Witteveen + Bos

VISION رؤية 2030 المملكة العربية السعودية KINGDOM OF SAUDI ARABIA

شركة المياه الوطنية National Water Company

Technical Seminar Wastewater Technology

Innovative solutions to achieve sustainable goals

Riyadh, 19 June 2023

Content

Witteveen + Bos

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Witteveen+Bos Consulting Engineers

Company Introduction

Witteveen+Bos consulting engineers

- Established in 1946, Witteveen+Bos is a large engineering and consulting company headquartered in the Netherlands.
- Over 1,500 employees work for W+B, based in 22 offices and 11 countries, including Dubai.
- 4 business lines:
  I. Built Environment
  II. Deltas, Coasts and Rivers
  III. Energy, Water and Environment
  IV. Infrastructure and Mobility.

Top expertise with a worldwide experience and a strong regional footprint

STP Manfouha IV, Saudi Arabia

Ajman Sewage Treatment Plant, UAE

Sharq Crossing, Qatar

Duqm Liquid Bulk Berth Terminal, Oman

Energy, Water and Environment

The need for access to good-quality water is recognized as one of the major contemporary challenges in the Middle East.

What we do:

- Sanitation and water supply
- Water and wastewater treatment
- Water re-use and recycling
- Renewable energy and energy efficiency
- Bio-energy and resource recovery

Reference Amsterdam WWTP

- 1,000,000 p.e.
- 180.000 m3 wastewater/day
- 8.400 m3/h max DWF, 33.000 m3/h max SWF
- 4 primary sedimentation tanks (8,400 m3/tank)
- 7 aeration tanks (17,000 m3/tank), 8 m water depth
- 14 final sedimentation tanks (9,200 m3/tank)
- 3 sludge digestion tanks (11,100 m3/tank)
- 4 CHP's each 1,110 kWe

Water Refinery, Innovative Wastewater Treatment

June 2023

Carbon Zero Wastewater Treatment and Resources Recovery

The Water and Resources Refinery

- Complete **innovative physical-chemical treatment** concept for water reuse + resource recovery
- **No oxidation nor biological conversion** of potentially valuable materials
- **Zero carbon process emissions** (No Green House Gases: CO_2, CH_4, N_2O)
- **High Quality Water** production (applicable as process water / irrigation water / feed to NEWater)
- Removal of **Micropollutants / Pharmaceutical** Residues and **Microplastics**
- Extraction and Refinery of **Circular Resources and Materials** (cellulose, organics, phosphorous, ammonia)

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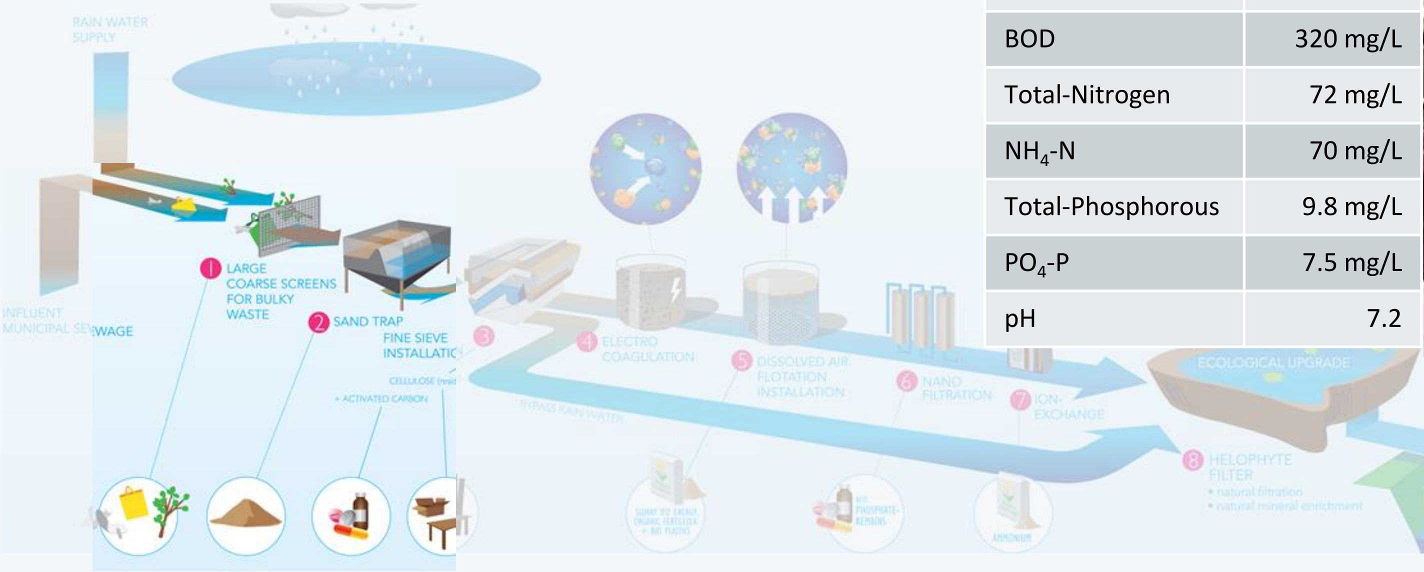
waterschap vallei en veluwe
Dutch Water Refinery

1. Screening and Sand Recovery

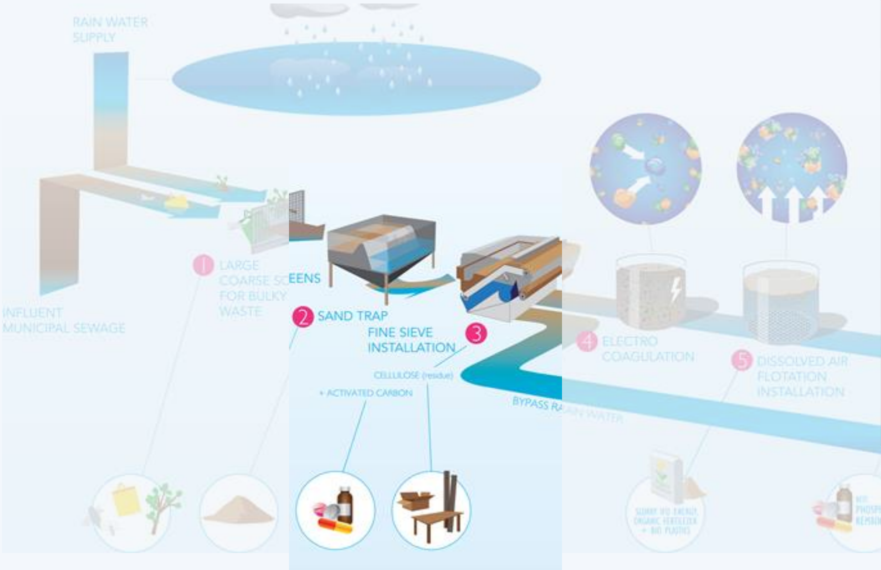


parameter	Feedwater
TSS	350 mg/L
COD	820 mg/L
BOD	320 mg/L
Total-Nitrogen	72 mg/L
NH_4-N	70 mg/L
Total-Phosphorous	9.8 mg/L
PO_4-P	7.5 mg/L
pH	7.2

Aims: - protection of installations
- grid and sand removal

Products: - screening material
- sand

2. Fine Sieving (350 µm)



Aims: - protection of installations

Product: - production of cellulose (for upcycling into bio-composite, green activated carbon, bio char)

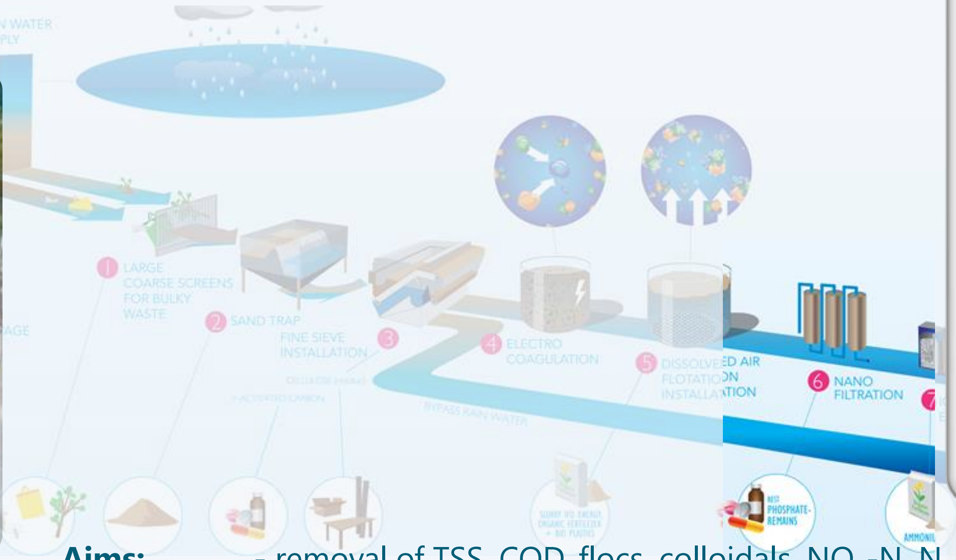
3. (Electro) Coagulation – Flocculation - Dissolved Air Flotation

400 Ampere / 6 V 0,5 ppm PE 20 m^3/m^2h

Aims: - coagulation + flocculation and floc separation as pre-treatment for nanofiltration
- precipitation of phosphorous, metals and complex organics

Products: - organic concentrate for biogas or fatty acids, bio-flocculants, bioplastics + phosphate precipitate

4. Direct hollow fiber Nanofiltration (400 Dalton)



Aims: - removal of TSS, COD, flocs, colloidals, NO_3-N, N_{org}, P_{org}, P_{total}
- removal of di-valente ions (and larger)
- removal of micropollutants and microplastics to op to 95% removal

Product: - high quality water with ammonia and mono valent salts

5. Ion Exchange (2x)

Parameter	Product water
TSS	< 0.1 mg/L
COD	~ 30 mg/L
BOD	~ 5 mg/L
Total-Nitrogen	< 1.0 mg/L
NH_4-N	< 0.8 mg/L
Total-Phosphorous	< 0,05 mg/L
PO_4-P	< 0,03 mg/L
pH	~ 3.5

Aims: - removal of mono valent hardness
- removal of ammonium to < 1 mg/L

Product: - produce a concentrated ammonium stream (5 g/L NH_4SO_4)
- high quality water for irrigation, green houses, industry and process water

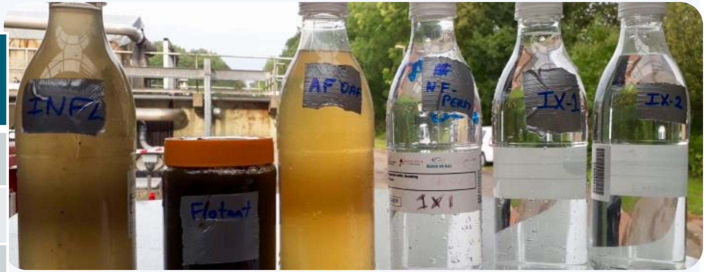
6. Optional: Ecology wetland filter (Biocascade® water purification)

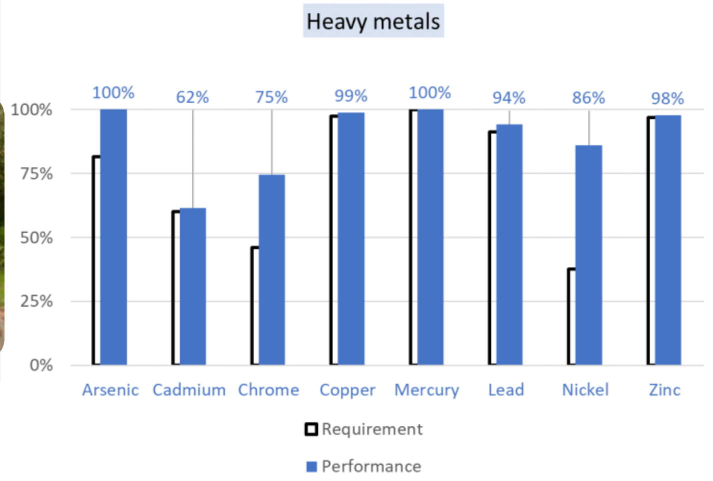
Aims: - remineralisation and revival of produced water + storm water treatment

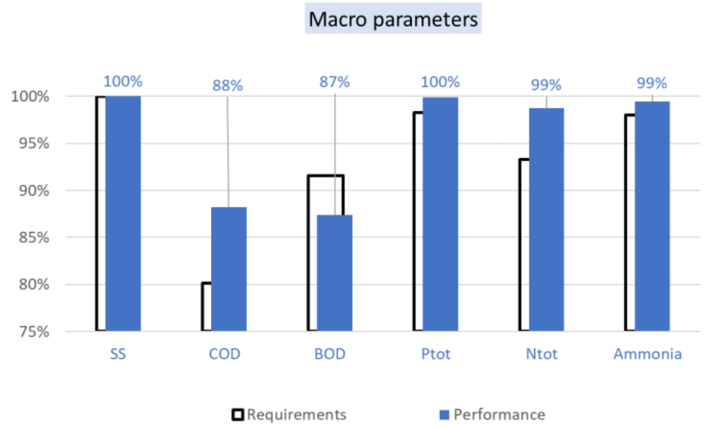
Product: - ecological water and groundwater recharge feed
- biomass for bio-composite, renewable bio-energy

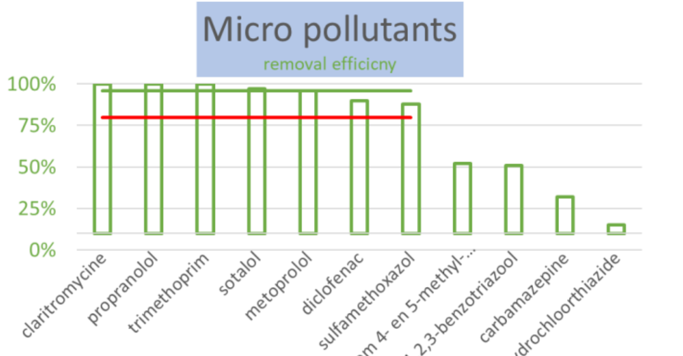
Excellent process water quality

Parameter	Product water
TSS	< 0.05 mg/L
COD	~ 30 mg/L
BOD	~ 5 mg/L
Total-Nitrogen	< 1.0 mg/L
NH_4-N	< 0.8 mg/L
Total-Phosphorous	< 0,05 mg/L
PO_4-P	< 0,03 mg/L
pH	~ 6-7



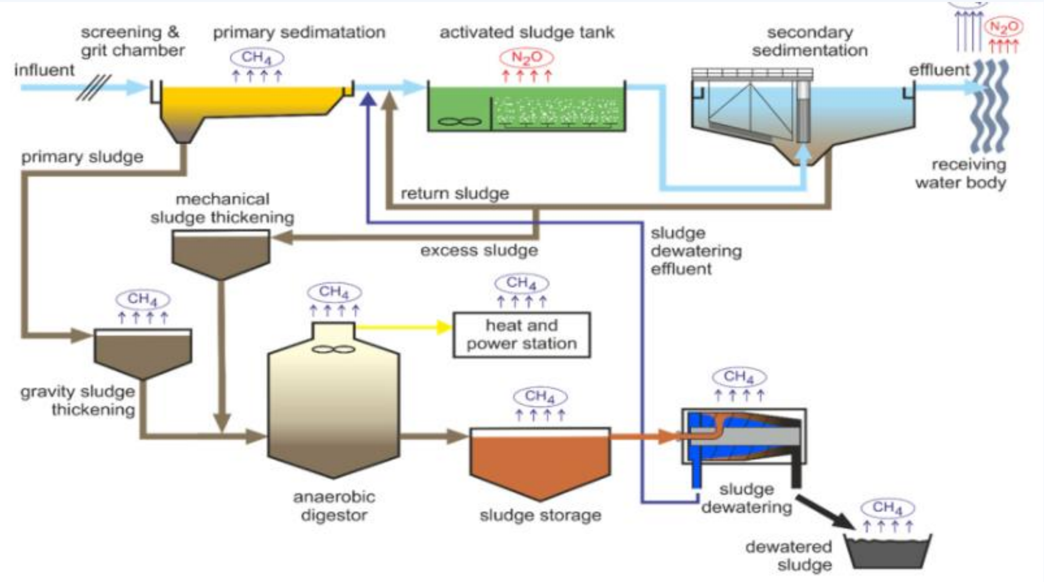






CO_2-equivalents

- **Process-related CO_2 emissions** (Green House Gases: CO_2, CH_4, N_2O)
- **Electricity** related CO_2 emissions
- CO_2 emission due to consumption of **chemicals** and production of **residuals**



CO_2 emissions

Conventional Activated Sludge: = 100%

Water Refinery + Sludge Digestion & Incineration: 50% CO_2-emission reduction

Water Refinery + Resources Valorisation: 100% CO_2-emission reduction

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Innovations in sludge treatment

Increased biogas production from sludge digestion and with new sludge treatment technologies

Sludge digestion in the Netherlands

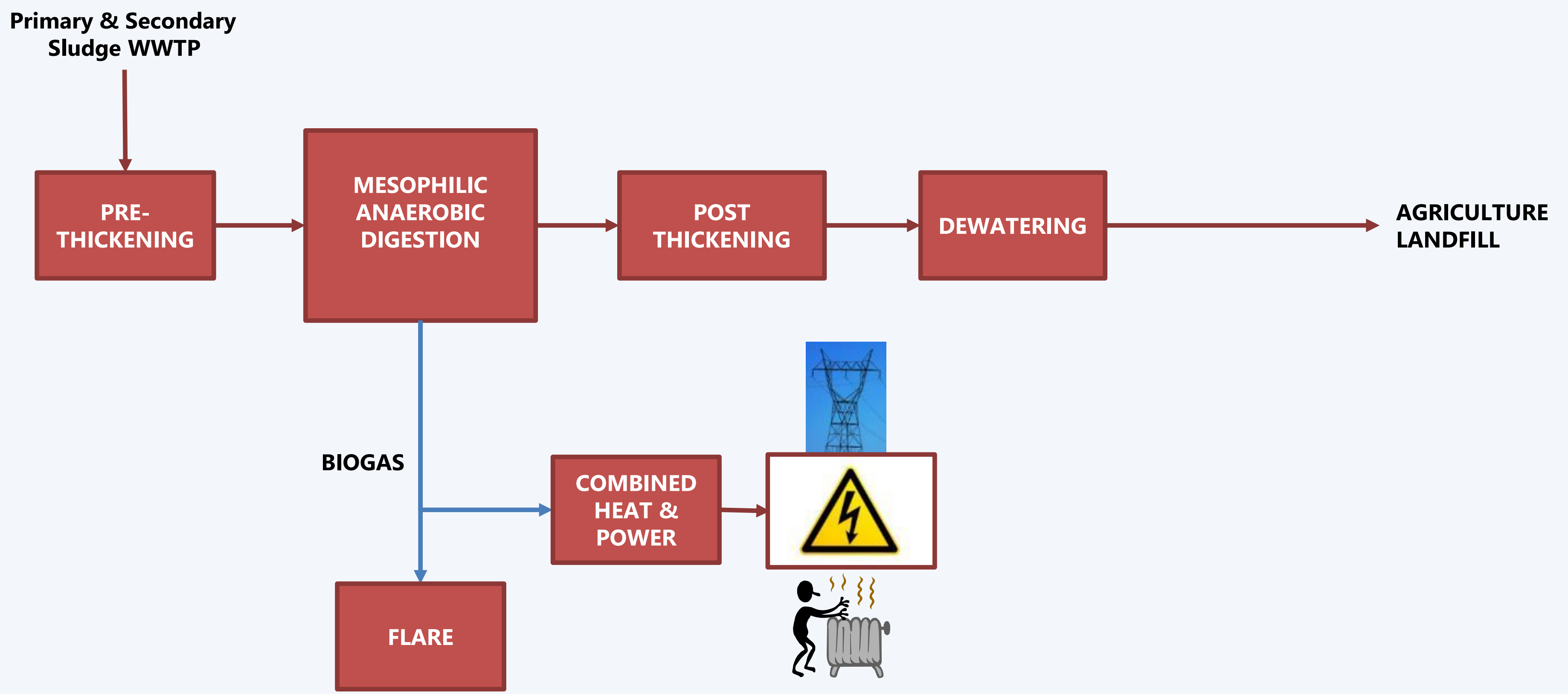
Overview sludge treatment in the Netherlands :

- >75% of total sludge production from municipal WWTPs is digested anaerobically
- Mainly Mesophilic (35°C) digestion, 1 Thermophilic (55°C) digestor operational
- Total sludge production increasing
- No new sludge digestion plants build over the last 10 years
- More sludge is digested and biogas production increased through higher dry solids content and thermal pre-treatment of sludge

Grounds to choose anaerobic sludge digestion:

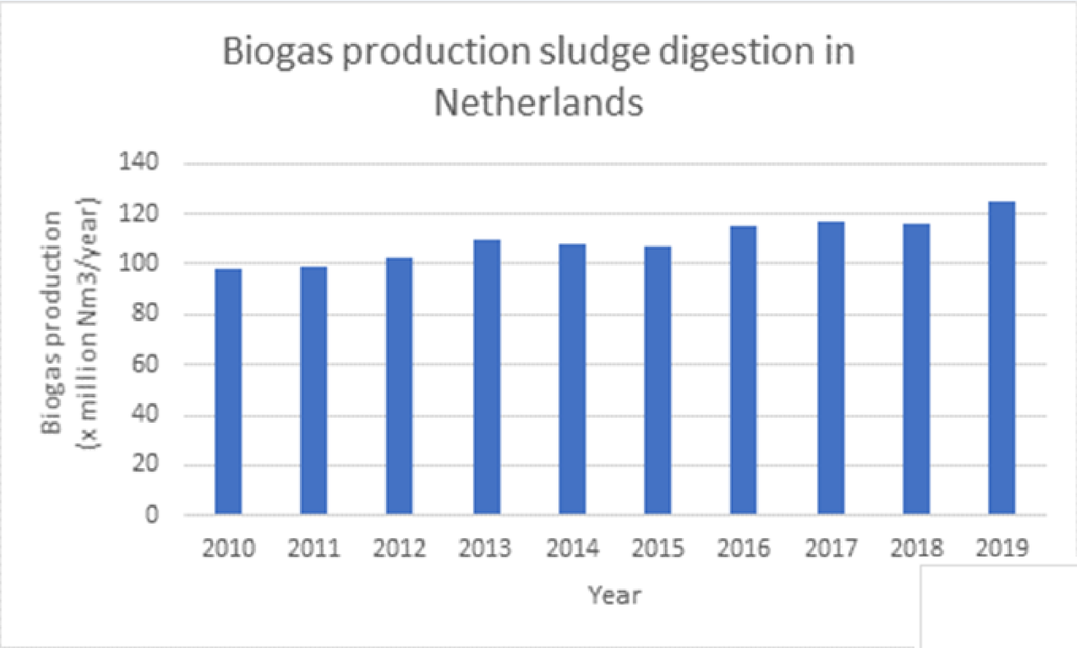
- (further) Stabilization
- Volume reduction
- Improvement of dewaterability
- Energy production

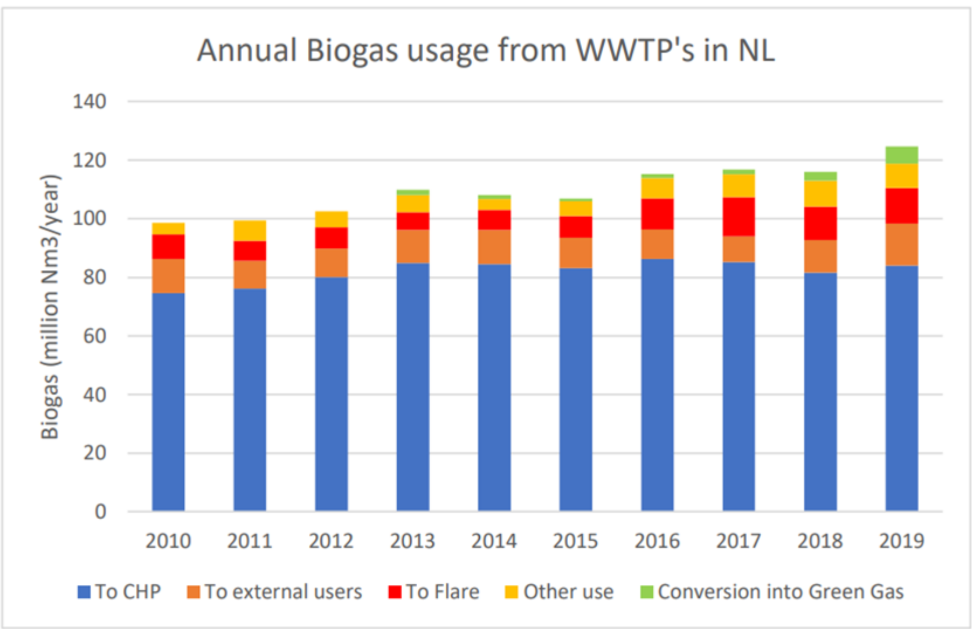
Conventional sludge digestion



- Pre-thickening by gravity till 3-4% DS
- Mechanical pre-thickening till 5-6% DS
- Biogas production mesophilic digesters able to supply 60-65 % power consumption of WWTP
- SRT Mesophilic digestion (35 oC) > 20 days, Thermophilic digestion (55 oC) ~ 12 days

Biogas production sludge digestion

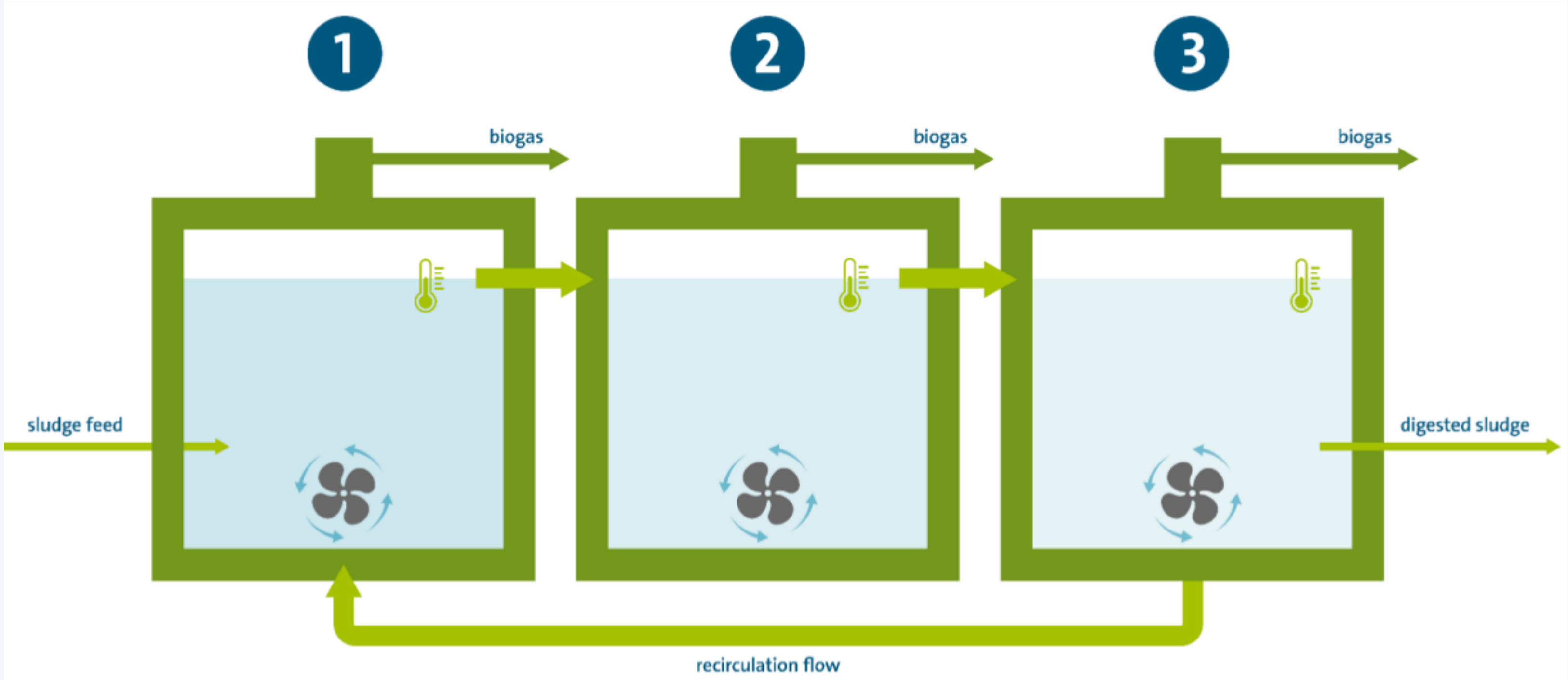




Developments in sludge treatment

- Thermophilic sludge digestion
- Sludge digestion at higher dry solids content
- Multiple (2-4) digesters in series with recirculation
- Thermal Pressure Hydrolysis as pre-treatment for sludge digestion
- Hydrothermolysis after sludge digestion or direct on secondary sludge

Multiple digesters in series with recirculation



- Plug flow regime (2-4 reactors)
- No short-circuiting
- Higher biogas production compared to single reactor with same SRT
- Reduced GHG emissions due to optimized digestion
- Design operating window SRT 8 – 15 days

Pre-treatment by Thermal Pressure Hydrolysis (TPH)

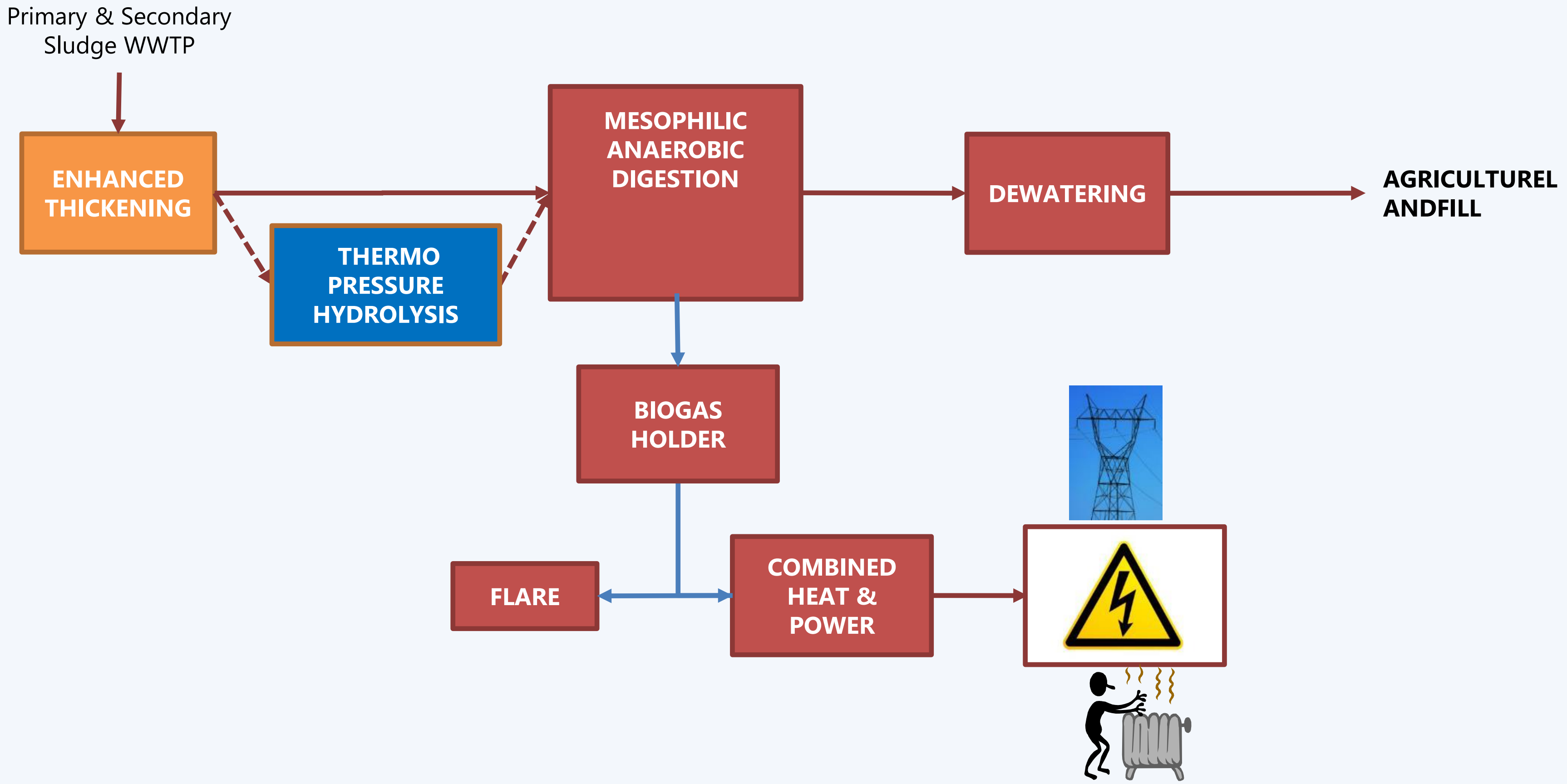
TPH hydrolyses organic material at high temperature (130 – 150 oC) and pressure (5 bar) by steam injection during approx. 1 hour

After hydrolysis the material can be digested easily

Benefits

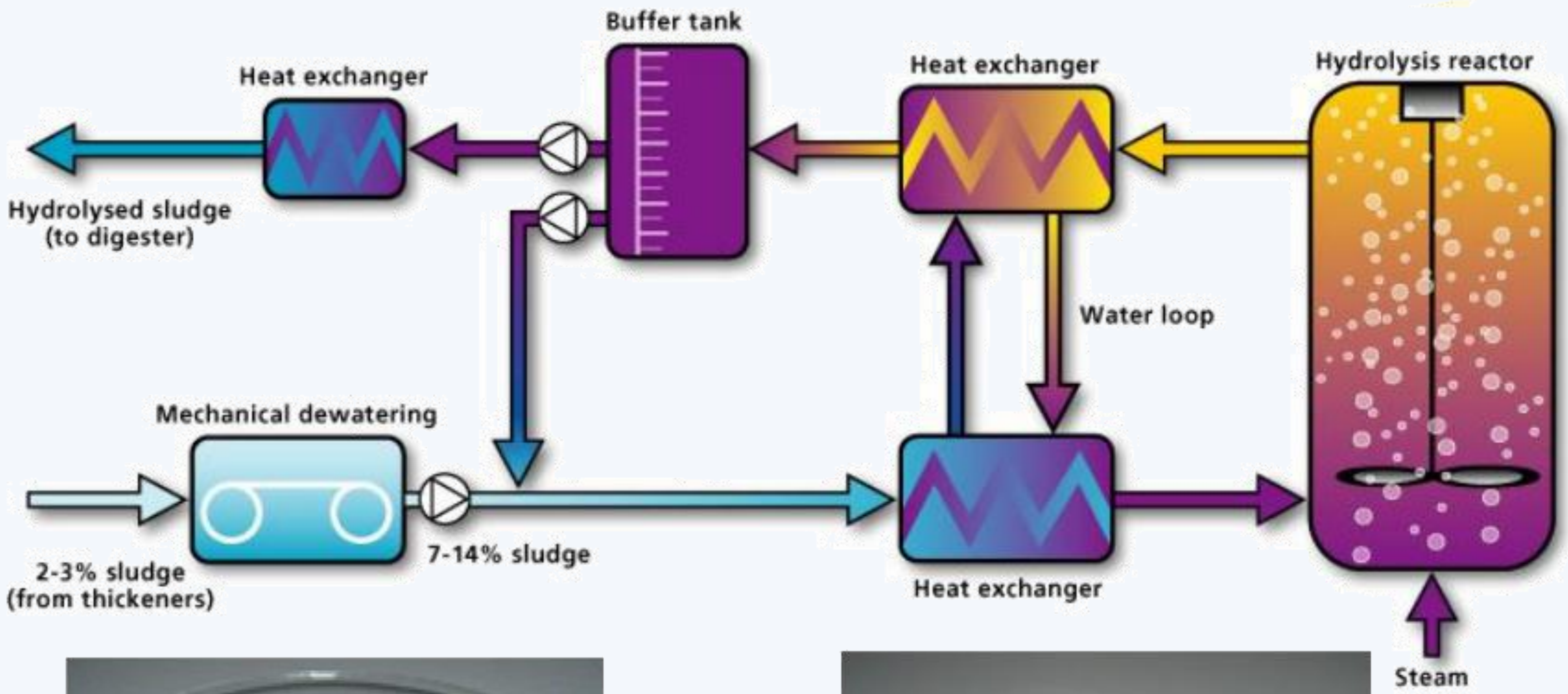
- higher fermentation efficiency (20 – 45% more)
- higher biogas yields (15 - 40% more)
- reduced retention time (so smaller digesters)
- lowering viscosity of sludge (easily pumping and mixing)
- improved dewaterability (sewage sludge > 30% DS)
- TPH delivers similar result as thermophilic digestion at same digestion tank volume

Enhancements sludge treatment

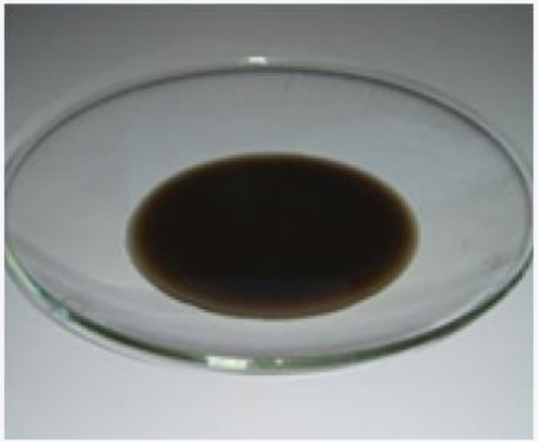


- Enhanced thickening till 7-14% DS. Smaller digestion tank volume and no post-thickening required
- Pre-treatment by thermal pressure hydrolysis to increase dry solid removal
- Biogas holder to maximize energy production, no flaring at peak production

Thermal Pressure Hydrolysis (TPH)




Thickened sludge before TPH


Thickened sludge after TPH

Energy Factory at Amsterdam and Apeldoorn WWTP

Amsterdam WWTP:

- Sludge production 32,000 tons DS/year
- 3 sludge digestion tanks each 11,000 m3
- 11.8 Mln m3/year biogas production
- 4 CHP's each 1,100 kWe
- Conversion biogas to Green gas

Apeldoorn WWTP:

- Sludge production 20,000 tons DS/year
- 8 Mln m3/year biogas production
- 4 CHP's each 750 kWe and 1x 880kWe

Sludge: Valuable waste but no sustainable treatment

Sludge is a global problem <u>and</u> opportunity

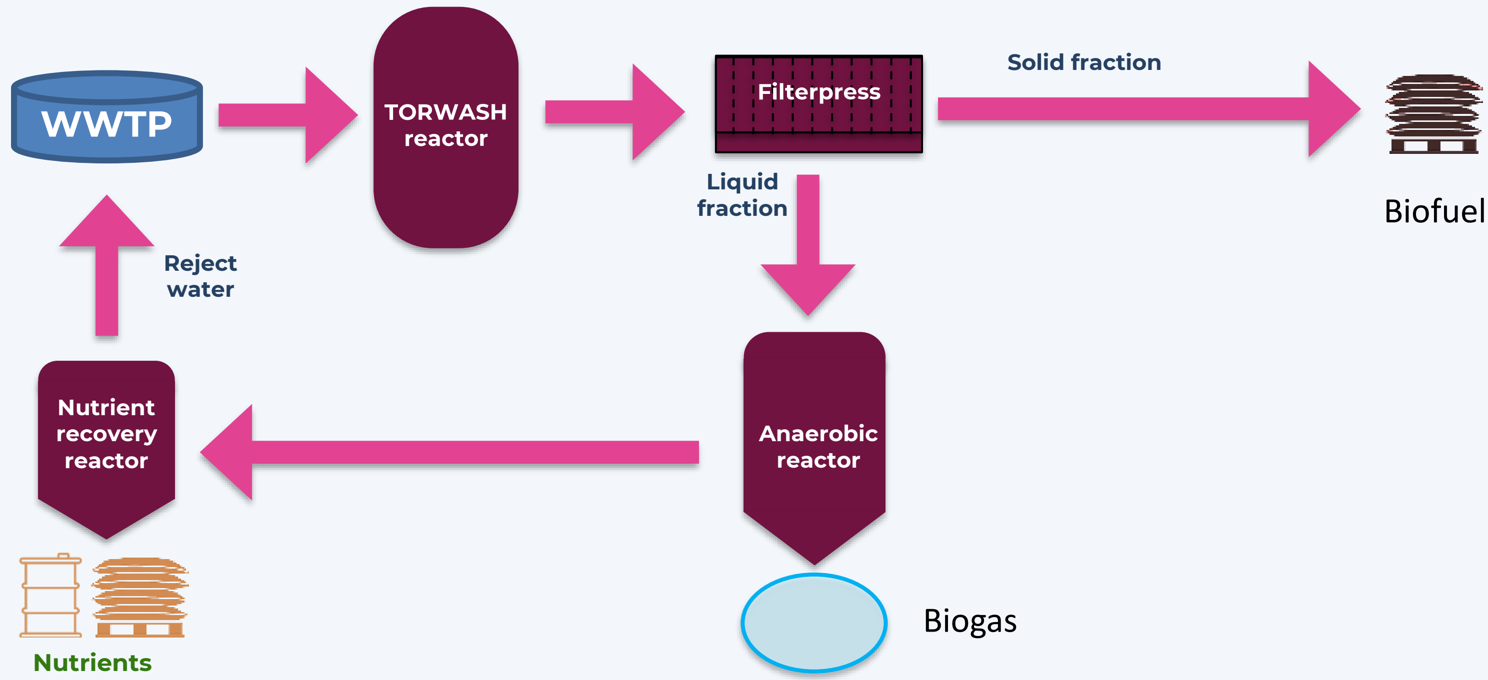
Sludge = (a lot of) waste …

- Wet and contaminated: landfill or incineration
- Worldwide insufficient treatment capacity
- No circular products
- Use of fossil chemicals and extensive road transport

Increasing demand for circular products

- Green gas
- Feedstock for biochemistry and biofuel
- Fertilizers
- Clean water

TORWASH, Hydrothermolysis of sludge



- Conditions TORWASH: 150-250 oC, max pressure 25 bar, retention time 20-30 minutes
- Dewatering in filterpress without dosing polymer, dry solid content 50-60% in sludge cake
- Organic matter is converted into fatty acids, effluent is treated anaerobically at 35 oC to produce biogas
- Nitrogen and phosphorus are recovered as fertilizers

TORWASH, innovative solution for sludge treatment

50% lower costs for sludge treatment

energy neutral process

60% phosphate recovery

solid biofuel approved for power plants

no chemicals (PE) consumption

90% less transport

50% lower CO_2- emission

Applications:

- After sludge digestion of primary and secondary sludge
- After digestion of secondary sludge
- Direct on secondary sludge

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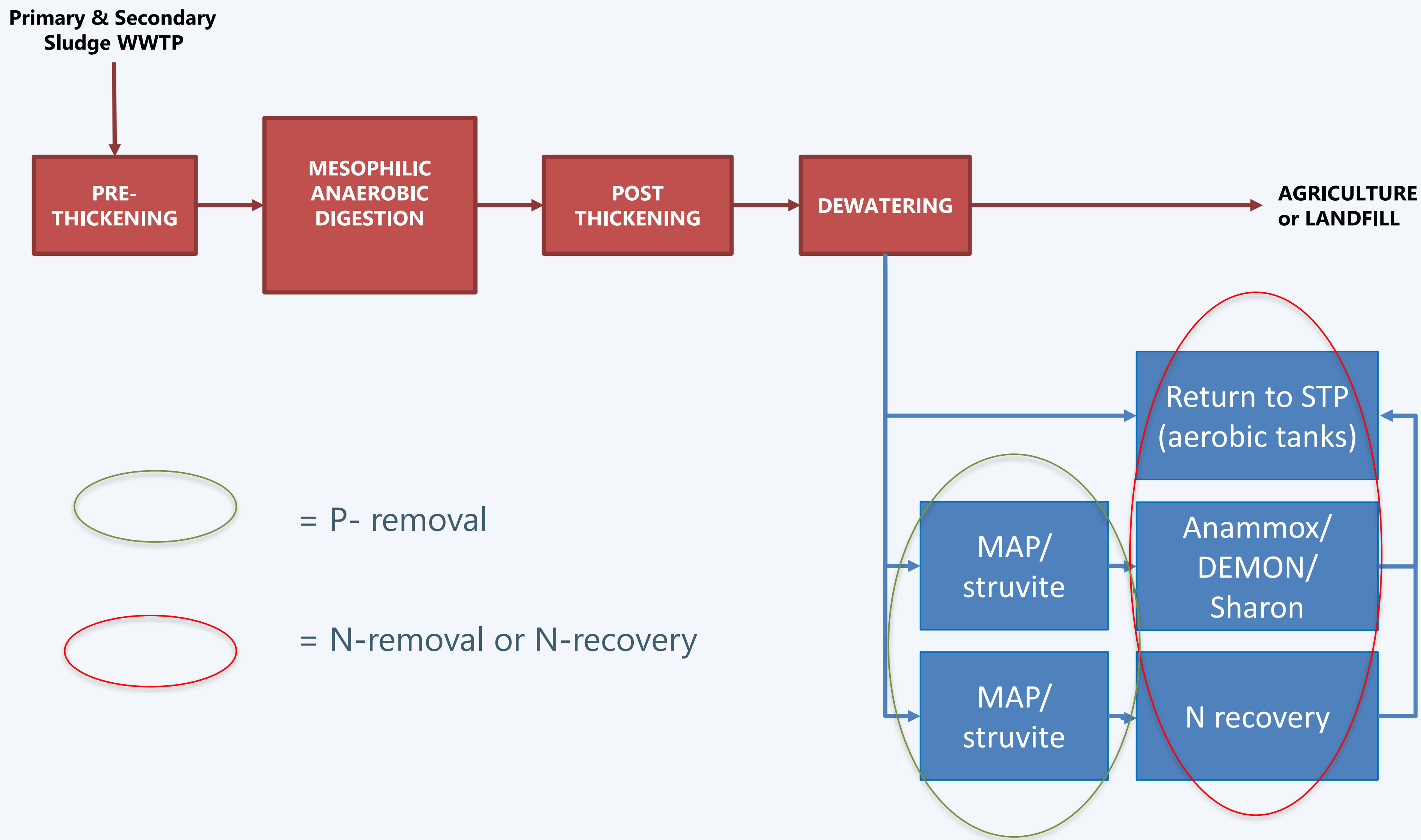
Resource Recovery from Sludge Dewatering

Treatment of liquid phase of digested sludge: phosphorous (P) and nitrogen (N)



P-recovery via MAP/struvite technology

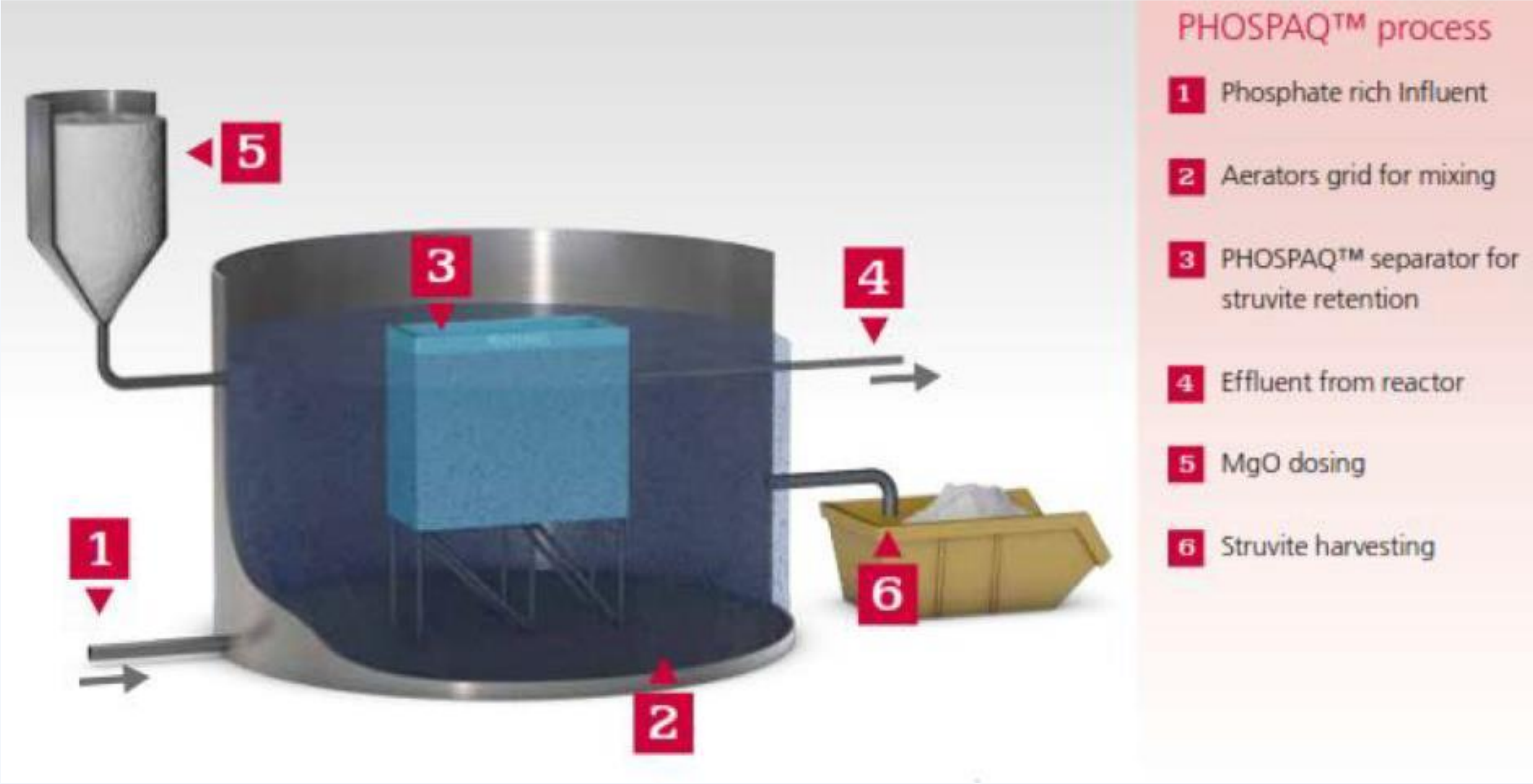
Dosing of MgO, $Mg(OH)_2$ or $MgCl_2$

- Source of Mg
- Increase pH to 8.3

Struvite precipitate ($MgNH_4PO_4$)

- Struvite is anorganic and doesn't contain organic material
- Dewatering by screw press till > 90 %DS
- It has no smell and can be stored for long time

P-recovery via MAP/struvite technology



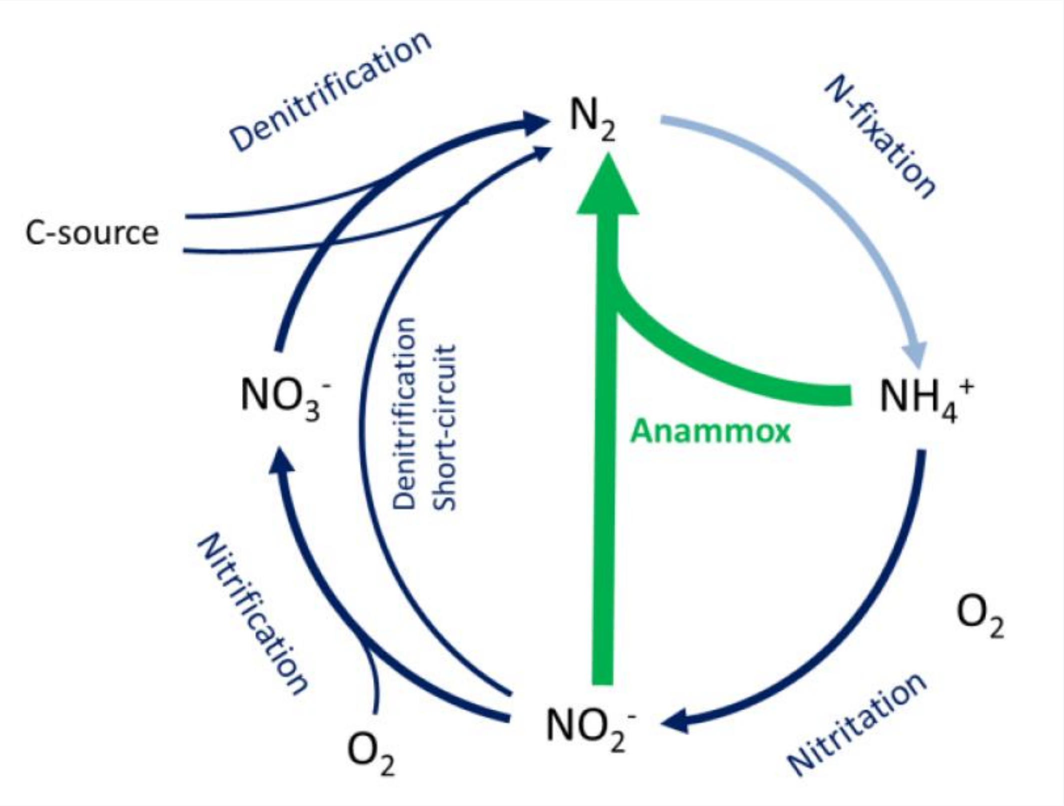
STP Amsterdam, the Netherlands, struvite recovery

Struvite reactor (average for 2016-2020):

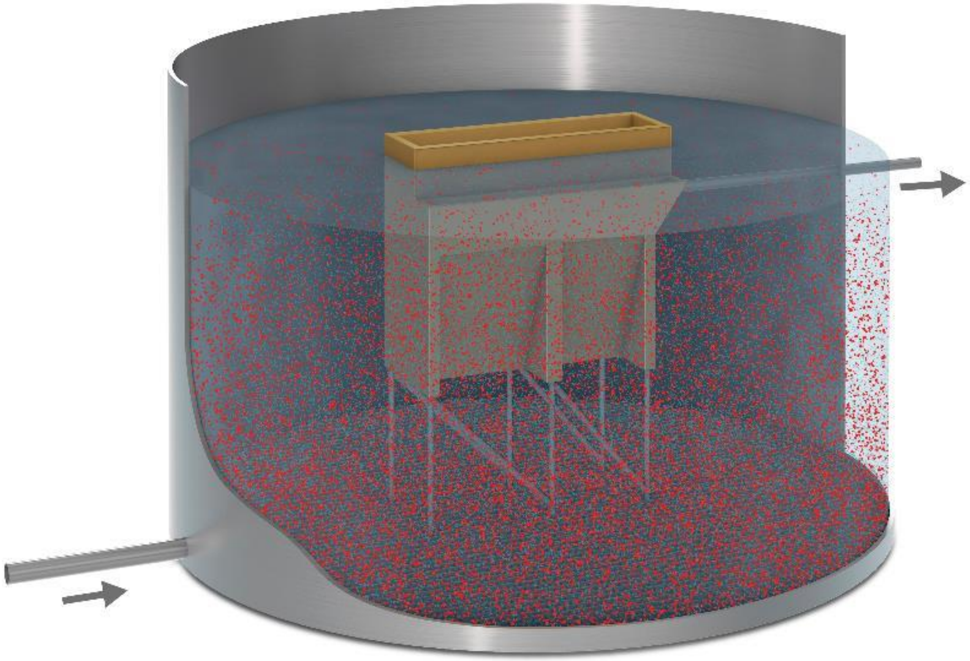
- Inlet: 400 mg P/L
- Outlet: 94 mg P/L
- Removal efficiency: 76%

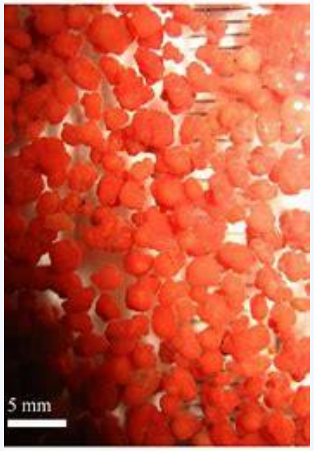
Anammox/DEMON N-removal process

Anaerobic **Amm**onium **Ox**idation

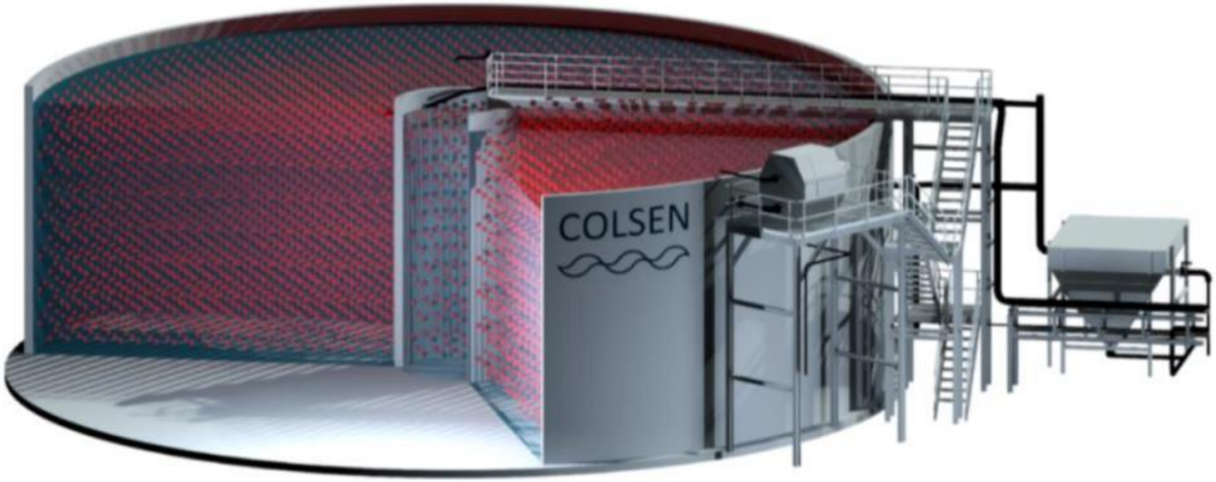


Anammox/DEMON technology





Anammox bacteria



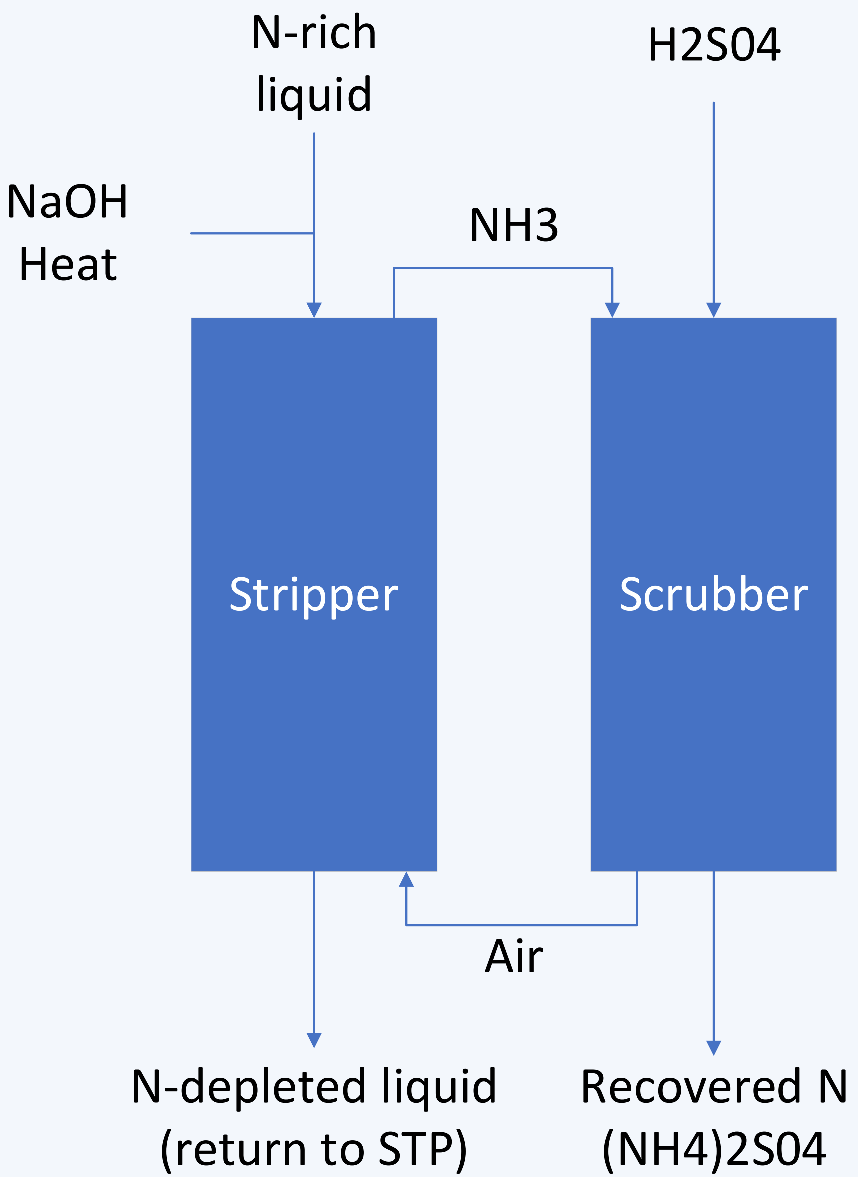
Anammox/DEMON

	Unit	Conventional treatment	Anammox
Power	kWh/kg N	2.8	1
Methanol	kg/kg N	3	0
Sludge production	kg VSS/kg N	0.5 – 1.0	0.1
CO_2 emission	kg/kg N	> 4.7	0.7

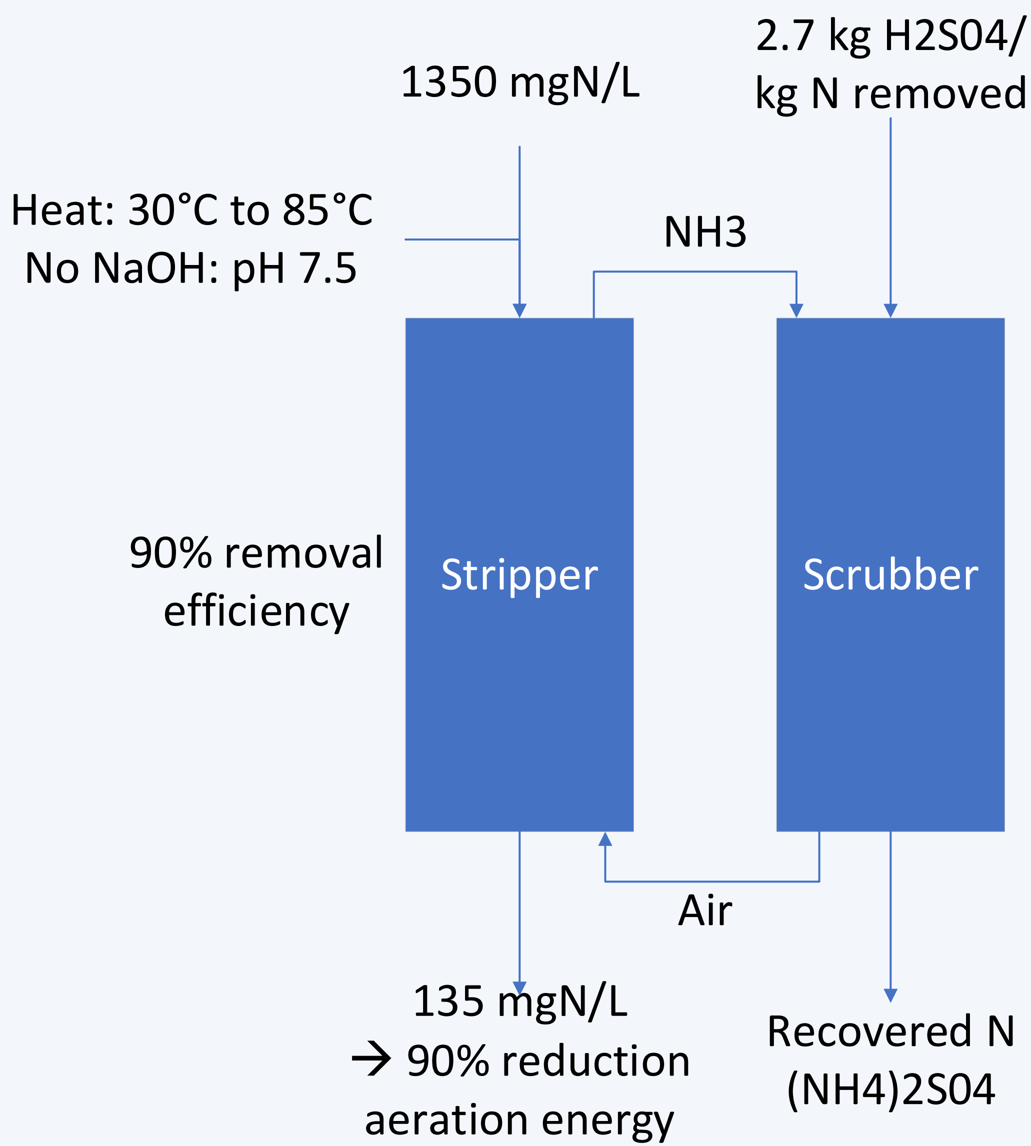
- 60% less power required (aeration)
- No carbon source required
- 5-10x lower sludge production

But: N_2O emission. N_2O is a Greenhouse Gas (265 times CO2)

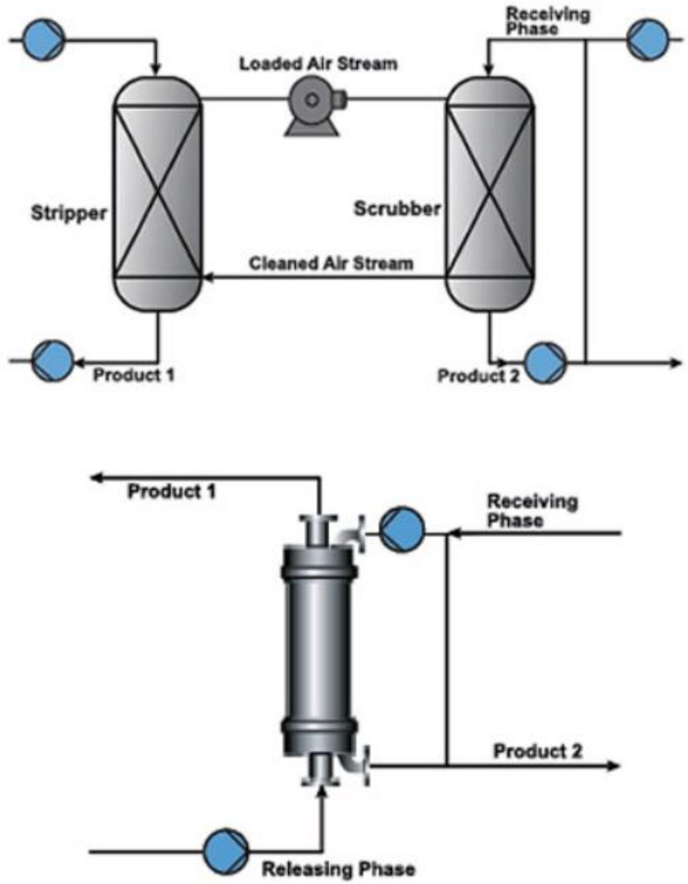
N-recovery technology – air stripping

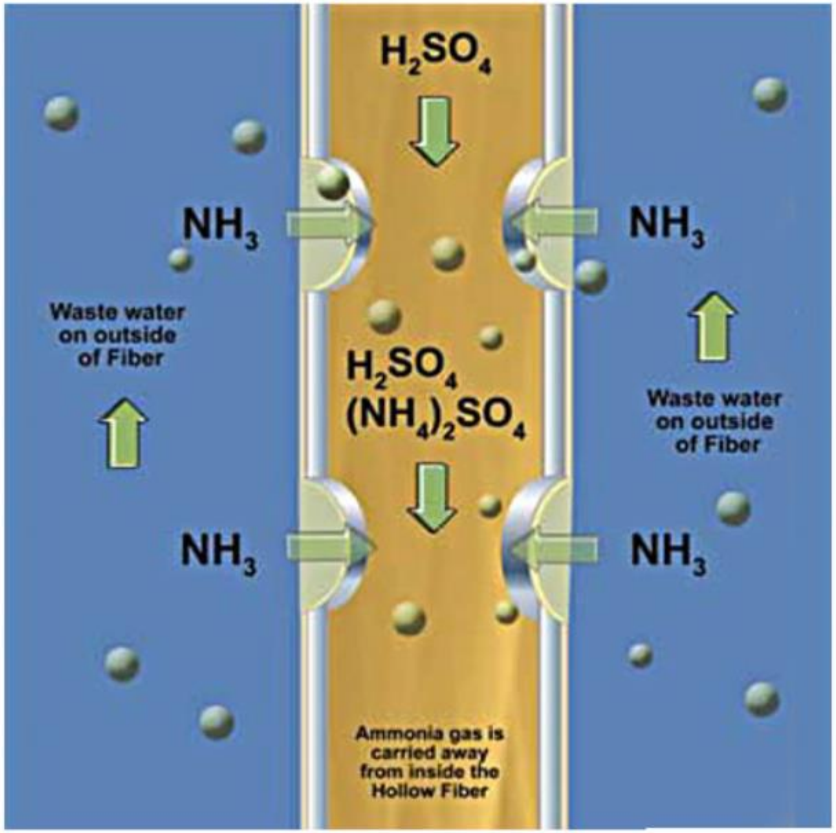


STP Echten, the Netherlands



N-recovery technology – membrane stripping





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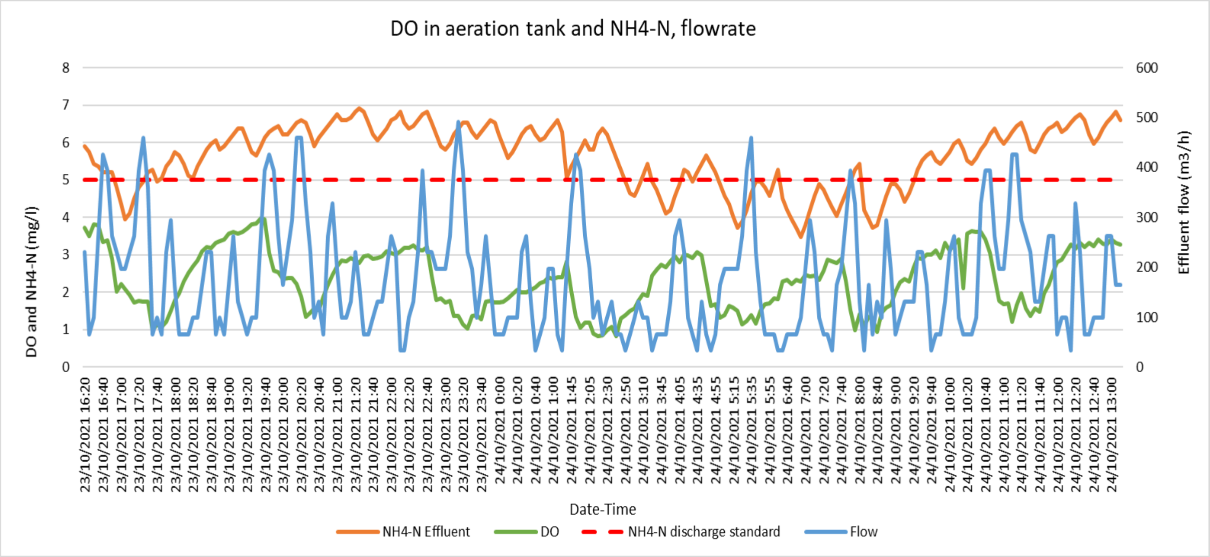
Advanced Process Control for optimal operation of Wastewater Treatment Plants

Monitoring and control system at WWTP's

Current practice:

- Many WWTP's have limited and not optimal monitoring control system, sometime only O2
- Aeration consumes 50-65% of total energy at a WWTP



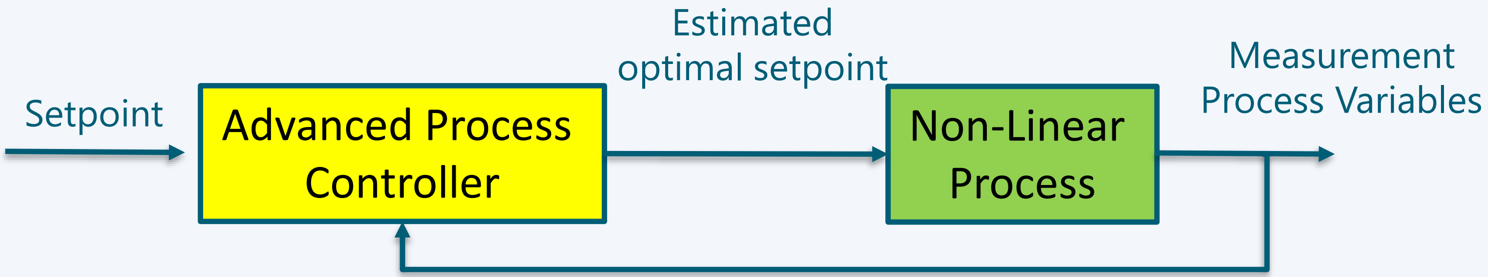
Disadvantages:

- Long delay time leads to overshoot or undershoot
- Missing interaction control among parameters

Problems:

- Large effluent quality fluctuation
- High energy and chemical consumption

WOMBAT – W+B Advanced Process Control



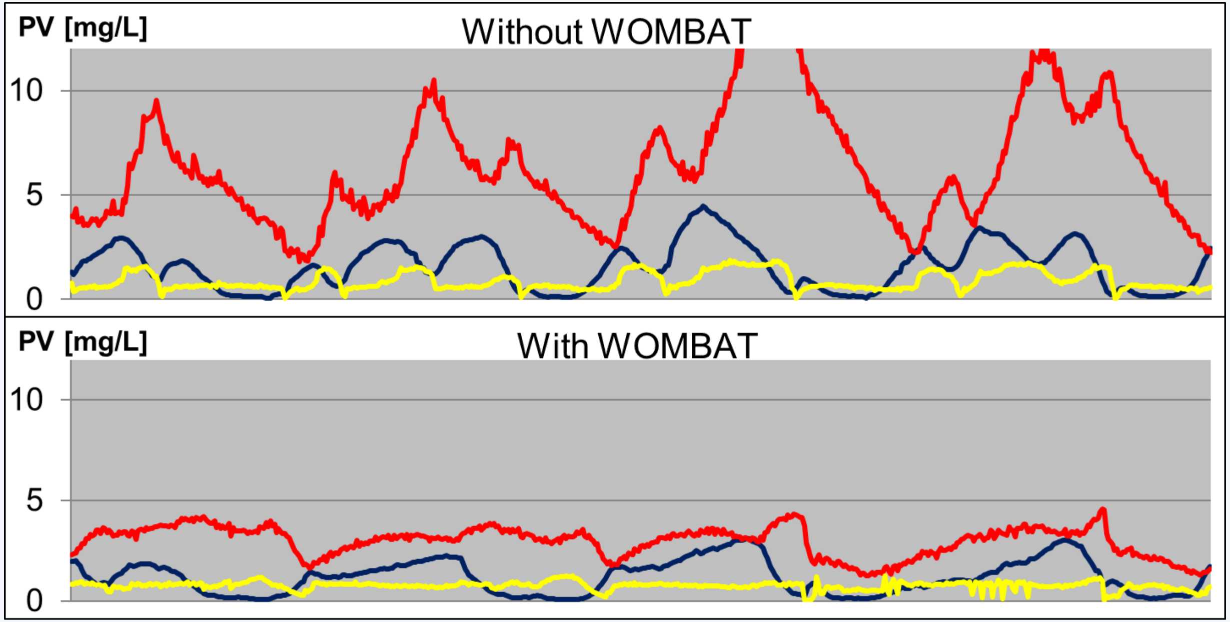
Predictive control enables efficient processes based on what will happen rather than what has happened

Features:
- Model predictive control
- Feed forward and Feedback control
- Self learning and adaptive control

Advantages:
- More stable effluent quality
- Higher energy efficiency
- Lower chemical consumption for denitrification

Benefits of WOMBAT in practise

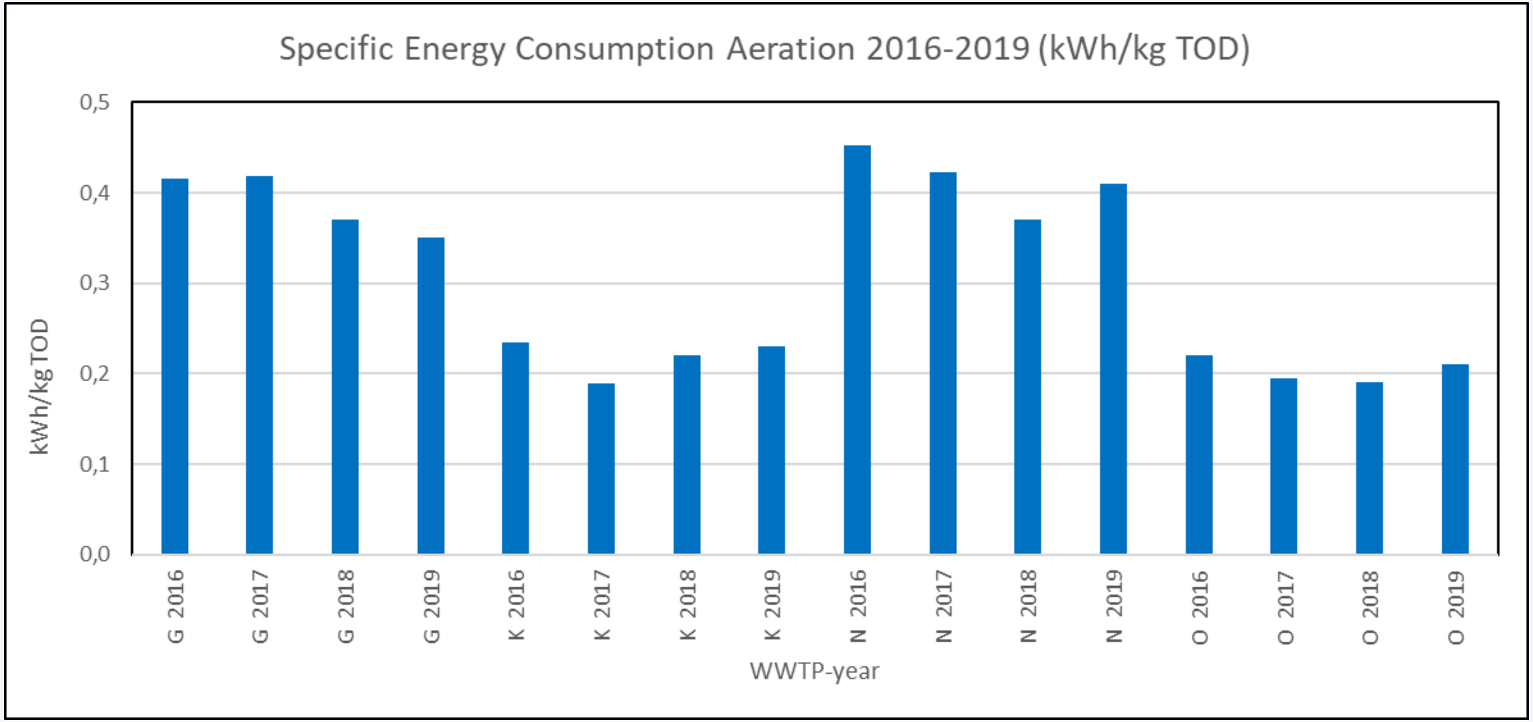
Nitrogen, Ammonium, Oxygen



Benefits

- Stable process and tighter process control also at fluctuating influent quality
- Lower NH4-N, NO3-N concentrations in effluent
- 5 - 25% reduction of energy consumption in aeration
- 5 - 10% lower sludge waste
- 5 - 30% reduction of chemicals used

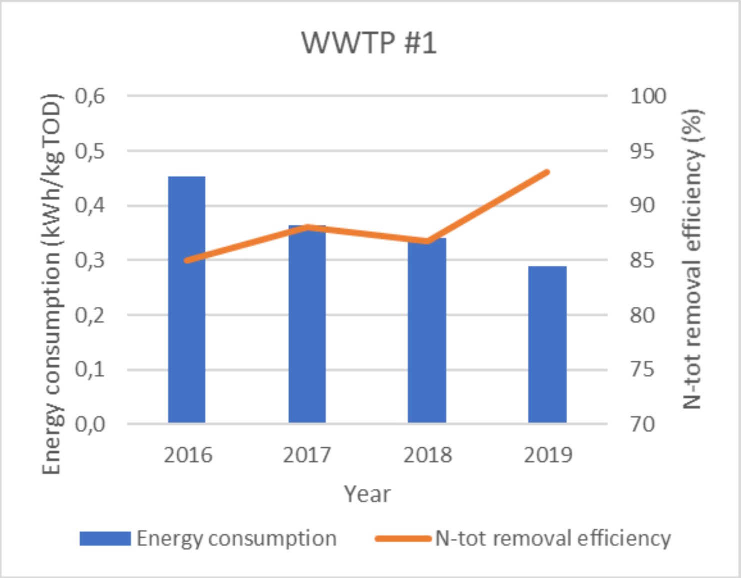
Benchmark energy consumption aeration WWTP's

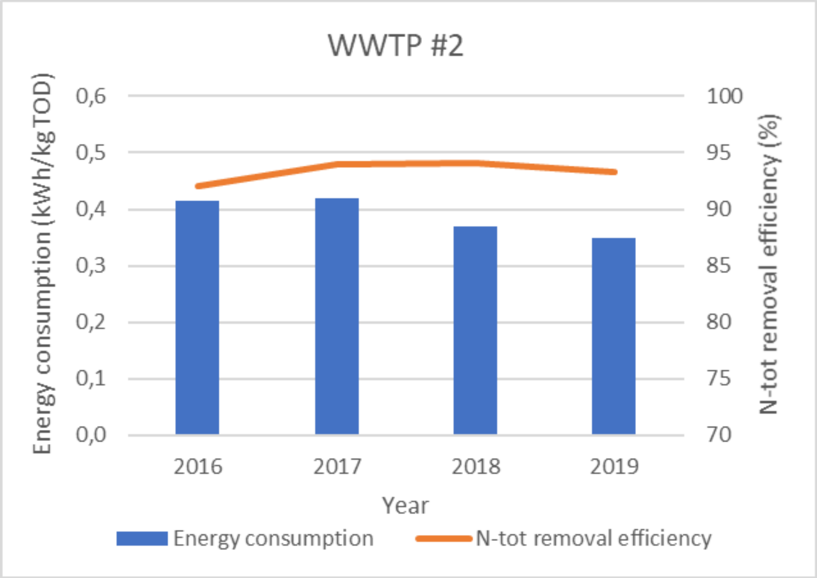


- Energy consumption of 4 WWTP's (G, K, N, O) with different aeration systems (2016-2019)
- Improvement of monitoring, control and setpoints

Note: TOD = COD + 4,57*TKN

Energy consumption and improved effluent quality





WWTP #1

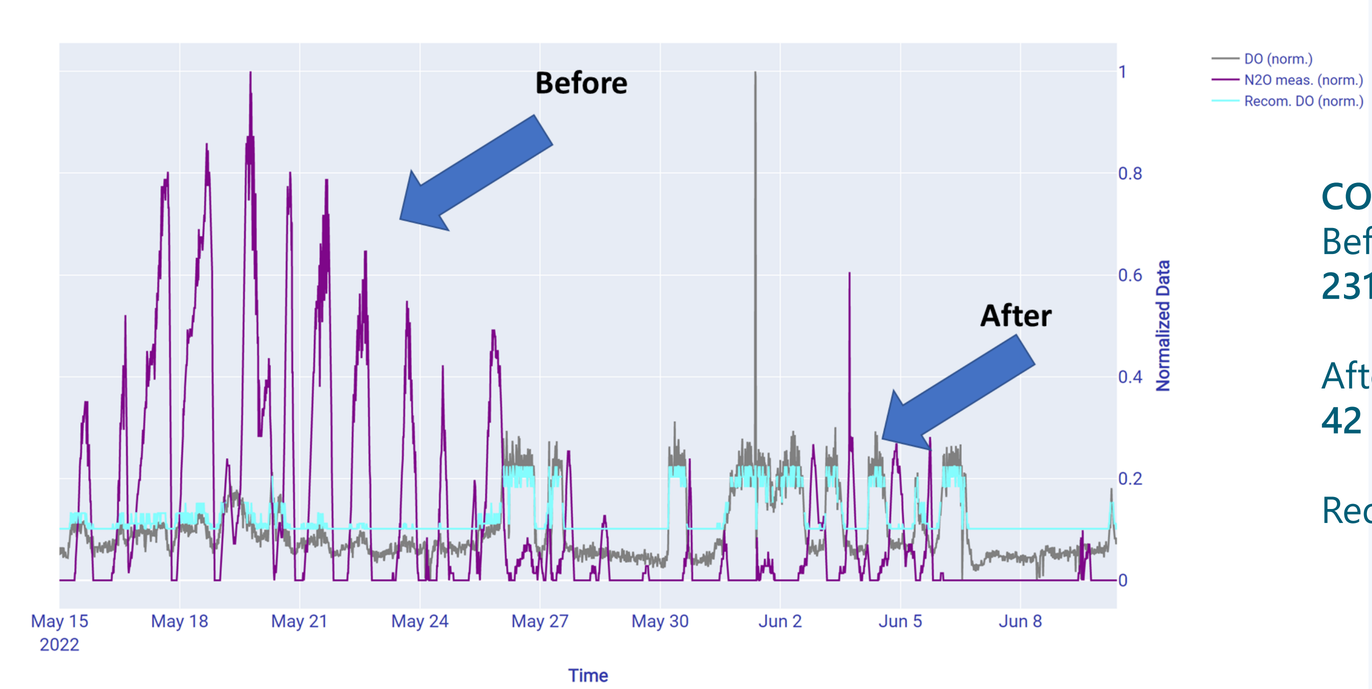
- Energy consumption decreased from 0.46 to 0.29 kWh/kg TOD, energy saving 37%
- N-tot removal efficiency increased from 85 to 93%

WWTP #2

- Energy consumption decreased from 0.41 to 0.35 kWh/kg TOD, energy saving 15%
- N-tot removal efficiency increased from 91 to 93%

N2O emission, before and after implementation of APC

- N2O is emitted from aeration tanks during nitrification and denitrification
- N2O is 265 time more harmful than CO2
- Advanced process control reduces the N2O emission. Implemented 25 May



CO2 emission:
Before (May 5 – May 25)
231 tons CO2e/year

After (May 25 – June 10)
42 tons CO2e/year

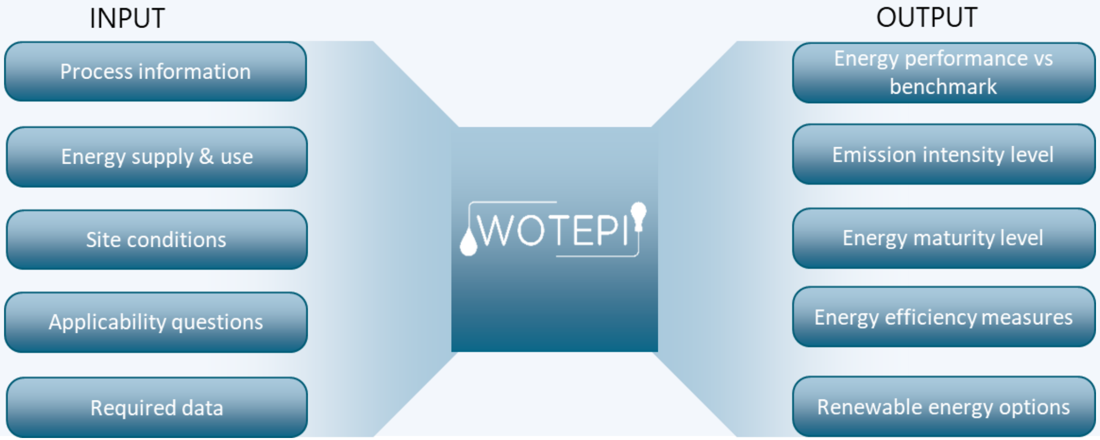
Reduction 82%

Water Operators Tool for Energy Performance and Improvement

WOTEPI: Water Operators Tool for Energy Performance and Improvement

For the European Bank for Reconstruction and Development (EBRD), Witteveen+Bos developed a toolkit that enables **water-** and **wastewater** treatment operators to **save energy** and **become future and climate proof.**

Promo film: https://vimeo.com/702920875/19f35bbff3



Energy and emissions performance

With WOTEPI, you get insight into your energy intensity comparison to benchmarks…

Energy Intensity:

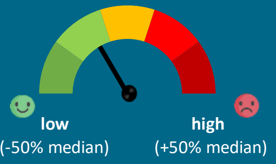
26.1

kWh/P.E.

(P.E. as 150 g TOD/day)

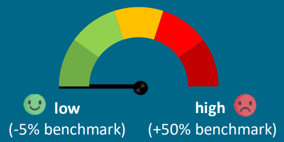
Energy Intensity

Comparison to EU Benchmark Co-op



Energy Intensity

Comparison to similar installation



WOTEPI provides a list of potential energy efficiency measures

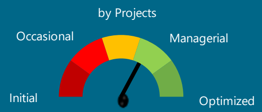
Emissions Intensity of the energy use

10.3

kg CO2 eq./P.E.

(P.E. as 150 g TOD/day)

Energy Maturity Level



managerial

The organization is now mature enough to understand that the reduction of consumption can be obtained more efficiently through a "day by day" management, rather than "by projects".

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Re-use of treated wastewater for production of boiler feed water

Quality WWTP Effluent

Parameter	Average	UoM
Turbidity	8	NTU
TSS	30	mg/l
EC	65	mS/cm
Chloride	90	mg/l
Sulphate	60	mg/l
TDS	500	mg/l
SiO2	17	mg/l
DOC	15	mg C/l
COD	60	mg/l
BOD	<10	mg/l
NH4-N	< 10	mg/l
NO3-N	< 10	mg/l

Ultra Pure Water (UPW) Production Plant

- 350 m3/h boiler feed water production from WWTP effluent. Start up in 2010.
- Requirements to recycled water:
  - Conductivity < 0,1 µS/cm
  - Ca, Mg, Si, Cu, Fe, Mn < detection limits
  - Low use of chemicals for biofouling and anti scalant

UPW Production Plant Technologies

Treatment technologies:

- Ultrafiltration: submerged membranes (ZeeWeed 500)
- Biological Activated Carbon Filtration (BACF) with oxygen supply.
- Desalination by double pass Reverse Osmosis (RO)
- Electro-De-Ionisation (EDI)

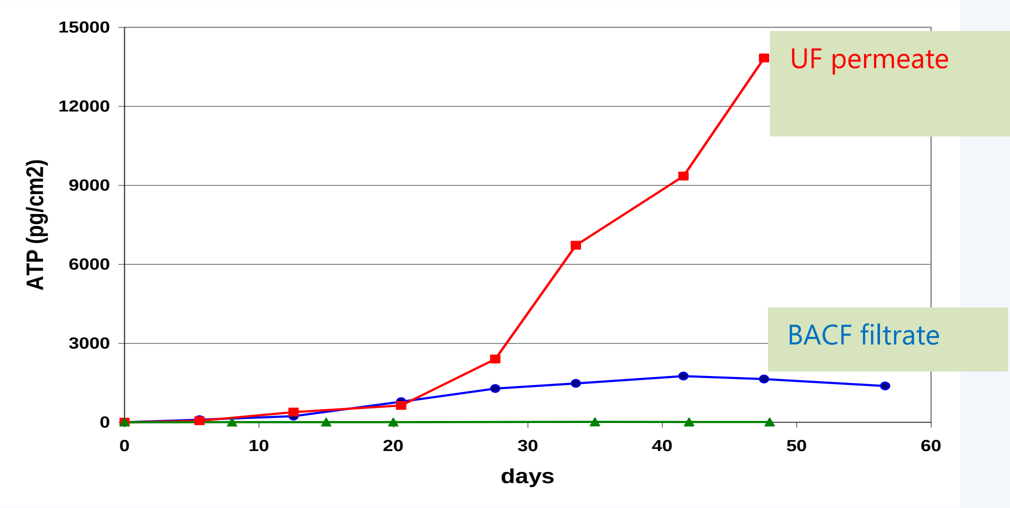
Biological Activated Carbon Filters operation

Effects BACF with oxygen supply:

- Biofilm growth on activated carbon, decrease of BOD and oxidise NH4 present in WWTP effluent and not removed by UF
- Low concentration of growth limiting substrates in the RO feed water and preventing biofouling on RO membranes
- pH decrease due to nitrification
- Lower dosing of anti scalant dose in feed RO

Backwash BACF	1 or 2 times a week
Nitrification	100%
Turbidity	< 0,1 FTU

Effect of BACF on biofilm forming rate



Biofilm Forming Rate

Effect of BACF on cartridge filter

RO-1 performance

Recovery	75%
EC feed	400 - 1700 µS/cm
EC product	5 - 15 µS/cm
Anti scalant dosing	2 ppm
CIP frequency	2-3 times a year
CIP chemicals	NaOH / HCl
Lifetime RO membranes	currently 13 years, projection >15 years

1-STEP® filter

Ultimate One Step Total Effluent Polishing filter

June 2023

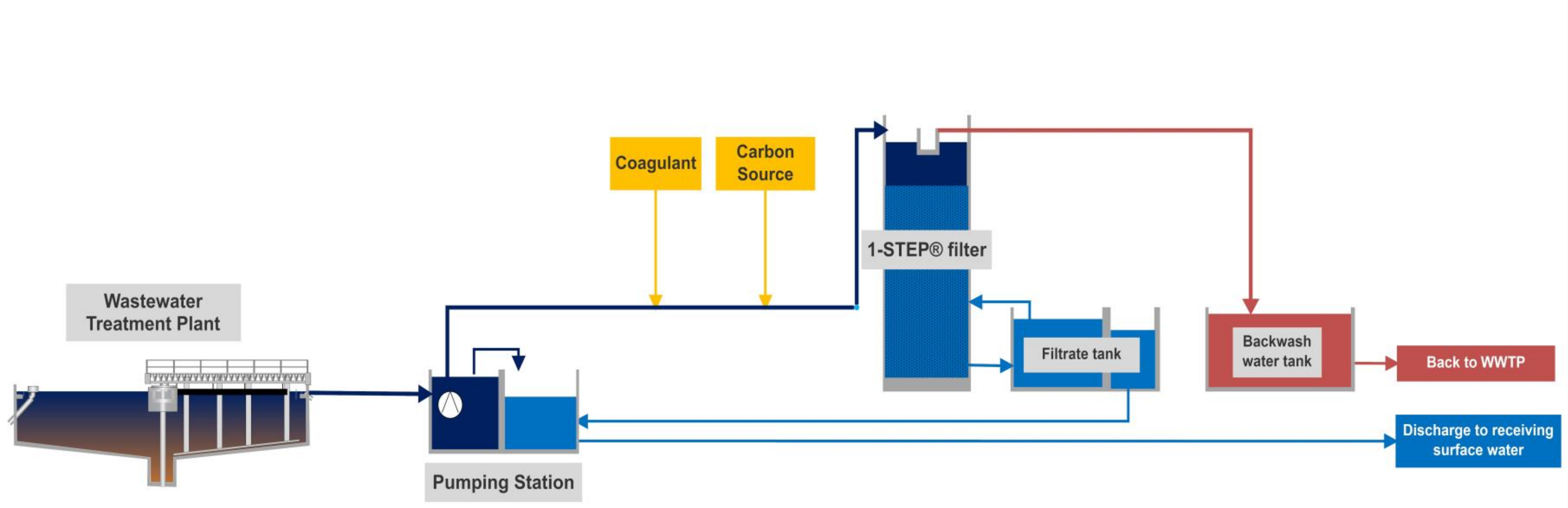
Drivers for innovation and implementation 1-STEP® filter

- A cleaner and protected environment; least-cost of compliance with stringent discharge limits (i.e. EU WFD) to protect water resources
  - Advanced nitrogen removal
  - Phosphorous removal to a standard < 0.25 mg P/l
  - Priority substances removal
  - Final effluent polishing
- Significant OPEX savings and limiting CAPEX in treated effluent recycling schemes

STP Horstermeer, the Netherlands (165,000 p.e.)

1-STEP® filter fully operational from 2013 onwards, capacity 1,500 m3/h

Flow diagram 1-STEP ® filter

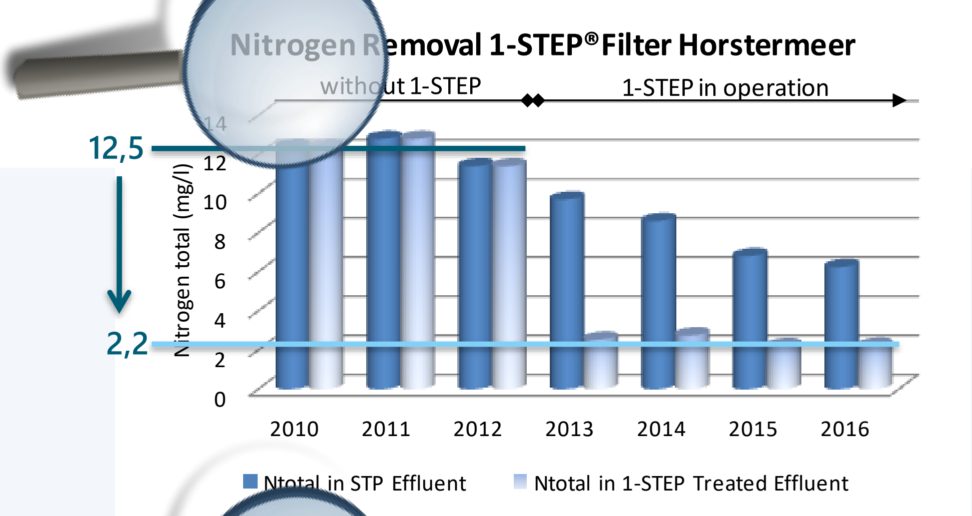


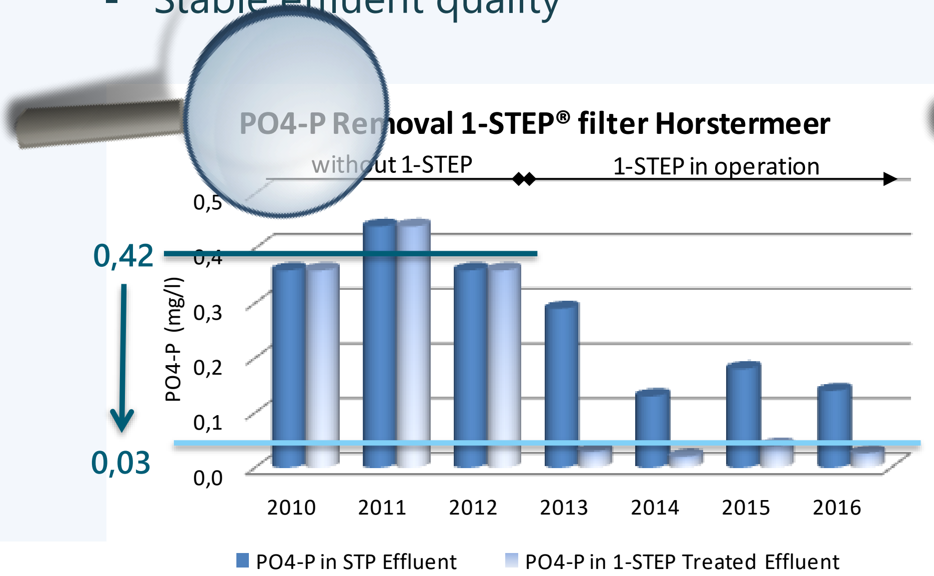
Our 1-STEP® filter solution

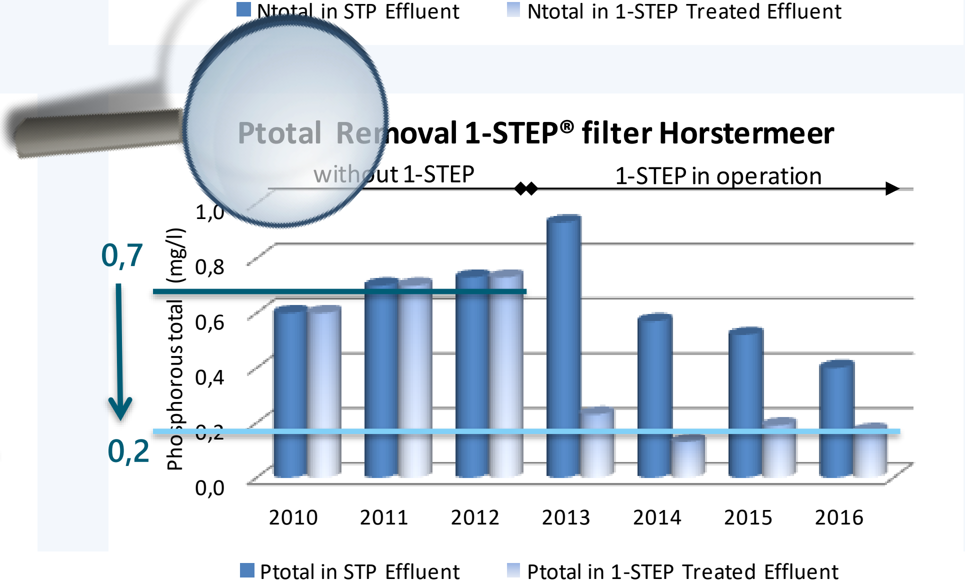
- 1 Step Total Effluent Polishing filter

Performance: nutrients

- High removal efficiency
- Stable effluent quality







Innovations resulting in excellent operational performance

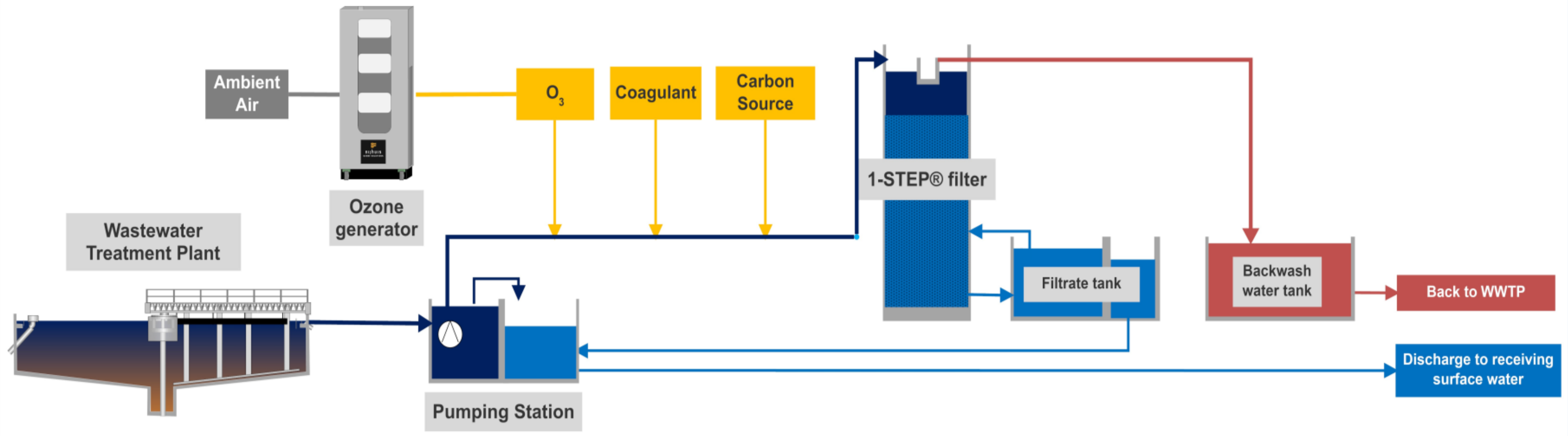
- Intelligent dosage and control of chemicals
  - Efficient PAC consumption for P-removal
  - Efficient MeOH dosage (N removal up to 4 kg N/m^3 filter bed volume)
- Intelligent filtration and backwash control
  - Selected type of activated carbon
  - High filtration rates: up to 15 m^3/m^2h
  - Backwashing down time: ~5%
- Low energy usage (0.04 kWh/m^3 treated)

Implementation for least-cost high quality treated effluent

- Easy to implement; small footprint; easy to integrate
- Lowest phosphorous level so far in practice, low nitrogen level
  - Best suited to applications where phosphorous and another polishing requirement is necessary
  - Future proof for pharmaceuticals and organic micro pollutants
- 30-50% saving in CAPEX and OPEX compared to conventional successive processes
  - 1-STEP® filter solution versus denitrification, sand filtration and GAC filtration

O_3-STEP® filter

- Oxidation of organic (micro)pollutants for improved biological degradation
- Further disinfection



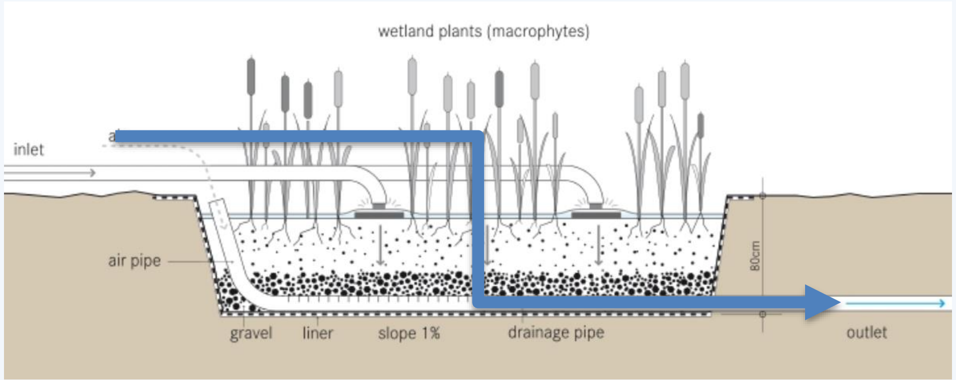
Constructed wetlands as post treatment of STP effluent

June 2023

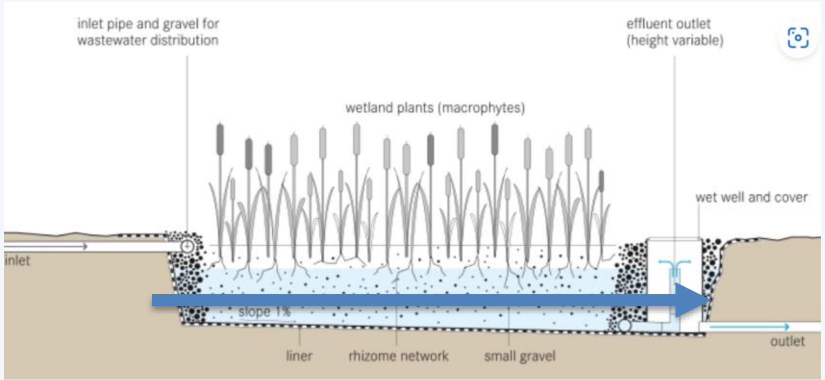
What are constructed wetlands?

- Engineered systems that use the natural functions of vegetation, soil and organisms to provide secondary treatment to wastewater
- Vertical and horizontal systems, based on direction of waterflow. Vertical systems have a soil passage.

Vertical system



Horizontal system



Impacts of wetlands

- Natural reduction of remaining organic pollution (BOD/COD), mostly by sedimentation and partly by conversion of bacteria, algae etc.
- Create a natural oxygen ritme before discharging
- Natural desinfection capacity: removal of pathogens mainly related to retention time
- Buffering of peak flow, and peaks in pollution concentrations
- Further reduction of nutrients

Pros and cons

PRO

- Natural systems, no need for chemicals
- Operation and maintenance is cheap and straight foreward
- Very good in buffering peak loads
- Create “natural” water that can be discharged to surface water without problems
- No need for disinfection of STE if treated by constructed wetlands

CON

- Demand large areas (especially the horizontal systems)
- Natural systems, so more uncontrolled natural fluctuations
- Evaporation

Wetlands Kristalbad, the Netherlands

- Functions: buffering storm water, biological treatment of STE of STP Enschede, nature development, recreation
- 400,000 m^2

Nimr, Oman

5.1 million m^2

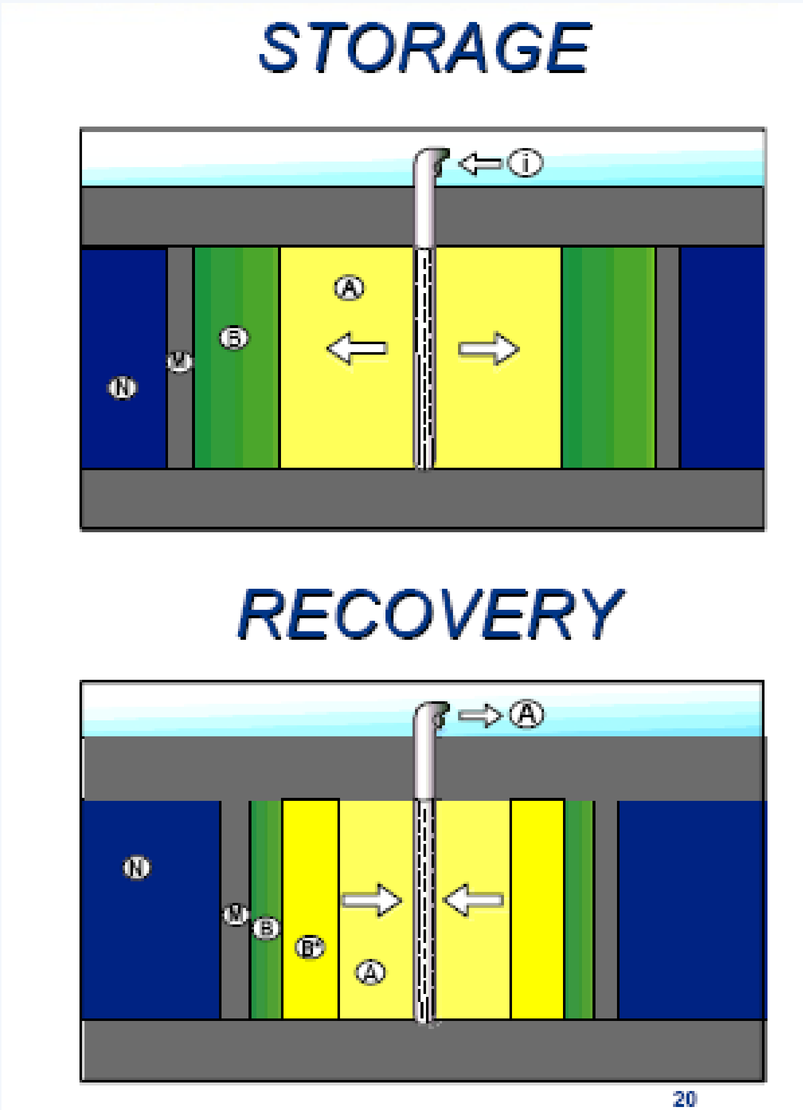
Wastewater of oil processing:

- 175,000 m^3/d
- up to 8,000 mg TDS/L (brackish)
- 500 mg oil/L (oil water separator)

Witteveen+Bos

Aquifer Storage and Recovery of Treated Effluent

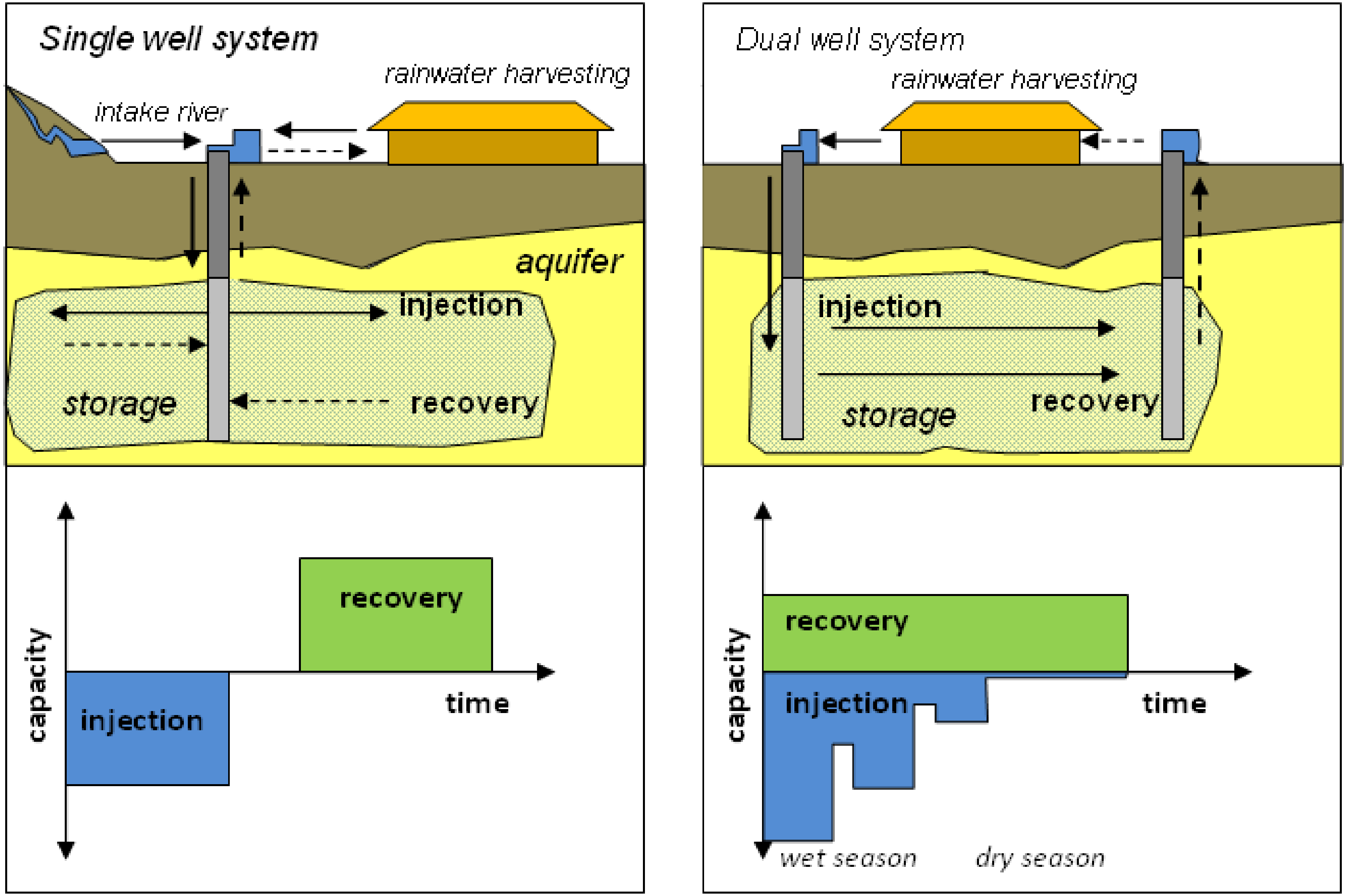
Aquifer Storage and Recovery (ASR)



Injection of water via a (deep) well in an aquifer

Extract water later, when needed, via the (deep) well

Aquifer Storage and Recovery (ASR)



Design criteria

- How large is the aquifer capacity?
- What is the constitution of the soil? ASR can have impact on geochemical processes such as precipitation of minerals, degradation of organic material, redox reactions, potential algae growth.
- How is the rearrangement of the particles in the aquifer?
- Clogging of the well is the biggest risk/problem.

Application in the Netherlands

- Growth of cities in the West of the Netherlands caused depletion of aquifers and drop in ground water levels.
- Prevent intrusion of salt sea water via underground
- ASR is applied in sand dunes (unconfined) since 1940
- Water recovery from aquifers: 180 million m^3/yr

Applications in KSA

Discharge treated effluent of STP Al Kharj after tertiary treatment into aquifer:

- Current discharge of 200,000 m^3/d via lagoons (Darkal) and percolation into the ground
- If phase III will be operational: 400,000 m^3/d discharge required. Lagoons cannot cope with this. Saudi legislation requires secondary treatment + nutrient removal for aquifer discharge
- Design deep well system to recharge aquifer for this large capacity