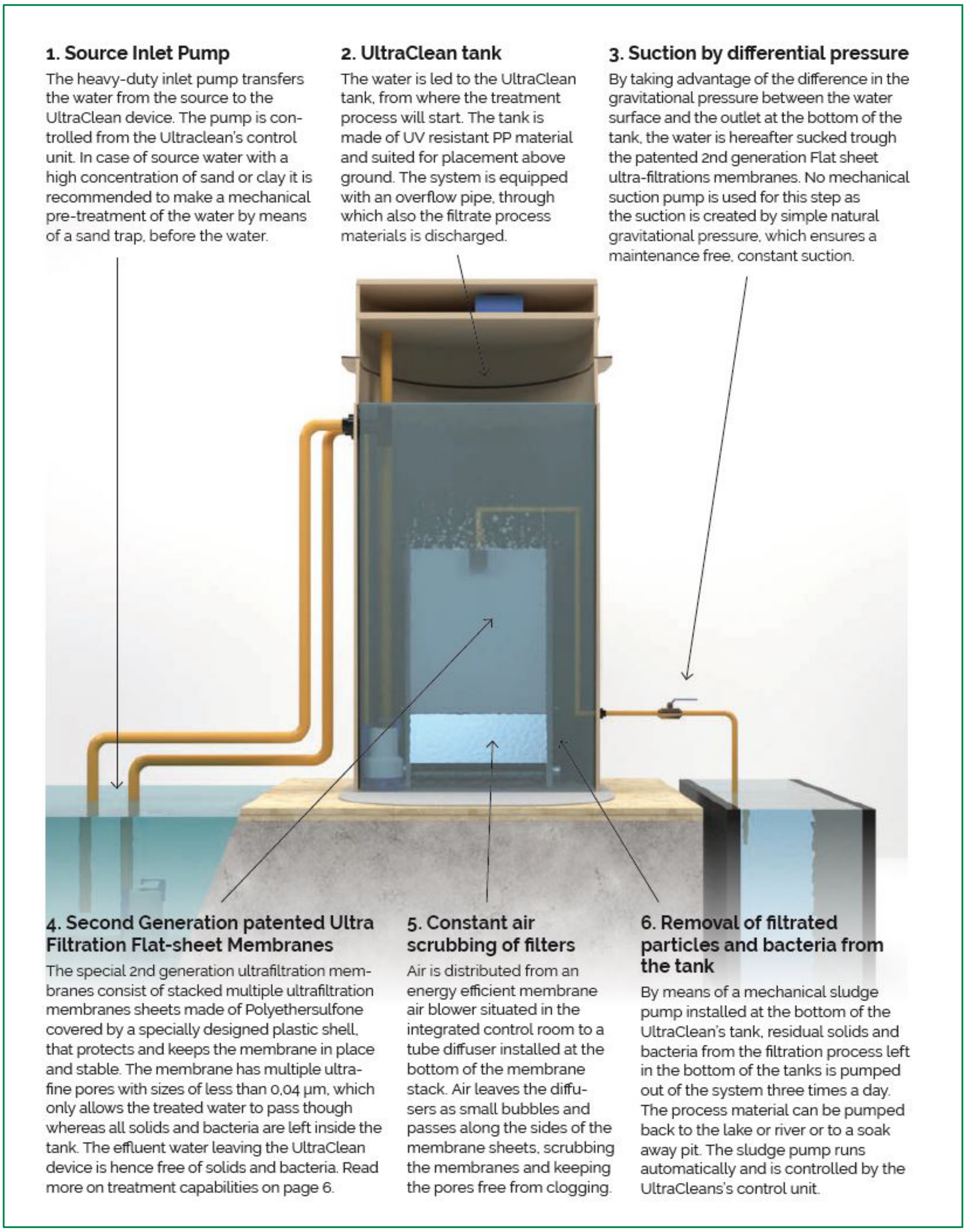

FIGURE 48. The functionality of BioKube's ULTRA/Clean system

How clean is the treated water?

Measurements for e.coli removal ULTRA/Clean

Location	Country	Date	water type	E.Coli before cfu /100 ml	E.Coli after cfu / 100 ml	Coliform before cfu / 100 ml	Coliform after cfu / 100 ml	removal rate
Dysted	Denmark	24-07-2019	Wastewater	500	< 1	< 2000	4	99.8 %
Mariatta	Denmark	17-07-2019	Wastewater	> 2000	< 1	< 2000	4	99,95
Gainswille, Florida	USA	12-04-2017	Wastewater	< 1.100.000	< 0,45			99.99
Gainswille, Florida	USA	19-05-2017	Wastewater	< 6.100.000	< 0,45			99,99
KAIPTC	Ghana	29.11-2018	Wastewater	558	< 1	1.302	< 1	99,99
Exodus	Zimbawe	02-08-2019	flood water	46	< 1	120	< 1	99,99
Creek	PNG	07-09-2019	river water	52	0	< 2000	15	99.99
Purari	PNG	08-09-2019	lake water	45	0	< 2000	0	99.99

FIGURE 49. Cleaning results for BioKube ULTRA/Clean.

You can see the removal rate is better than 99.9 % and that the content of E.coli is in accordance with drinking water requirement.[59]

Consider adding Chlorine.

Since the system is based on filtration and “only” removes 99,999% of all bacteria, to be sure that E. coli and other bacteria are 100% removed, consider adding Chlorine to the treated water if it is to be used for drinking water.

[59] See link to WHO guidelines for drinking water

8. Changing focus and technologies during the project.

During the initial research and evaluation of the operational possibilities several significant changes were implemented in the project with the acceptance of The Danish Environmental Protection Agency.

Part of the change in focus was due to the fact that the Danish consulting and research institute DHI A/S - DHI Water Environment Health closed their department for Industry and Water Technology in June 2017. This meant that the research, testing and documentation that was to have been performed by DHI was not available for the project. Focus for the research and operational part of the project therefore had to be moved to outside Denmark without the assistance of DHI.
This changed focus of operations also had substantial influence on the participation of the two Danish water companies Ultra Aqua and CM Aqua in the operational testing of their respective technologies.

8.1 Containerized solution verses permanent.

We had expected that the potential users of the systems to be developed would ask for temporary solutions that could easily be relocated i.e. wastewater systems in containers.
This proved not to be the case for several reasons

Lower demand for relocation than expected.
We had expected that demand for a specific location or camp would be of a short timeframe before the camp was evacuated and the wastewater system relocated and that the demand for wastewater systems in refugee camps would arise quickly and unexpectedly
The parties and organizations we talked with told us that relocation was not a major request.
The expectancy was that the major part of refugee camps would be in operation for such a long time that it would cover the full expected service life of a containerized system.
Quick on-site delivery from stock was also not an important demand
Since BioKube can deliver containerized systems with a delivery time from the factory of only 8 - 10 weeks no parties were willing to pay to have them on stock.

Containerized systems are more expensive.

Since systems in containers must be build more “rugged” and stronger to cope with the stress of relocation often over difficult terrain, they are more expensive.
Since our enquiries to potentially interested parties showed little demand for relocation, the increased price was not justified.

Also, most of the camps where the systems could be used were so large that a permanent standard BioKube system in ground would be better and cheaper.
For this reason the practical proof-of-concept work was relocated to an operational Biokube system in operation in Accra, Ghana.

In many ways the system in operation in Ghana is comparable to a system needed in a refugee camp.
The water treated in the system comes from collection tanks at public toilets and individual houses.
Also the system in operation in Ghana made it possible for us to give a evaluation of a full scale system in operation treating wastewater from over 8.000 persons. It processes sewage from 50 sludge trucks with 5 m^3 black toilet water each per day. The system could easily be expanded to 20.000 PE.
The project funding would only allow the test of the technology with a 20 foot container. So, moving the test to Ghana gave a much better proof-of-concept on a large “real life” system. A system in a 20-foot container can only treat wastewater from ca 300 persons.

FIGURE 50. Biokube 20 foot container wastewater system at work camp in Guinea.
The aluminum “tube” on the right side is the UV lighting system for removing all pathogen bacteria.

8.2 Aftertreatment of water using drum filter and UV verses Ultrafiltration membranes.

At the upstart of the project we planned to treat the water for reuse using drum filters and UV lighting to remove all SS and bacteria tor the treated water to be safe for reuse.

Using drum filters
The Danish company CM Aqua (see www.cmaqua.dk) makes excellent high-quality drum filters that were planned to be used in the project. CM Aqua’s drum filters are successfully sold globally.

It was known at the start of the project that these drum filters would eliminate SS to very low numbers. And that the water after passing the drum filter would we well suited for reuse for irrigation.

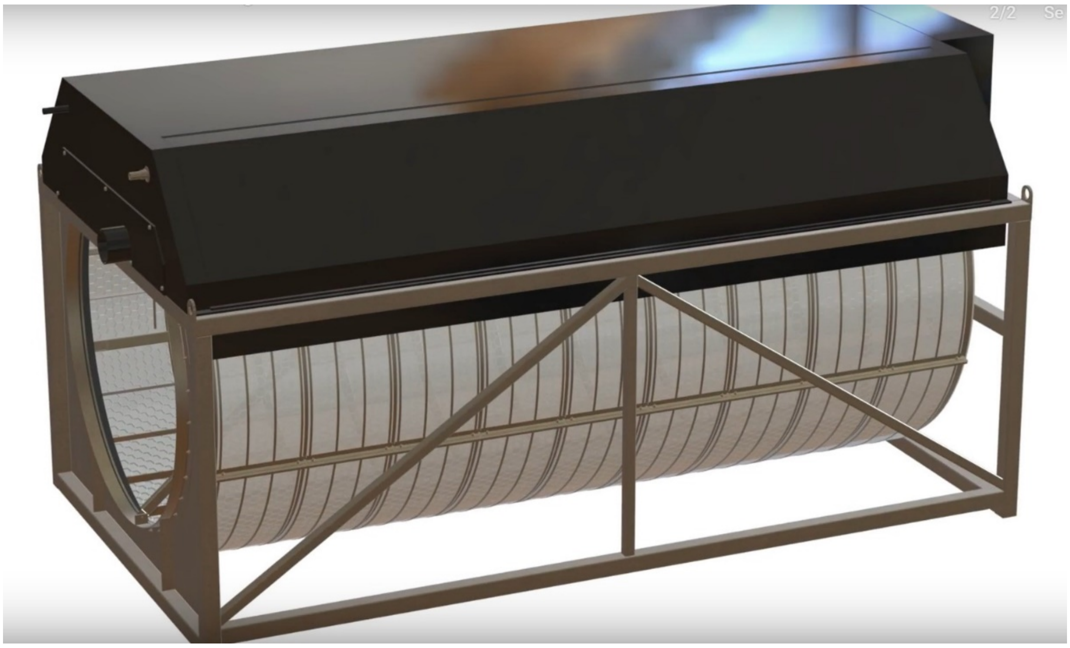

FIGURE 51. 3D drawing of drum filter from CM Aqua

Using UV lighting

The Danish company Ultra Aqua (see www.ultraaqua.com) makes high quality efficient UV lighting systems that globally has proven to be able to eliminate harmful bacteria.
It was known from the start of the project that systems from Ultra Aqua could remove all harmful and make the water safe for reuse also for irrigation of editable plants.

FIGURE 52. UV systems from Ultra Aqua for different amounts of water.

Ultra Filtration.

With the changed focus for the project due to DHI’s closing of their department for urban water we also looked for other alternatives than the two very well functional and known systems from CM Aqua and Ultra Aqua.
We searched for simpler technologies to implement and test at the full-scale system in Ghana.

We therefore found it reasonable to look at the latest filtering technologies. There are in the market several Ultra Filtration solutions that were expected could remove both SS and bacteria.
So, this solution was implemented in the project for us to get an operational proof-of-concept of this technology.

9. Link to Documents and Video

9.1 Link to Documents and references

9.2 Introduction

See link to BioKube Company Presentation illustrating the different solutions.
www.biokube.com See general description of all BioKube solutions and products

9.3 Wastewater: From a problem to an asset

See link to Encyclopaedia Britannica, On-Line version
See link to EU Water Framework Directive.
See link to EU Proposal for a regulation on minimum requirements for water reuse
Se link to EU strategy on Water scarcity & Drought.
Se link to UN SDG 6 “Ensure availability and sustainable management of water and sanitation for al”
See link to The European Innovation Partnership on Water
See link to Blueprint to Safeguard Europe's Water Resources
See link to Wikipedia on Dissolved air Flotation technology
See link to Wikipedia on Anaerobic digestion

9.4 Reuse of treated wastewater

See link to detailed theoretical documentation for BioKube patented treatment technology
See link to BioKube patent
See link to Wikipedia describing activated sludge
Se link to the standard CEN 12566-3 Small wastewater treatment systems for up to 50 PT - Part 3:
See link to BioKube ETV Verification
See link to EU Water Framework Directive
See link to Danish legislation
See link to UK legislation
See link to Swedish legislation
See link to requirements in Kuwait
See link to CEN 12566-3 Small wastewater treatment systems for up to 50 PT - Part 3: Packaged and/or site assembled domestic wastewater treatment plants
See link to NSF/ANSI 40: Residential Onsite Systems from NSF (The Public Health and Safety Organization
See link to BioKube treatment results from all 4.000 small systems installed in Denmark
See link to description of BioKube ULTRA/Clean
See link to EU Bathing water directive.
See link to Water Scarcity and Drought in the European Union

See link to Wikipedia description of Cooling Towers
See link to Reclamation of wastewater for cooling tower operations

9.5 Reuse of sludge

See link to IWA sludge handling solutions
See link to BioKube sludge disposal technologies
See link to Wastewater sludge as a resource: Sludge disposal strategies and corresponding treatment technologies aimed at sustainable handling of wastewater sludge
See link to Sewage sludge treatment on Wikipedia
See link to EU Introduction to sewage sludge
See link to Directive 86/278/EEC on protection of the environment, and in particular of the soil, when sewage sludge is used in agriculture
See link to Danish RootZone technology for sludge disposal
See link to Danish consulting company Orbicon description of treatment (dewatering and mineralization) of sludge in Sludge Treatment Reed Beds (STRB) or Sludge Treatment Wetlands (STW
See link to GeoTube operation manual
See link to United States Environmental Protection Agency, “Frequent Questions about Biosolids”
See link to Wikipedia regarding reuse of human waste, including sludge
See link to FAO “Agricultural use of sewage sludge
See link to 2017 WHO World Water Day
See link to production of energy from sludge at Copenhagen largest wastewater treatment plant
See link to USA EPA Report on Global Greenhouse Gas Emission.
See link to BBC documentary from COP21 regarding production of charcoal from sludge in Ghana. It is a BioKube developed solution that has received international recognition
See link to YouTube of Charcoal Made from Human Poop in Kenya. “It is Great for BBQ Grilling”. Article in New York Post
See link to “Fuel from faeces, a solution to Kampala’s charcoal crisis”
See link to burning Charcoal from sludge and other Biomass as being carbon neutral.
See link to UN report “Safe, systematic collection of human waste in low resource countries could yield valuable fuels, invaluable health and environmental benefits”
See link to Wikipedia regarding also small-scale local production of charcoal
See link to Charcoal production
See link to very large biogas system installed at Copenhagen main wastewater treatment plant
See link to IWA “Phosphorus recovery and reuse from wastewater”
See link to Billund BioRefinery

9.6 Drinking water from poor quality water

See link to WHO & UNICEF document “1 in 3 people globally do not have access to safe drinking water”
See link to BioKube ULTRA/Clean brochure

See link to WHO guidelines for drinking water

9.7 Link to Video

See link to video showing how the BioKube system in Ghana works.
See links to making charcoal here – here – here - here
Reuse sludge as charcoal in Kenya. See link

Wastewater & Circular Economy with focus on Third World

In accordance with United Nations Sustainable Development Goals the future focus should be:
Wastewater is not a problem.
Wastewater is an asset, and everything should be reused

Sludge is a significant hassle and expense when treating wastewater.
Using simple technologies, sludge can be reused typically as fertilizer or
energy. Sewage sludge is a carbon-neutral biomass and could be an effective resource for reducing CO2 emission and help prevention of global warming. Among lots of biomass, sewage sludge has an advantage that the generated amount and quality is almost constant throughout the year, so in business fields in which lots of fossil fuel is used, sewage sludge has been considered as an effective new energy resource for prevention of global warming.

The report describes an operational system where sludge from wastewater using with simple means is converted to charcoal.

Wastewater treated to sufficient quality can be reused typically for irrigation, toilet flushing or other secondary use.

Finally, the report describes how poor quality water from rivers and bad wells can be converted to drinking water.

See also www.biokube.com.

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