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ULTIMATE
WATER SMART INDUSTRIAL SYMBIOSIS

Deliverable 1.8

Lessons learned from synergy workshops

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[1] PU = Public
PP = Restricted to other programme participants (including the Commission Services)
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CO = Confidential, only for members of the consortium (including the Commission Services)

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Executive Summary

Background and objective of the synergy workshops

Ultimate aims to promote, establish and extend water smart industrial symbioses (WSIS) between the industrial sector and service providers of the water sector. The WSIS are the foundation for a successful implementation of circular economy technologies, because one partner produces the resource and the other partner has the demand for product. Thus, they cooperate to create a win-win situation for a WSIS. In Ultimate, circular economy technologies are developed and demonstrated via a symbiotic management through the WSIS at nine case studies.

In this frame, eight workshops have been conducted for the case studies to identify synergies among the Ultimate partners and with other Horizon 2020 projects such as B-WaterSmart (GA 869171), Water Mining (GA 869474), REwaise (GA 869496) and Wider Uptake (GA 869283), NextGen (GA 776541), Smart-Plant (GA 690323), Sea4value (GA 869703), Run4life (GA 730285), digital-water.city (GA 820954), Fiware4water (GA 821036), Routes (GA 265156), Res-urbis (GA 730349), Water2Return (GA 730398) as well as two national projects such as Sludge4.0 (7165.24052017.112000002) and BioKS (0324029A).

This deliverable provides an overview about the take home-messages from the workshops, the lessons learned from the discussions and the opportunities for further corporations among the case studies and sister projects.

Lessons learned in general

In general, we learned from the workshops that we should plan our Ultimate solutions with a technological flexibility to easily change the experimental set-up in order to conduct different kind of trials which might even simulate a critical state of the investigated processes and which allow the project participants to follow new “crazy” ideas that might have a risk to fail, but also suggest a high benefit, in the case they do not fail.

In terms of the WSIS, we identified the most important success factor to be the commitment and willingness to act together to “make it happen”. Therefore, a common goal is necessary, success stories as motivation to act together and a charismatic person serving as an initiator to spread and start ideas among the partners. Another important success factor is an open and evidence-based communication to convince people and to gain their trust.

Based on the knowledge, how important an open and evidence-based communication is for a WSIS, we conclude that this is also true for a project consortium involving multiple WSISs. Hence, the continuation of our workshops, which focus mainly on the development and optimisation of our technologies, is seen as a crucial step towards the successful project execution to inform and involve all project partners even those, who are not directly involved case study specific tasks. Furthermore, the technology

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evidence base (Kleyböcker et al. 2021a; https://mp.uwmh.eu/teb/) will contribute to an open and evidence-based communication about the outcomes of our project and spread the successful circular economy solutions in Europe.
In the following three paragraphs, the lessons learned from the technological workshops for water, material and energy recovery and reuse are outlined.

Water recovery workshops

The membrane technology workshop revealed, a further demand for research in terms of the development of new membrane materials, the optimisation of membrane properties and their configurations. If membrane technologies are combined and implemented sequentially, these treatment trains allow to obtain higher water recovery rates and better water qualities, promoting water reuse and fostering circular economy. Furthermore, wastes streams, normally brines, are minimised. A special and novel application of membranes, is the small bioreactor platform. It can be implemented in existing biological treatment units to cope with shock loads to increase their treatment capacity. It is a small-scale standalone solution with low costs. For the recovery of fit-for-purpose water from biotech effluent with high fractions of non-degradable organic matter, the possibility to reduce operations costs is investigated. Therefore, a novel ultra-tight ultrafiltration membrane is used as pre-treatment upstream to a reverse osmosis membrane. The goal is to reduce the demand for cleaning in place treatments of the reverse osmosis membrane as well as reducing the demand for coagulants upstream of the membranes.

The adsorption technology workshop showed that a low-cost alternative to remove ammonium from water is via adsorption processes. They are more energy efficient than a standard reverse osmosis. In general, the adsorption technology is very versatile in terms of inorganic and organic pollutants removal from water. However, adsorbent characteristics and properties have a great impact on the pollutant's removal selectivity and efficiency. Therefore, the adsorption technologies can be used in two ways: to remove pollutants from wastewater and to recover materials from the regeneration solutions. Although adsorption is a well-known technology, current research is focused on the development of new adsorbent materials, for instance, structures printed in 3D or adsorbents produced from renewable materials.

Energy recovery workshops

The biogas technology workshop revealed that anaerobic treatment processes in combination with biogas recovery allow for a decrease in the organic loading rate to the downstream activated sludge process and hence, for a lower CO_2 footprint of a WWTP. However, special attention should be paid to the methane recovery from effluents of anaerobic reactors. This is an important treatment step to avoid high methane losses, which is crucial when aiming for lower CO_2 footprint.

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In addition, the reuse of excess heat can contribute to a decrease in the CO_2-footprint of a technology. For two of our Ultimate processes, low grade excess heat might be beneficially reused. For the ammonia air stripping process, excess heat can be used to increase its process temperature to save chemicals for an otherwise required increase in pH to reach the same ammonia recovery rate. Furthermore, the increase in the temperature of the feed stream of a reverse osmosis filtration unit might increase the energy efficiency of the filtration process due to a lower dynamic viscosity of the feed stream. However, higher temperatures can also lead to higher organic fouling rates, what would be a disadvantage.

From the discussion about high temperature - aquifer thermal energy storages (HT-ATES), we learned that the bigger the storage is and the better the layer to the upper subsurface isolates, the higher the heat or cold recovery efficiencies are.
A temperature shift in the ATES from 15-18 °C to 25-40 °C did not show a severe effect on the geohydrological environment. However, at higher temperatures heavy metals were released. As soon as the temperature decreased, the heavy metals precipitated again. The temperature increase was suitable to compensate the imbalance of a higher heat demand in winter compared to the cooling demand in summer.
Depending on the characteristics of the geothermal system, microbial induced corrosion can severely affect the stable operation of such a system. Sulphur oxidising bacteria clearly indicate an oxygen ingress to a borehole after geothermal plant downtimes, especially when gas measurements are not sensitive enough to detect those. Periodic heat shocks are a promising procedure to reduce biofilms and thus, to diminish microbial induced corrosion processes.

In general, a way to increase energy efficiency at a wastewater treatment plant is to avoid over-aeration and hence, to maintain a demand-driven aeration process. Therefore, digitalisation in combination with modelling are valuable tools. However, a model can be only as good as the quality of its used data is. Thus, reliable sensors and regular maintenance of those are mandatory. Hence, data validation and reconciliation as well as its quality control are crucial. Furthermore, developments of digital solutions based on Fiware architecture allow for a better compatibility and open access. This will help to replicate such solutions.

Material recovery workshops

In terms of nutrient recovery, different innovative technologies have been successfully implemented and applied for wastewater, sludge and kitchen waste such as advanced biodrying and composting, bioelectrochemical systems and ultra-low-flush toilets coupled with (hyper-)thermophilic anaerobic digestion. Within Ultimate, different technologies are under investigation to recover nutrients from greenhouse, distillery and brewery wastewaters that refer to similar topics such electrodialysis,

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electrostimulated anaerobic digestion systems and struvite recovery. The main barriers for the implementation of such concepts were related to regulatory gaps, the need of increasing social acceptance and market competition.

The recovery of value-added compounds can bring multiple advantages: removing of components which are harmful for a specific treatment, obtaining marketable products, allowing for the reuse of a residual/out of specification material. Recovery of value-added compounds usually require the implementation of different treatment steps to be implemented in existing plants. Both laboratory and pilot tests are a key step for the implementation of a value-added compound recovery process. The quality of the final product is fundamental for the market accessibility; specific treatment steps are usually necessary to reach an adequate quality. The legislation is fundamental for the recognition of a recovered material as product, if it is generated by a waste (end-of-waste).

Exploitation and EU-added value of workshop outcomes

The workshops resulted in a synergetic networking between Ultimate and its sister projects B-WaterSmart, Water Mining, REwaise and Wider Uptake. In addition, those projects learned from further progressed projects such as NextGen, Smart-Plant, Sea4value, Run4life, Digital-water.city and Fiware4water, Routes, Res-urbis, Water2Return, Sludge4.0 and BioKS. The case study leaders profit from the lessons learned and discussions about their concepts to set up their demo cases properly. This will contribute to the successful implementation of thoughtful Ultimate solutions and provide useful results for new approaches and best practices of the Ultimate solutions within symbioses clusters (D1.3, D1.4, and D1.5) and for the technology evidence base (TEB, D1.7). The collection and open access presentation of the technologies in this evidence base will support decision makers and investors to gain a fast overview of the opportunities and proven concepts of circular economy. Together with the Marketplace (D5.5), the TEB will severely contribute to the transition from a linear to a circular economy in Europe.

Ultimate promotes technologies that are in line with the ambitions of the European Green Deal (European Commission 2019) its Action Plan for Circular Economy (European Commission 2020) to reduce strongly our greenhouse gas emissions, to provide clean water, to maintain healthy soil, make industry resilient and produce cleaner energy. The TEB presents technologies that can be applied in the frame of the Regulation (EU) 2020/741 on minimum requirements for water reuse, the Regulation (EU) 2019/1009 laying down rules on the making available on the market of EU fertilising products and the Directive (EU) 2018/2001 on the promotion of the use of energy from renewable sources.

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Outlook

The workshops will continue throughout the project, because they revealed to deliver valuable information for the participants and identified important topics for further cooperation and discussion among the Ultimate partners and the other projects. Hence, further workshops are planned for the following topics in cooperation with the other work packages:

- Legal risk assessments of the Ultimate solutions and policy gaps (in cooperation with WP2 and WP4)
- Lessons learned from the installation and start-up of the pilot plants (in cooperation with WP5)
- Technical risk assessments of the Ultimate solutions and potential for replication of the concepts (in cooperation with WP2 and WP5)
- Chemical risk assessment of the products as well as their reuse and marketability (in cooperation with WP2 and WP5)

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Abbreviations

AAT	Advanced anaerobic treatment (immobilised high-rate anaerobic reactor)
AI	Artificial intelligence
AnMBR	Anaerobic membrane bioreactor
AM	Additive manufacturing
AOP	Advanced oxidation process
ATES	Aquifer thermal energy storage
BES	Bioelectrochemical systems
CAPEX	Capital expenditures
CE	Circular economy
COD	Chemical oxygen demand
CS	Case study
CTG	Cross-cutting technology group
ELSAR	Electrostimulated anaerobic reactor
GAC	Granulated activated carbon
HTAD	Hyper-thermophilic anaerobic digestion
HT-ATES	High temperature aquifer thermal energy storage
HTC	Hydrothermal carbonisation
LTE	Low temperature evaporator
MBR	Membrane bioreactor
MED	Multi-effect distillation
NPK	Nitrogen phosphorus potassium
nZLD	Near zero liquid discharge
PE	Population equivalent
PHA	Polyhydroxyalkanoate
RO	Reverse osmosis
SBP	Small bioreactor platform
SBR	Sequencing batch reactor
SCWE	Supercritical water extraction
SME	Small and medium enterprises
SOB	Sulphur oxidising bacteria
TEB	Technology evidence base
UASB	Upflow anaerobic sludge blanket
UF	Ultrafiltration
WSIS	Water smart industrial symbiosis
WWTP	Wastewater treatment plant

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1. Introduction

Ultimate aims to promote, establish and extend water smart industrial symbioses (WSIS) between the industrial sector and service providers of the water sector. The WSIS are the foundation for a successful implementation of circular economy technologies, because one partner produces the resource and the other partner has the demand for product. Thus, they cooperate to create a win-win situation for WSIS. In Ultimate, circular economy technologies are developed and demonstrated via a symbiotic management at nine case studies distributed across Europe and Israel (Table 1).

Table 1 Overview about the Ultimate case studies, their type of symbiosis, their resources and their field of activity for circular economy solutions

Case study	Water Smart Industrial Symbioses	Resources	Closing the cycles of WATER, ENERGY, MATERIAL		
			WATER	ENERGY	MATERIAL
CS1 Tarragona (ES)	**Internal symbiosis within multi-industry utility**: municipal and industrial WWTP & urban WRP	Municipal wastewater and industrial wastewater from the petrochemical complex	✓		
CS2 Nieuw Prinsenland (NL)	**Internal symbiosis within cooperative**: greenhouses & water treatment facility	Drain water from greenhouses; residual and geothermal heat	✓	✓	✓
CS3 Rosignano (IT)	**Municipal utility, multi-industry utility & SME**: Sewer system, municipal WWTP, WRP	Municipal wastewater mixed with seawater due to an undesired intrusion of seawater; byproducts from industry for reuse in water treatment	✓		✓
CS4 Nafplio (EL)	**Industrial utility & SME:** industrial WWTP	Wastewater from fruit processing industry	✓		✓
CS5 Lleida (ES)	**Municipal utility & multi-industry utility**: industrial WWTP & municipal WWTP	Wastewater from brewery & municipal wastewater	✓	✓	✓
CS6 Karmiel/ Shafdan (IL)	**Municipal utility & two SMEs**: two municipal WWTPs & WRP	Wastewater from olive oil production, slaughter-houses and wineries & municipal wastewater		✓	✓
CS7 Tain (UK)	**Distillery, water company, & SME**: industrial WWTP	Wastewater from whiskey distillery	✓	✓	✓
CS8 Chem. Platform Roussillion (FR)	**Internal symbiosis within multi-industry utility**: industrial WWTP	Wastewater from chemical industry		✓	✓
CS9 Kalundborg (DK)	**Municipal utility & multi-industry utility**: municipal WWTP & industrial WWTP	Wastewater from pharma & biotech industry and municipal wastewater	✓	✓	✓

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More information regarding the baseline conditions for each case study and the detailed description of each WSIS can be found in Kleyböcker et al. (2021b).

Depending on the type of wastewater and resource, different treatment trains are applied. In total, 21 innovative technologies are investigated in Ultimate. In order to exploit synergies between the different recovery groups for water, material and energy, similar concepts and the development as well as the performance of those technologies were and will be discussed in so called cross-cutting technology groups (CTGs). For each CTG, different topics were defined as shown in Figure 1.

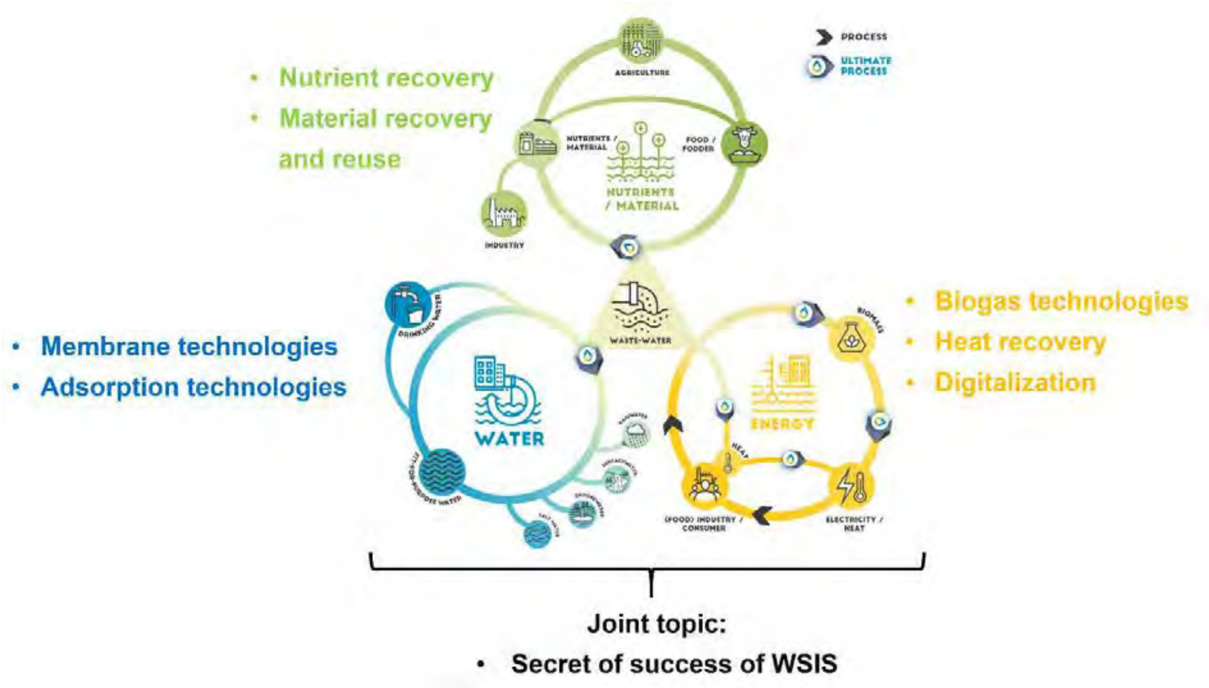

Figure 1 Cross-cutting technology groups and their sub-categories related to the types of technologies applied in Ultimate

In this frame, eight workshops have been conducted, each dedicated to one of the topics in Figure 1. In the workshops, the Ultimate concepts were discussed and external experts from ten other H2020 projects had been invited to share their lessons learned with the Ultimate consortium and to discuss the Ultimate concepts.

This deliverable provides an overview about the take home-messages from the different presenters for each workshop, the lessons learned from the discussions and the opportunities for further corporations among the case studies and sister projects.

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2. Lessons learned from the synergy workshops

The conducted workshops are outlined in Table 2. It also provides an overview about the case study specific technologies and the projects, from which we learned. Together, with our sister projects B-WaterSmart (GA 869171), Water Mining (GA 869474), REwaise (GA 869496) and Wider uptake (GA 869283) and with the further progressed or even completed projects such as NextGen (GA 776541), Smart-Plant (GA 690323), Sea4value (GA 869703), Run4life (GA 730285), digital-water.city (GA 820954), Fiware4water (GA 821036), Routes (GA 265156), Res-urbis (GA 730349), Water2Return (GA 730398), Sludge4.0 (7165.24052017.112000002) and BioKS (0324029A), we discussed our solutions.

Table 2 Overview about the discussed Ultimate concepts

Workshop	CS	Topics of Ultimate presentations	Presentations from other projects or organisations
Membrane technologies	CS1	Near zero liquid discharge systems in the petrochemical industry	water mining
	CS4	Filtration and small bioreactor platform for wastewater reuse in the food industry	
	CS7	AnMBR and RO treatment for water recovery in the beverage industry	
	CS9	Novel ultra-tight ultrafiltration membrane as pre-treatment for wastewater from biotech industry for water reuse	
Adsorption technologies	CS1	Removal of ammonia from wastewater by adsorption with zeolites	SMART-Plant SEA4 VALUE water mining
	CS4	Hybrid adsorption and subcritical water extraction	
Biogas technologies	CS5	AnMBR vs. bioelectrochemical fluidised bed reactor for biogas production from brewery wastewater	nextGen Circular Water Solutions SMART-Plant
	CS6	Immobilised high-rate anaerobic system & biogas process stabilizing measures	
	CS7	Biogas production in an anaerobic membrane reactor from distillery wastewater	
Heat recovery	CS2	High temperature aquifer thermal energy solution in greenhouses	nextGen Circular Water Solutions BioKS
	CS7	Heat recovery from anaerobic membrane bioreactor effluent	
	CS8	Recovery of heat from flue gas washing water	
Digitalisation	CS3	Early warning system for high chlorine concentrations and matchmaking platform to produce fit-for-purpose water	Digital Water .City FIWARE 4 WATER
	CS5	Early warning system for membrane fouling	
	CS9	Joint control system for two WWTPs	

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Nutrient recovery	CS2	Recovery of nutrients from greenhouse wastewater via electrodialysis
	CS5	Recovery of nutrients from brewery digestates
	CS7	Recovery of ammonia from distillery wastewater after an AnMBR treatment
Material reuse and recovery	CS3	Use of by-products of local industries for wastewater treatment
	CS4	Recovery of antioxidants and polyphenols from fruit processing water and olive mill wastewater
	CS6	
Secret of successful WSIS	CS1	Success of the Tarragona Symbiosis and strategy of the Water-Smart Industry Vision Leadership
	CS3	The ARETUSA symbiosis for local and regional water-smart sustainability
	CS9	Kalundborg Symbiosis and the secret behind a resilient partnership

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2.1. Water recovery: membrane technologies

Around 30 persons participated in the workshop “Membrane technologies” on November, 25th 2020 and the case studies Tarragona (CS1), Nafplio (CS4), Tain (CS7) and Kalundborg (CS9) presented their concepts. The project Water Mining shared its outcome with us.
After the key lessons from the discussion, the main take-home-messages of the presenters are summarised. The full presentations are shown in Annex 1.

Key lessons from the discussion:

1) Membrane processes are well-known, and current research is focused on the development of new membrane materials, properties and configurations. Furthermore, new applications are under research (i.e. biological process using membranes).

2) Membrane technologies can be combined and implemented sequentially. These membrane processes trains allow to obtain higher water recovery rates and better water qualities, promoting water reuse and fostering circular economy. Furthermore, wastes streams, normally brines, are minimised.

3) The small bioreactor platform can be implemented in existing biological treatment units to cope with shock loads to increase their treatment capacity. It is a small-scale standalone solution with low costs.

4) Operational costs might be reduced for the production of fit-for-purpose water from biotech industrial wastewater through a novel ultra-tight ultrafiltration membrane as pre-treatment upstream to a reverse osmosis membrane via reducing the demand for cleaning in place treatments as well as reducing the demand for coagulants.

2.1.1. Near zero liquid discharge systems in the petrochemical industry in CS1 Tarragona

Sandra Casas from Eurecat presented the CS1 Tarragona concept. In the petrochemical complex of Tarragona (Spain), more than 30 companies depend on water transfers from the Ebro River to meet their consumption needs. However, increasing demand outpaced the system capacity and a water reclamation plant to feed industrial uses was put in operation in 2012. The plant reclaims municipal WWTP effluent using coagulation/flocculation, filtration, reverse osmosis, as its main process, and finally disinfection. The reclaimed water is used primarily for cooling towers and boilers.
In order to meet future water requirements, an industrial WWTP will be commissioned in 2022 to polish the aggregated wastewater from the petrochemical complex and to produce reclaimed water for the complex.

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Water reclamation for industrial reuse from this new industrial WWTP (tertiary treatment) with near ZLD systems will be studied in the project at bench and pilot scale, treating the outlet of the industrial WWTP. Technologies train proposed to optimize reclaimed water production and minimize wastes through brine treatment is flow-reversal RO coupled to membrane distillation. This tertiary treatment is expected to increase water availability for industrial reuse in the complex.

2.1.2. Wastewater reuse in the food industry in CS4 Nafplio: filtration and small bioreactor platform

Dimitri Iossifidis from Greener than Greener presented the CS4 Nafplio concept. The activities in ULTIMATE target the recovery of various inorganic and organic contaminants from the processing water and the reuse of the purified water. In Alberta's fruit processing plant, a mobile pilot plant will demonstrate a hybrid adsorption and supercritical water extraction process to extract high added-value compounds such as antioxidants from the wastewater.
Residual wastewater will be treated in pilot-scale by an advanced oxidation process (AOP) before polishing it on-site using a small bioreactor platform (SBP). The SBP is a patented technology by BioCastel (Israel), where bacteria are encapsulated within a porous membrane of cellulose acetate. The membrane keeps the bacteria safe from other microorganisms and prevents the biomass from escaping to the environment. Dissolved pollutants in water migrate to the porous and they are metabolised by bacteria. After two months approx., the cellulose acetate membrane has been decomposed to sugar. However, some problems have been addressed, such as the control of the composition of microbial community that is needed and the amount of biomass.
This technology can be implemented to assist existing biological treatment units to cope with seasonal and unexpected shock load episodes, to increase the water treatment capacity with minimal capital expenditures (CAPEX). Hence, it is a small-scale standalone solution without the need of high costs and extensive infrastructure.

2.1.3. Water recovery in the beverage industry in CS7 Tain: AnMBR and RO

Marc Pidou from Cranfield University presented the concept of CS7 in Tain. The symbiosis is between the Glenmorangie whiskey distillery and an SME (Aquabio) which provides circular economy enabling treatment/reuse solutions.
An anaerobic membrane bioreactor (AnMBR), with ultrafiltration (UF) membrane modules to recover biomass, is already installed at the distillery for wastewater treatment, reducing the chemical oxygen demand (COD) discharged into the Dornoch Firth by 95%. In addition, the AnMBR plant also produces biogas and provides low-cost energy to heat the distilleries, decreasing the fossil fuels consumption by 15%. The sludge produced is a copper-rich fertiliser used to enrich barley fields in the region.

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Resource recovery from the AnMBR effluent will be demonstrated in pilot-scale, where ammonia will be recovered. Heat from the AnMBR effluent (35-40 °C) will be recovered and used in treatment and/or distillery processes. The reverse osmosis (RO) treatment of the AnMBR effluent will allow for water to be internally reused in cleaning processes of the distillery, reducing freshwater demand from the utility Scottish Water.

2.1.4. Fit-for-purpose water treatment systems in the biochemical industry in CS9 Kalendburg: Ultratight UF

Leo Vredenbregt from X-Flow presented the concept to produce fit-for-purpose water in Kalundborg. The Kalundborg Industrial Symbiosis exists already since 1972 and different CE approaches for water, energy and materials are already implemented. In Ultimate, options for water reuse will be investigated by treating the effluents from the industrial and municipal wastewater treatment plants (WWTP) in order to produce fit-for-purpose water for cooling and/or steam production. As the WWTP effluent contains a high fraction of non-degradable organic compounds from the biotech industry, it has a high potential for organic fouling. Thus, depending on the type of effluent, different treatment trains will be used. For the effluent from the municipal WWTP, two scenarios will be investigated: (scenario I) ultrafiltration and reverse osmosis and (scenario II) ozonation, sand filtration, ultrafiltration and reverse osmosis. The effluent from the industrial WWTP will be treated using coagulation, sand filtration, ultrafiltration and reverse osmosis as scenario III. In order to protect the reverse osmosis membrane against fouling and to reduce the demands for cleaning in place of the reverse osmosis membrane and for the coagulant, a novel ultra-tight ultrafiltration membrane will be tested. Thus, this idea is to reduce operational costs for the treatment via reducing the demand for cleaning in place treatments as well as reducing the demand for coagulants.

2.1.5. Watermining Synergies: Pilot System for Water, Salt and Energy recovery from urban wastewater

Maria Kyriazi from NTUA presented the Larnaka (Cyprus) case study. The Larnaka WWTP has been designed for 100,000-person equivalent (PE), treating an average inlet flow rate of 18,000 m^3/day. The main challenge is the high salinity of the treated water that can be disadvantageous for agricultural irrigation.

In the Water Mining project, different objectives have been proposed: to achieve a very low phosphorus concentration in the effluent, to recover phosphorus and NaCl as well as to reclaim water. To achieve these goals, different processes based on membrane technologies have been implemented in a pilot plant with a flow rate of 1 m^3/h to treat the Larnaka WWTP effluent.

The effluent from the membrane bioreactor will be treated in a pilot scale “Biophree” installation, where the remaining phosphorus is adsorbed from the permeate. This technology decreases the phosphorus concentration from 0.5 mg/L to 10-40 ppb. At

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these low levels, the biological growth is limited, so that also biofouling is reduced and the intermediate reservoirs are prevented from harmful algae growth.
The effluent of the Biophree unit enters in a nanofiltration process, where monovalent and divalent ions are separated. The concentrate is treated in a low temperature evaporator (LTE) unit to recover salts such as magnesium and calcium. The nanofiltration permeate enters a reverse osmosis (RO) process, where water with low conductivity is obtained. The reverse Osmosis concentrate is sent to a multi-effect distillation (MED) and NaCl solution is concentrated. Finally in the crystallizer, the MED effluent is concentrated until a saturated NaCl solution is obtained. The saturated solution will be used in the chlorination unit.
The MED evaporator will be coupled with solar panels and photovoltaics will be used for the energy supply for the other technologies in order to reduce the CO_2 footprint of the system.

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2.2. Water recovery: adsorption technologies

On March, 31st 2021, the Ultimate case studies Tarragona (CS1), Nafplio (CS4) and Karmiel (CS6) discussed in the workshop “Adsorption technologies” with 45 persons their concepts. In addition, the projects Smart-Plant, Sea4Value and Water Mining presented their outcomes.
After the key lessons from the discussion, the main take-home-messages of the presenters are summarised. The full presentations are shown in Annex 3.

Key lessons from the discussion:

1) Adsorption process to remove ammonium from water has been proposed as a low-cost alternative in terms of energy consumption in comparison with standard reverse osmosis.

2) Adsorption technology is very versatile in terms of inorganic and organic pollutants removal from water. However, adsorbent characteristics and properties have a great impact on the pollutant's removal selectivity and efficiency.

3) Adsorption technology is proposed not only to remove pollutants from wastewater but also to recover materials from the regeneration solutions.

4) Although adsorption is a well-known technology, current research is focused on the development of new adsorbent materials, for instance, structures printed in 3D or adsorbents produced from renewable materials.

2.2.1. Ammonium removal from wastewater in CS1 Tarragona: adsorption on zeolites

Andrea Naves Arnaldos from Eurecat presented the concept for the Tarragona case study. The water smart industrial symbiosis interlinks the Water Reclamation Plant in Camp de Tarragona, run by AITASA, and the Tarragona petrochemical complex comprising more than 30 companies.
AITASA currently provides reclaimed water mainly, as cooling water to the different local companies. This reclaimed water has to fulfil the required quality standards, for example, that the ammonium concentration has to be lower than 0.8 mg/L to avoid corrosion processes. In the current water reclamation process, ammonium is removed via the 2-passes reverse osmosis (RO) process.
Although there are different technologies to remove ammonium from wastewater, in CS1 adsorption on zeolites will be tested as a low-cost alternative to the RO process. This technology has been tested at laboratory scale, using a commercial zeolite (based on clinoptilolite), obtaining promising results in terms of ammonium adsorption capacity.

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2.2.2. Adsorption - methodologies for the extraction of value-added compounds from food-processing wastewater in CS4 Nafplio and CS6 Karmiel, Shafdan

Dimitri Iossifidis from Greener than Greener presented the CS4 Nafplio and CS6 Karmiel planned concepts.

In CS4 is focused on the Alberta fruit processing plant. For this case study, the recovery of various inorganic and organic contaminants from the processing water and the reuse of the purified water will be studied. In Alberta’s fruit processing plant, a mobile pilot plant will demonstrate a hybrid adsorption – supercritical water extraction (SCWE) process to extract high added-value compounds such as antioxidants from the wastewater. Residual wastewater will be treated in pilot-scale by an AOP before polishing in an on-site Small Bioreactor Platform (SBP) for reuse in irrigation or discharge into the municipal WWTP to reduce operational costs. The extracted compounds will be assessed for their use by Alberta making “fortified juice” with antioxidant properties increasing the value of their product, but also by selling the extract to the food supplement sector.

In CS6, at the Karmiel WWTP, Ultimate will demonstrate the treatment of agroindustrial wastewater prior to the common aerobic biological process using an immobilised high-rate anaerobic system (Agrobics AAT) in combination with pre-extraction (coupling IEX and SFE) of valuable polyphenols from Olive Mill Wastewater.

An existing demo-scale system will be upgraded to optimise sludge production and biogas recovery, coupled with IEX and SFE to extract added-value marketable polyphenols.

2.2.3. Smart-Plant: Removal of key pollutants from wastewater by adsorption: N, P and COD

Ana Soares from Cranfield University presented results of nitrogen, phosphorus and COD removal from wastewater through adsorption technology. The results were obtained treating the secondary effluent from Cranfield University wastewater treatment plant. Experiments were carried out in a 10 m^3/day pilot plant. Ammonium and phosphorus were removed using different adsorption media: zeolites (zeolite-N and clinoptilotite) for ammonium removal and hybrid anion exchange resins for phosphorus removal.

Ammonium removal by adsorption on zeolite-N (potassium based) has been studied for raw wastewaters and liquors at Cranfield University, obtaining breakthrough curves and ammonium adsorption capacities. Furthermore, regeneration cycles with potassium chloride solution were studied as well, obtaining very good results. The next step was to study how to recover the ammonium from the brines from regeneration step. Two different commercial alternatives were explored at laboratory scale: ammonia steam stripping and hollow fibre membrane contactor.

Regarding phosphorus removal, a commercial strong resin was studied a pilot plant scale, achieving great results in terms of phosphorus and organic matter removal

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(COD). This resin was regenerated with sodium hydroxide solution, and it was reused up to times. Phosphate could be recovered adding lime and obtaining calcium phosphate as precipitate.

2.2.4. SEA4VALUE: 3D-printed adsorbents for metal recovery

Eveliina Repo from Lut University of Technology (Finland) explained the 3D printed adsorbents for metal recovery, a new area under strong development.

3D printing allows to optimise the porosity and geometry of the adsorbents, where fluid channels and holes can be aligned with the fluid flow. This means a decrease of the pressure drop and less energy needed for pumping. These kinds of structures only be manufactured with a 3D-printing technology also called additive manufacturing (AM).

Adsorption is based on the interactions between the surface and species in the liquid or gas phase, limited by the number of active sites on the surface. AM offers the possibility to optimise the shape, size, and flow properties, enhancing interactions and enhancing adsorption processes.

In the Sea4Value project, adsorption/ion-exchange technologies are studied as effective and selective way to recover trace amounts of metals. Inks and printing powders will be prepared by mixing matrix materials (polymers) with selective ion-exchange resins. Printing will be conducted by Selective Laser Sintering or Direct-Ink Writing using optimised models. 3D-printed modules will be tested for selective recovery and concentration of scandium, indium, vanadium, boron, and molybdenum. Finally, adsorption/desorption cycles will be optimised.

2.2.5. Water Mining: BioPhree: Reversible phosphate adsorption for P-removal to ultra-low levels and P-recovery. Demonstrations and perspectives

Wokke Wijdeveld from Wetsus (The Netherlands) explained the BioPhree technology to remove and recover phosphorus. BioPhree is an adsorption technology that can reach ultra-low phosphorus concentrations below 10 ppb. This fact is important, for example, to avoid eutrophication and to enhance water reuse from nZLD processes, avoiding biofouling.

The BioPhree technology adsorbs phosphorus from wastewater to columns that are later on regenerated. The phosphorus is recovered from the regeneration solution by precipitation or via a further nanofiltration process.

The BioPhree technology was demonstrated in eutrophicated marsh water in Canada and treated up to 32 m^3/day of water with orthophosphate and particulate phosphorus concentrations of 0.177 mg/L and 0.220 mg/L, respectively. The installation consisted of an advanced filtration stage for the particulate phosphorus removal, followed by an iron oxide-based resin adsorbent system for orthophosphate adsorption. The adsorbent was regenerated and re-used and phosphorus was recovered from the regenerant solution as raw material for fertiliser application. The regeneration is a key

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factor which considerably decreases operational cost of adsorbent systems. The total orthophosphate and particulate phosphorus removal was 97% and 78%, respectively.

2.2.6. NextGen: Renewable granular active carbon for removal of organic micropollutants in urban wastewater

Luca Loreggian from the University of Applied Science and Arts Northwestern Switzerland talked about the production of renewable granular activated carbon (GAC) and its application to remove organic micropollutants from urban wastewater.

Laboratory and pilot plant experiments were conducted to investigate the effect of pyrolysis and activation on the GAC performance. In the NextGen process, 21 different renewable GAC samples were produced, varying the operation conditions: renewable sources (cherry pit and sewage sludge), conditions of the pyrolysis and activation temperature, activation gas and residence time. All the obtained GACs samples were characterised to define physical properties (particle size distribution, density, hardness, specific surface, and porous size distribution) and performances.

Two different renewable GAC types were tested at pilot plant scale to treat wastewater and remove micropollutants.

After five months of operation, the first results indicated the successful elimination of organic micropollutants using the GAC filter (better results with sewage sludge GAC). On the other hand, standard operating conditions do not ensure sufficient elimination as demanded by the Swiss ordinance (i.e. 80% elimination). Therefore, the operating conditions of the filters will be optimised by varying the empty bed contact time and the O_3 dosage.

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2.3. Energy recovery: biogas technologies

In the workshop "Biogas technologies" on October, 30th 2020, 26 persons participated and the case studies Lleida (CS5), Karmiel/Shafdan (CS6) and Tain (CS7) presented their concepts. In addition, we learned from the projects Smart-Plant and NextGen about their outcomes of the projects, discussed our concepts and the results of the other projects.

After the key lessons from the discussion, the main take-home-messages of the presenters are summarised. The full presentations are shown in Annex 3.

Key lessons from the discussion:

1) Anaerobic treatment processes in combination with biogas recovery allow for a decrease in the organic loading rate to the downstream activated sludge process and hence, for a better energy balance of a WWTP, because energy is recovered and energy can be saved in the aeration process due to the lower organic loading rate.

2) Methane recovery from an AnMBR effluent is an important step, because the methane loss can be very high without its recovery. This should also be considered for similar systems.

3) Technological flexibility is very important for research and demo cases in order to conduct trials which simulate a critical state of the investigated processes and which allow the project participants to follow new "crazy" ideas.

2.3.1. Biogas production in CS5 Lleida: anaerobic membrane bioreactor versus electrostimulated anaerobic reactor

Antonio Giménez Lorang from FCC Aqualia presented the planned concept in Lleida. The water smart industrial symbiosis interlinks the Mahou San Miguel (MSM) brewery with a multinational utility Aqualia as well as the local municipal utility of Lleida and the Catalan Water Agency.

The brewery has its own wastewater treatment plant. However, up to now, there is no water reclaimed and no energy recovered. In terms of energy recovery in the form of biogas, an anaerobic membrane bioreactor (AnMBR) will be operated in parallel with an electrostimulated anaerobic reactor. Both shall be compared in terms of their performance, specific energy demand, methane yield, process stability and nutrient removal capacity. The expectations are, that the AnMBR provides a higher water quality of the effluent of the reactor than the ELASR. However, the process stability and the specific energy demand of the ELSAR are expected to be better and lower compared to the AnMBR, respectively. The difference between the methane yields and

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the heat values of the biogas streams resulting from both systems is uncertain until now. Those will be investigated in this case study.

2.3.2. Biogas production in CS6 Shafdan & Karmiel: Immobilised high rate anaerobic system & biogas process stabilising measures

Isam Sabbah from The Galilee Society presented the concepts for Shafdan and Karmiel. The symbioses in Karmiel and Shafdan interconnect two SMEs from the agro-food sector with a public wastewater utility. The agro-industrial sector includes agriculture, food industry, olive oil mills and water treatment.

The agro-industrial sector causes high organic load peaks depending on the season. In Karmiel, Ultimate wants to reduce those peaks by mixing olive mill and slaughterhouse wastewater with municipal wastewater and pretreat it using an immobilised high rate anaerobic system (AAT). In Shafdan, the wastewater composition is slightly different. Wineries, dairies and olive mills discharge their wastewater to the WWTP in Shafdan, where it is jointly treated with municipal wastewater. To reduce high organic load peaks, those wastewater streams will also be mixed in a buffer tank and pretreated in an AAT. In addition to the ATT, a novel AnMBR is implemented downstream of the AAT. Here, the use of immobilised biomass in powdered activated carbon fixed foam instead of granular biomass offers a promising approach for fouling reduction which is unexplored yet within AnMBR technologies.

2.3.3. Biogas production in CS7 Tain: Biogas production in an anaerobic membrane bioreactor (AnMBR) from distillery effluent

Marc Pidou from Cranfield University presented the concept for Tain. Here, the symbiosis first interlinks the Glenmorangie whisky distillery and the SME Aquabio which provides circular economy (CE) enabling treatment and reuse solutions. In 2017, an anaerobic membrane bioreactor (AnMBR) was installed to treat the wastewater generated in the distillery during the whisky making processes and allows to discharge the treated effluent in the local estuary, the Dornoch Firth. As part of Ultimate, Aquabio and Cranfield University (partners in the project) will collaborate with the Glenmorangie distillery and Alpheus, the current operator of the treatment site, (both stakeholders but not beneficiaries) to evaluate options to expand the CE approach at the site. The AnMBR effluent provides opportunities for heat recovery, nutrient recovery and finally with further advanced treatment for water recycling within the distillery.

2.3.4. NextGen: Anaerobic treatment of weak effluents at low temperatures

Ana Soares from Cranfield University (United Kingdom) belongs to the NextGen consortium and contributes as the scientific partner to the case study “Spernal”. Since 2003, her research group focuses on anaerobic membrane bioreactors and their optimised application in wastewater treatment. The AnMBR is a hybrid unit combining

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an upflow anaerobic sludge blanket (UASB) reactor with a membrane bioreactor (MBR). Soares et al. showed that the methane yield of an AnMBR at low temperatures between 7 °C and 20 °C is 1.46 times higher than that of an UASB reactor. They highly recommend using a membrane degassing unit to recover the dissolved methane from the AnMBR effluent, since more than 90% of the total methane content are dissolved. In the frame of NextGen at the case study of Spernal, an AnMBR with a membrane degassing unit was built. In addition, an ion exchange process will be implemented to recover nitrogen and phosphorus from the effluent.
The benefits of the AnMBR are:

- no aeration energy for COD removal necessary,
- low sludge production and hence reduced downstream sludge treatment costs,
- biogas production,
- pathogen and solid free effluent that can be reused in a number of applications (e.g. farming and industrial reuse).

2.3.5. **Smart-Plant:** Biogas recovery in primary treatment with a polyfoam biofilter (AAT)

Before Ultimate, Isam Sabbah from the Galilee Society (Israel) was part of the Smart-Plant project, in which his research group evaluated and simulated biogas recovery with a polyfoam biofilter advanced anaerobic treatment (AAT). They used the AAT as a pre-treatment of municipal wastewater in Karmiel upstream to the activated sludge process to reduce the organic loading rate to the aerated tanks and thus, to save operational costs for the aeration process. In the AAT, the microorganisms grow in a “bio-stabilised” polyurethane-based matrix. This matrix has a large surface area to enable biofilm formation. This structure protects the microorganisms against wash out and contributes to a stable process operation.
The system can be applied either after the primary clarifier or directly without a primary clarifier. The microorganisms adapt well to the corresponding conditions. A model of the AAT was set up that can be further used to design similar processes and to allow for process optimisation under varying process conditions.

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2.4. Energy recovery: heat recovery

On February, 26th 2021 in the workshop "Heat recovery", 36 persons participated and the case studies Nieuw-Prinsenland (CS2), Tain (CS7) and the Chemical platform of Roussillon (CS8) presented their concepts. In addition, we learned from the projects NextGen and BioKS about their outcomes of the projects, discussed our concepts and the results of the other projects.

After the key lessons from the discussion, the main take-home-messages of the presenters are summarised. The full presentations are shown in Annex 4.

Key lessons from the discussion:

Low-grade heat recovery
1) The reuse of excess heat in the ammonia air stripping process to increase the process temperature shifts the equilibrium between ammonium and ammonia to the ammonia side and thus, can contribute to save chemicals for an otherwise required increase in pH to reach the same ammonia recovery rate.

2) The reuse of excess heat to increase the temperature of the feed stream of a reverse osmosis filtration unit can lead to a higher flux, because the higher temperature decreases the dynamic viscosity of the feed stream. Thus, the energy efficiency of the filtration process can be increased. However, the higher temperatures could also lead to a higher organic fouling rate, since microbial activities increase with temperature.

→ CS7 will consider to install a flexible system in order to investigate different options

High temperature - aquifer thermal energy storage (HT-ATES)
3) HT-ATES: The bigger the storage is and the better the layer to the upper subsurface isolates, the higher the heat or cold recovery efficiencies are.

4) HT-ATES: A temperature shift in the ATES from 15-18 °C to 25°C-40 °C did not show a severe effect on the geohydrological environment. However, at higher temperatures heavy metals were released. As soon as the temperature decreased the heavy metals precipitated again. The temperature increase was suitable to compensate the imbalance of a higher heat demand in winter compared to the cooling demand in summer.

5) HT-ATES: Sulphur oxidising bacteria clearly indicate an oxygen ingress to a borehole after geothermal plant downtimes. Periodic heat shocks are a promising procedure to reduce biofilms and thus, to diminish corrosion processes.

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2.4.1. CS7 Tain: Heat recovery from anaerobic membrane bioreactor effluent

The concept for heat recovery for the case study in Tain was presented by Marc Pidou from Cranfield University. In Tain, the wastewater from the Glenmorangie whisky distillery is treated in an anaerobic membrane bioreactor (AnMBR). The company Aquabio and Cranfield University want to expand the circular economy approach together with the Glenmorangie distillery and Alpheus, the current operator of the treatment site. One part of this approach is the recovery of heat from the AnMBR effluent and to reuse it at the site. Different scenarios are investigated in terms of their feasibility. One scenario involves the heat utilisation for the ammonia stripping process. The higher the temperature of the fluid is, the higher the shift of the equilibrium between ammonium and ammonia towards the ammonia side is. Thus, a higher temperature is beneficial for the stripping process. On the other hand, the heat could also be beneficial for the reverse osmosis filtration process at the end of the treatment train for the new water reuse concept. The higher the temperature of the feed water is, the lower its viscosity becomes, which increases the flux through the membrane. Hence, the feasibility of both concepts need to be assessed in order to choose the most beneficial scenario.

2.4.2. CS8 Chemical platform of Roussillon: Recovery of heat from flue gas washing water

Anne Reguer from Sues RR IWS Chemicals presented the concept for the heat recovery feasibility study at the chemical platform of Roussillon. On this platform, Sues RR IWS Chemicals operates two hazardous waste incinerators. Each incineration line has one furnace with quenching to cool the flue gas. The gaseous effluents from incineration are washed to eliminate gases and dust in order to comply with current discharge standards. The washing water is sent to a physical-chemical WWTP. The first unit of the physical-chemical WWTP allows the cooling of the wastewater through a set of heat exchangers to reduce the temperature from 87 °C to 30°C. Until now, the removed heat from this wastewater is entirely lost. Therefore, a feasibility study shall analyse the potential to recover this thermal energy and to produce electricity and/or vapor on-site from the hot washing water for a local use. The pH is around 5 and the water contains high salt concentrations.

2.4.3. CS2 Nieuw-Prinsenland: High temperature aquifer thermal energy solution in greenhouses

The concept for heat storage and reuse related to the case study in Nieuw-Prinsenland was presented by Marette Zwamborn from KWR. In Nieuw-Prinsenland is known for its agro-food industry and its greenhouses. Especially during winter periods, the demand for heat in greenhouses is high, while in summer usually excess heat occurs. To tackle this challenge in a sustainable way, a high temperature aquifer thermal energy storage (HT-ATES) is a possible solution to store the excess heat in summer

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in the subsurface and to recover it in winter. Ultimate aims to develop and demonstrate a cost-effective method to identify and characterise suitable aquifers for HT-ATES. Therefore, the drilling of a geothermal well in the Westland area is combined with data logging in order to screen for potential HT-ATES aquifers. In that way, geohydrological data are gained without the need of a separate test drilling.

2.4.4. **NextGen:** Aquifer thermal energy system at the greenhouse of Koppert-Cress

Martin Bloemendal from the Technical University Delft and KWR (The Netherlands) presented the outcomes of the project NextGen. The Westland region in the Netherlands is known for its greenhouses and horticulture. A greenhouse belonging to the Koppert-Cress company, is heated in winter via the recovered heat from an aquifer thermal energy system (ATES). In summer, the excess heat is stored in the subsurface. However, the heat demand in summer is higher than the cooling demand in summer. Hence, the system is not in balance. One option to mitigate this imbalance is to add extra heat and thus, to increase its temperature. Therefore, in NextGen, the ATES was used as a pilot project to investigate the impact of a temperature increase from the original range between 15 °C and 18 °C to an increased range between 25°C and 40°C. The temperature shift did not show a severe effect on the geohydrological environment. However, at higher temperatures heavy metals were released, but as soon as the temperature decreased, the heavy metals precipitated again. Hence, an imbalanced system can be efficiently compensated with external heat.

2.4.5. **BioKS:** How to avoid corrosion and scaling in aquifer thermal energy systems in Germany?

Hilke Würdemann from the Merseburg University of Applied Sciences (Germany) presented results from the German research project BioKS. In Neubrandenburg, an ATES delivers heat in winter for district heating and in summer, excess heat from a power plant is stored. The temperature of the cold well and of the warm well are around 47 °C and 75 °C, respectively. The cold well is highly affected by microbial induced corrosion due to the activity of sulphate reducing and sulphur oxidising bacteria. The growth of sulphur oxidising bacteria (SOB) indicated oxygen ingress to the borehole during downtime phases of the geothermal plant (Westphal et al. 2016). The fast decline of the SOBs after the restart of the plant indicated the exclusive affection of the well. Corrosion experiments in a bypass system onsite, revealed periodic heat shocks as a promising procedure to reduce biofilms and thus, to diminish corrosion processes (Kleyböcker et al. 2017).

In the Molasse Basin, the risk of scaling in geothermal plants is quite high. Therefore, a scaling inhibitor was tested in situ after successful laboratory tests. The permit to apply such an inhibitor in an open geothermal system depends on its biodegradability and thus, on its environmental impacts. In situ investigations showed that fermentative

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bacteria dominated the microbial community and their abundance increased after heat extraction suggesting the anaerobic biodegradation of the inhibitor (Otten et al. 2021).

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2.5. Nutrient recovery

During the workshop "Nutrient recovery" on December, 17th 2020, the concepts of the research activities related to the case studies Nieuw Prinsenland (CS2) and Tain (CS7) were presented to 30 participants. In addition, outcomes and lessons learned from other projects, such as Smart-Plant, NextGen and Run4Life, were discussed and debated.

After the key lessons from the discussion, the main take-home-messages of the presenters are summarised. The full presentations are shown in Annex 5.

Key lessons from the discussion:

1) Different innovative technologies for the recovery of nutrients have been successfully implemented and applied for wastewater, sludge and kitchen waste:
- advanced biodrying and composting,
- bioelectrochemical systems and
- ultra-low flush toilet coupled with (hyper-)thermophilic anaerobic digestion.

2) Within ULTIMATE different technologies are under investigation to recover nutrients from greenhouses and distillery wastewater.

3) Nutrient recovery is possible in different forms: struvite, ammonium sulphate, phosphorus as $CaPO_4$ compounds, biofertilisers, phosphoric acid and solid NPK fertilizer.

4) Main barriers identified for nutrient recovery are related with regulations, social acceptance of the products and market competition.

2.5.1. Nutrient recovery in CS2: KWR expertise in Nutrient recovery and conceptual presentation of Nutrient recovery in CS2

The presentation by KWR team was divided in two parts. First Tavishi Guleria presented the ULTIMATE case study 2, Nieuw Prinsenland in the Netherlands. The CS aims at making the cultivation practices in greenhouses more sustainable through the treatment of the produced wastewater. The specific goals are to reuse the wastewater and to recover nutrients, which are currently discharged to the sewer system. In particular, the effects of nutrient composition in the reused water on plant growth and health (e.g. Na/K ratio) will be investigated in a demo-greenhouse with the aim to reach the optimum nutrient balance and prevent the accumulation of specific minerals (B, Cu, etc.). Finally, an economic analysis of potential cost savings by using

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recovered nutrients will be performed. In the second part of the presentation, Nienke Koeman-Stein presented some successful examples of nutrient recovery projects of KWR. These projects, carried out in cooperation with Aqua Minerals, succeeded in reusing calcite obtained from the drinking water production. Particularly, calcite was proposed as a key ingredient in face scrubs. Other reused materials were ferric (hydr)oxide pellets for the removal of sulphur from (bio)gas, phosphorus from (surface) water and arsenic from (ground)water. Moreover, in the CoRe (Concentration, Recovery & Reuse) process, a liquid fertiliser was recovered from wastewater after anaerobic digestion of the concentrated residue from a combination of forward osmosis and reverse osmosis treatment.

2.5.2. **Nutrient recovery in CS7 Tain:** Recovery of ammonia from distillery wastewater by IEX/packed columns after AnMBR

Mark Pidou from Cranfield University presented the nutrient recovery concept in Tain. Particularly, in the current situation the wastewater produced by the Glenmorangie whisky distillery is treated via AnMBR, which produces an effluent with very high ammonium and phosphate concentrations. The investigation of different nutrient recovery technologies will be done in order to identify the most cost-effective option that will be integrated in the demonstration system to be tested at the distillery.
Three alternatives are currently being analysed:

- Stripping columns: established technology, but very energy intensive and with a large footprint
- Precipitation as a pretreatment for the ammonia stripping unit: through pH adjustment and addition of magnesium, struvite can be precipitated.
- Ion exchange: the technology is characterised by a small CO2 footprint, but tests are needed to understand if the adsorption capacity is sufficient at high concentrations.

Laboratory experiments will be performed to investigate the impact of the ammonium concentration on the efficiency of the proposed recovery technologies. The aim is to identify the best technology and its optimal operational conditions to maximize ammonia recovery from distillery wastewater.

2.5.3. **Smart-Plant:** bio-based fertilizer recovery from wastewater and sewage sludge

Sergio Ponsá is the leader of the BETA Technology Centre. His research group is involved in different projects where nutrient recovery is investigated. Within the Smart-Plant project, nutrients were recovered in different forms (struvite, ammonia and phosphorus as $CaPO_4$ compounds, tailor-made biofertilisers), BETA developed an advanced biodrying and composting process to recover both energy and nutrients contained in sludge. The quality of bio-based fertilisers was analysed through agronomic tests in terms of their emerging pollutant contents and heavy metals concentrations. Barriers and opportunities for the recovered materials were discussed:

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- Barriers: regulatory difficulties related to the exclusion of sewage sludge as input material for the production of fertilisers according to the European regulation as well as in regard to the market competition.
- Opportunities: decentralised production (near of the end-users), WWTP turning into biorefineries, job opportunities for the production of tailor-made fertilisers (reducing heterogeneity, improving delivery, etc.)

Finally, the comparison of the SMART-Plant biofertilisers to traditional fertilizing products revealed a higher content of nutrients, a lower energy demand for their production and a higher costs.

2.5.4. **Nextgen:** Full-scale nutrient recovery via struvite and ammonium sulfate production at a municipal wastewater treatment plant

Jonas Schneider from Abwasserverband Braunschweig (Germany), partner of the NextGen project, talked about their new full-scale nutrient recovery plant. Within the project, nutrient recovery is achieved at the WWTP in Braunschweig that includes units for struvite precipitation and ammonium sulphate production. In the case of struvite precipitation, the first results showed a very low recovery rate with small crystal size. The main challenges relate to the long time necessary for increasing particle size and the need for a very low concentration of TSS in the process. On the other hand, the ammonium sulphate unit allowed to reach ammonia recovery rates even higher than required. As a follow up of these observations, for struvite precipitation an improvement of the process aiming at increasing grain size and reaching high phosphorus recovery rates will be evaluated by changing the hydrocyclone geometry, using different $MgCl_2$ dosages and varying the hydraulic retention time in the precipitation reactor. On the other hand, for the ammonium sulphate production variations in temperature and NaOH addition will be tested to maintain a high ammonia recovery rate, while reducing the energy and/or NaOH consumption.

2.5.5. **Run4Life:** current results and exploitation pathways

Nicolás Morales Pereira from Aqualia (Spain) is the Run4Life project manager and gave a presentation about current results and exploitation pathways of the project. The main concept of Run4Life is the source-separated sanitation and resource recovery from wastewater and kitchen waste. The concept is applied at four demo sites. Different technologies such as an upflow anaerobic sludge blanket (UASB) reactor, an AnMBR and a (hyper-)thermophilic anaerobic digestion (HTAD) reactor are applied to treat kitchen waste and/or black water recovering nutrients in the form of struvite (a phosphate fertiliser), phosphoric acid (a phosphate fertiliser) ammonium sulphate (a nitrogen fertiliser) and solid NPK fertiliser. Social aspects and involvement of citizens and farmers was a crucial aspect to evaluate the acceptance of the fertilizers. In Lemmerweg case study an ultra-low flush toilet was developed obtaining highly concentrated backwater to be treated via HTAD. Using this technology, it is possible to obtain biogas production, hygienisation and two main fertiliser streams. Finally, at

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the Porto do Molle demo site, up to 61% of initial N have been recovered with bioelectrochemical systems.

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2.6. Material recovery and reuse

During the workshop "Material recovery and reuse" on June, 23rd 2021, the concepts of the research activities related to the case studies in Israel (CS6), Greece (CS4) and Italy (CS3) were presented to around 20 participants. In addition, outcomes and lessons learned from previous projects, including Smart-Plant, Routes, Res-Urbis, Water2REturn and Sludge4.0 were discussed and debated.

After the key lessons from the discussion, the main take-home-messages of the presenters are summarised. The full presentations are shown in Annex 6.

Key lessons from the discussion:

1) Recovery of value-added compounds can bring multiple advantages: removing of components which are harmful for a specific treatment, obtaining marketable products, allowing for the reuse of a residual/out of specification material.

2) Recovery of value-added compounds usually require the implementation of different treatment steps to be implemented in existing plants.

3) Both laboratory and pilot tests are a key step for the implementation of a value-added compound recovery process.

4) The quality of the final product is fundamental for the market accessibility; specific treatment steps are usually necessary to reach an adequate quality.

5) Legislation is fundamental for the recognition of a recovered material as product if it is generated by a waste (end-of-waste).

2.6.1. Material recovery in CS4 & CS6: Recovery of antioxidants and polyphenols from fruit processing and olive mill wastewater

Dimitris Iossifidis from GTG is involved in the research activities related to CS6 and CS4, leading the research tasks on material recovery. In CS4, located in Nafplio, the objective is to treat wastewater produced by the fruit processing industry to isolate useful/value-added compounds such as polyphenols, flavonoids and anthocynins. The treatment system is composed of coagulation/sedimentation steps to precipitate suspended solids, an extraction process to recover value added compounds, advanced oxidation and a biological treatment. Value added compounds are selectively adsorbed on a solid phase such as resins followed by an extraction with suitable solvents. Subcritical water extraction will be applied as a non-hazardous method with high efficiency and low costs. Polyphenols will be recovered, which are

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found in fruit and vegetables with significant biological activity and/or health promoting properties and that have a high market value. Static and dynamic adsorption experiments have been carried out to determine the optimal condition for polyphenols adsorption, resulting in a 60-95% removal. In terms of recovery, the best results were achieved using MeOH-H2O as solvent. In CS6, located in Israel, the objective is the recovery of polyphenols from olive oil mill wastewater. In this case the removal of polyphenolic compounds is also necessary to avoid the inhibition of anaerobic digestion that may lead to a reduction in biogas yield. Polyphenols from olives and grapes have a market value ranging from 1620 €/g to 7240 €/g. A similar treatment system to that employed in CS4 will be also utilised in CS6: polyphenols in olive mill wastewater will be adsorbed on resins using hot water and methanol as solvent.

2.6.2. **Material recovery in CS3:** Use of by-products of local industries for wastewater treatment in Rosignano

Francesco Fatone from UNIVPM and Francesco Rossi from CPTM presented CS3 in Italy. The case study concerns the Aretusa WWTP which is a tertiary plant aiming at refining the quality of the effluent water from the municipal WWTP of Cecina and Rosignano to make it usable for the cooling towers of Solvay industry. To allow industrial reuse, specific quality limits must be met, which is challenging in terms of salinity and chemical oxygen demand (COD). Therefore, the reuse of by-products from the industrial area, will be tested to increase the quality of the final water. In particular:

- The possibility to reuse chemical (i.e., alum/ferric) sludge from coagulation/flocculation in the WWRP will be analysed and potential users will be identified via the Alu Circles Initiative.
- A pilot scale adsorption system will be tested with alternative sludge-biowaste-originated GAC. The monitoring system will include sensors for the measurement of conductivity, pH and UV and fluorescence, which are surrogate parameters for the determination of the COD.
- Mineral by-products will be used as alternative coagulants and/or adsorbents.

Several industrial by-products have been tested in the laboratory. Adsorption tests showed that organoclay has a much lower adsorption capacity compared to an activated hydrochar for the removal of organic matter and target micro-contaminants (i.e. diclofenac). Softening tests with granulated limestone and “Soda Solvay” showed a very good hardness removal in the tested wastewater with reductions ranging between 46% and 87%.

2.6.3. **SLUDGE 4.0:** Thermochemical treatment and down-stream strategies for materials recovery from sewage sludge

Riccardo Gori from UNIFI (Italy), a partner of the Sludge4.0 consortium, talked about material recovery from sewage sludge. The project investigated the benefits obtainable from the products of hydrothermal carbonisation (HTC) of sludge, namely hydrochar

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and process water, with a focus on the optimisation of the process cycle, and on the social, economic and environmental sustainability of the technology.
HTC is a non-oxidative thermochemical treatment conducted at medium-high temperatures (180-250 °C) and developed to process organic materials. In the project SLUDGE 4.0, HTC has been applied to primary, secondary and digested sludge allowing for the production and recovery of hydrochar and process water rich in nutrients that can be used for fertigation.
The produced hydrochar is a carbonaceous solid classifiable as lignite, which can be reused as a fuel product, soil improver or adsorbent after an activation procedure. The process water is the result of the mechanical separation that is carried out downstream of the HTC reaction. In this liquid fraction, numerous inorganic and organic compounds of great interest for agriculture. They are dissolved and can be recovered through water treatment and concentration technologies.

2.6.4. **Smart-Plant:** Cellulose recovery from municipal wastewater and safe reuse

Marit van Veen, from CirTec (The Netherlands), presented the cellulose recovery from sewage and the work performed as partner in the H2020 Smart-Plant project. Dynamic rotating belts with fine screen have been used as pre-treatment in wastewater treatment plants, obtaining cellulosic material as recovered product. The process has different advantages for the wastewater treatment plant, including the reduction of energy requirement (15-20%), lower production of sludge (20%), lower use of chemicals (20%) and reduction of maintenance cost. However, the recovered products are not saleable, because they contain too many pollutants and impurities. The “Cellvation plant” was developed as a treatment unit including the following steps: grit removal, cellulose washer, rotating belt fine screen, screw press, thermal dryer, and finally hammer mill or pelletiser (https://www.cell-vation.com/cellvation-process). The material produced, called Recell, can be obtained in the form of cellulose fluff or as pellet. Recell-based products as asphalt additives, biocomposite, insulation boards and building blocks have been produced and already been applied in real environments.

2.6.5. **Water2REturn:** Microalgal biomass recovery and reuse

Robert Reinhardt from AlgEn (Slovenia) talked about resource recovery with algae in the frame of the Water2REturn project. The project aims to solve slaughterhouse wastewater management problems by recovering and recycling nutrients turned into value added products for the agro-chemical industry. In this process, wastewater from the slaughterhouse is treated in a sequencing batch reactor (SBR). Then, a filtration process including microfiltration, ultrafiltration and reverse osmosis allows the recovery of a concentrate rich in nitrate and phosphate and useful to produce an organic fertiliser. The sludge resulting from the wastewater treatment process is firstly sanitised and then, enters a bioreactor where it is fermented with *Bacillus sp.*. From the

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hydrolysed sludge, a biostimulant is produced. In the energy line, the hydrolysed sludge is treated through anaerobic digestion to produce biogas and subsequently methane and CO_2. The latter is captured in the final algae line, where the AlgaBioGas technology is used to recover an algal biomass, which is used to produce a second biostimulant. Preliminary sprouting tests and pot tests have already been performed and agricultural field tests are ongoing. Up to now, results showed that biostimulants seem to be effective.

2.6.6. Routes, Smart-Plant, Res-Urbis: Polyhydroxyalkanoate recovery from sewage sludge and foodwaste

Mauro Majone from the Sapienza University of Rome (Italy) spoke about his experience in polyhydroxyalkanoates (PHA) recovery in the framework of three EU projects: the project Routes and the two H2020 projects Smart-Plant and Res-Urbis. PHA is a family of copolymers constituents of several bioplastics, with a wide portfolio of applications. PHA are produced from renewable feedstock through biological processes and are easily and “truly” biodegradable. In addition, they have a high market potential. Treatment steps to recover PHA from urban bio-wastes are largely validated at lab-scale, but a pilot scale experimentation is essential to supply technical-economic data and to identify the best management procedures for optimising the process. In Routes, PHA were recovered from municipal wastewater through a pilot system that included the processes of fermentation, biomass production, polymer production and polymer recovery. In Smart-Plant, PHA were recovered from sewage sludge through the SHEPPAR unit in SMARTech 5 (https://www.smart-plant.eu/index.php/technical-factsheets). The recovery process includes fermentation, aerobic/anoxi feast/famine SBRs, a nitritation SBR and a batch reactor for PHA accumulation. A recovery rate of 0.7-0.8 kg PHA/d was achieved through the pilot plant, with a recovery projection of 1-1.2 kg PHA per population equivalent for a full-scale process. In Res Urbis, PHA were recovered from urban organic waste through acidogenic fermentation, solid/liquid separation, an aerobic SBR for biomass production and an aerobic batch reactor for polymer production. Finally, through an extraction/purification process, bioplastics were recovered from the polymer-rich biomass. The PHA content of contaminants is generally low. Preliminary results showed that waste based PHAs slightly exceed the limits for heavy metals set by the EU Regulation (EU 2011/10) on recovered plastic materials that can be in contact with food. On the other hand, the PHA samples complied with the EU limits for the safety of toys and plastic materials that can be in contact with refrigerated or frozen food.

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2.7. Digitalisation

In the workshop "Digitalisation" on May, 20th 2021, 56 persons participated and the case studies Rosignano (CS3), Lleida (CS5) and Kalundborg (CS9) presented their concepts. In addition, we learned from the projects Digital Water City and Fiware4Water about their outcomes of the projects, discussed our concepts and the results of the other projects.

After the key lessons from the discussion, the main take-home-messages of the presenters are summarised. The full presentations are shown in Annex 7.

Key lessons from the discussion:

1) A model can be only as good as the quality of its used data is. Thus, reliable sensors and regular maintenance of those are mandatory. Hence, data validation and reconciliation as well as its quality control are crucial.

2) Developments of digital solutions based on Fiware architecture allow for a better compatibility and open access.

2.7.1. CS3 Rosignano: Development of an early warning system for saltwater intrusion in the sewer system

Cecilia Bruni from the Marche Polytechnic University and Simone Neri from West presented the setup and first results related to an early warning system for saltwater intrusion in the sewer system. In Rosignano, the Aretusa consortium produces fit-for-purpose water from the secondary effluents of two municipal wastewater treatment plants (WWTPs). The sewer systems leading to both WWTPs are affected by currently unpredictable seawater intrusions which increase the chloride concentrations of the wastewater to unacceptable levels.
A real-time data driven monitoring and process control system for seawater intrusion and infiltration in the subcatchment and sewers sub-system is setup to avoid salinity peaks in the influent to the wastewater reclamation plant (WWRP). Therefore, flow splitting and equalisation of the secondary WWTP effluents is tested and a model-based approach with hydrometeorological forecasts combined with hydrogeological data will be used to predict saltwater intrusions and impacts from sea spray. To allow for water reuse during periods of very high salinity, the potential for others water uses outside of Solvay will be screened regarding the highest admissible chloride content. These potential uses will be integrated in a data-driven matchmaking platform for water reuse.

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2.7.2. CS5 Lleida: Development and implementation of an early warning system for membrane fouling

Concept to implement an early warning system for membrane fouling was presented by Antonio Giménez Lorang from FCC Aqualia. In order to close the water loop at the case study in Lleida, the wastewater from the brewery will be treated anaerobic membrane bioreactor (AnMBR). The AnMBR effluent will be post-treated via ultrafiltration, reverse osmosis, advanced oxidation processes and UV disinfection in order to reuse the treated water for cooling towers.

For the optimisation of the AnMBR operation, a new method for online monitoring of membrane fouling will be tested. It will be implemented in the programmable logic controller (PLC) and allow for the maximisation of the reactor performance and the minimisation of chemical consumption for cleaning purposes.

2.7.3. CS9 Kalundborg: Development of a joint control system for an industrial and a municipal wastewater treatment plant

Anne Kleyböcker from Competence Center for Water Berlin (KWB) and Line Rodenkam Melchiorsen from Kalundborg Utility (KCR) presented the concept for the case study in Kalundborg. Here, an industrial wastewater treatment plant (WWTP) pre-treats the wastewater from the biotech and pharma industry. The effluent from the industrial plant is then together with the municipal wastewater treated in the municipal WWTP. Ultimate focuses on the optimisation of both WWTPs aiming to develop and implement a joint control system for both plants. Through digitalization, the joint operation of the two WWTPs shall increase the energy efficiency of their treatment processes as well as their environmental efficiency. As a first step, a digital twin is currently developed in order to test the joint control system prior to its real implementation.

2.7.4. Digital-water.city: Early warning system for bathing water quality and water reuse

The project digital-water.city was presented by Nicolas Caradot from the Competence Center for Water Berlin (Germany). The project aims to develop and demonstrate 15 advanced digital solutions to address water-related challenges in five cities Copenhagen, Berlin, Paris, Milan and Sofia. In Paris, an early warning system is used to forecast bathing water quality and to improve the bathing water management in the river Seine for 2024. It is based on real-time measurements of bacterial contamination and composed of a statistical and deterministic model of the rivers in Paris. In Milan, an early warning system is developed to prevent microbial and toxic contamination in order to provide water for safe reuse in agriculture.

2.7.5. Fiware4Water: Intelligent control for a wastewater treatment plant

Alex van der Helm from Waternet and Siddharth Seshan from KWR and TU Delft (The Netherlands) presented results from the project Fiware4Water. At four case studies in Athens, Cannes, Great Torrington and Amsterdam, smart solutions are developed and

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applied for the water sector. For the WWTP Amsterdam West, an intelligent control system has been created. It is based on online measurements of nitrous oxide emissions in the off-gas of the aeration tanks with the objective to reduce those emissions and to reduce the energy consumption of the aeration process via a data-driven artificial intelligence (AI) control. Therefore, an AI digital twin was developed to predict the aeration process behaviour. The digital twin, together with an AI influent prediction, are used to train the control model by reinforcement learning. Because a model is only as good as the quality of its used data, a high emphasis was put on the automatic real-time validation and reconciliation of data and its quality control. As a result, an AI-based data validation application was developed to screen key operational parameters and perform data reconciliation. Furthermore, Fiware was integrated in the legacy system of the WWTP, where real-time Fiware4Water smart applications are run.

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2.8. Secret of successful symbioses

On March, 23rd 2022, the workshop “Secret of successful symbioses” was conducted in cooperation with the “stakeholder engagement” work package 3. Around 50 persons participated and the case studies Tarragona (CS1), Rosignano (CS3) and Kalundborg (CS9) presented their symbioses and the reasons for their resilience and success. In addition, we learned from the multi-utility company IRES and from the project AquaSPICE about their strategies to foster successful industrial symbioses.

After the key lessons from the discussion, the main take-home-messages of the presenters are summarised. The full presentations are shown in Annex 8.

Key lessons from the discussion:

The most important factors to create and maintain a successful symbiosis were identified to be:

1) **Commitment and willingness to act together in order to “make it happen”**
To create the willingness among the stakeholders, the key factors are
- the common need to reach a goal such as the reduction of the water footprint,
- success stories and sharing this and
- a charismatic person that serves an initiator. Creating a feeling of success motivates people to be part of this movement. The initiator can be neutral, but also needs to understand the conditions and to know the key persons which are crucial to “make it happen”.

2) **Communication and engagement with partners and stakeholders**
An open communication is crucial to build trust among the partners and stakeholders. In addition, an evidence and data driven communication successfully convinced people and contributed significantly to gain their trust. Thus, sharing of and access to data, information and experiences is highly recommended in order to establish and maintain a resilient symbiosis.

2.8.1. CS1: Success of the Tarragona Symbiosis and strategy of the Water-Smart Industry Vision Leadership

Miquel Rovira Boixaderas from Eurecat explained the strategy and success of the Tarragona Symbiosis. Tarragona is close located to the UNESCO Biospere Reserve Network named Ebre River Delta. Tarragona receives water from the Ebre River, before it is entering the Ebre Delta through a water transfer. Hence, Tarragona depends on its water resources and suffers seasonally from water stress with water

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shortages. The industrial and petrochemical complex Camp de Tarragona hosts more than 100 companies. In order to cope with the water stress, the Tarragona symbiosis has implemented an advanced water reclamation plant that reclaims secondary effluent from two nearby WWTPs. The reclamation plant is operated by industrially owned water utility AITASA and provides water for cooling towers and boilers. Lessons learned from the industrial symbiosis between AITASA and the industry are

- Social awareness regarding water, climate change and the Ebre River Delta is important and increasing.
- Involvement of citizenship is crucial.
- Demonstration of the technologies is important to convince people of its suitability.
- Climate change adaptation of the industrial activities and the protection of the ecosystem are important drivers.
- The cooperation in private public partnership is a successful way.

2.8.2. CS3: The ARETUSA symbiosis for local and regional water-smart sustainability

Gianluca Pettinello from Solvay and Lorenzo Bagnoni from ARETUSA presented the secret of success from the perspective of the ARETUSA symbiosis. They revealed that a common target of the industry, public authorities, universities and local stakeholders us a significant factor for the success. In the case of ARETUSA, the common need occurred to recycle and reuse water for the industry due to water scarcity. In order to reduce its water footprint, the ARETUSA symbiosis committed itself to foster water reuse strategies, to optimize the processes in its water reclamation plant, to enhance their solutions via digitalization, to identify potential replication possibilities of its circular economy systems and thus, to enhance the circular integrated water management in the area. Hereby, crucial factors are the open communication between the parties, the suitable scientific approach to solve the environmental challenge and the willingness of all parties to “make it happen”. Hereby, important key factors are a continuous dialogue between the parties, the removal of prejudices, to listen to each other, to talk the “same language” as well as to invest adequate resources and to create competences to reach the common target.

2.8.3. CS9: Kalundborg Symbiosis and the secret behind a resilient partnership

Lisbeth Randers, the head of secretariat of the famous Kalundborg Industrial Symbiosis, explained its history and strategy to maintain a resilient partnership. The cooperation among the partners in Kalundborg started already 50 years ago. Today, thirteen public and private companies profit from circular economy solutions for water, energy and materials. A life cycle assessment revealed that last year 586,000 t CO_2 were saved, 4 million m³ of groundwater were substituted by surface water and 62,000

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tons of residual materials were recycled. The drivers behind this resilient partnership are:

- Hard work to create trustful relations that take time to build and are achieved through continuous cooperation between the partners
- Recognition of challenges for instance to access water and consider it as a mutual challenge to be solved together
- Flexibility to adapt business models with changing times/circumstances
- Boost of innovations with the aim to implement them at full-scale
- Establishment of a social economy and awareness of social responsibility of the industrial cluster and the municipality: joint projects with social entrepreneurs
- Overview and clear priorities through data: you cannot fix everything at the same time, so you need to have a prioritized action plan

2.8.4. IREN: Strategy and role of multi-utilities to deliver territorial symbioses and circular economy

Enrico Pochettino is the head of innovation from IREN, a multi-utility company in Italy. He presented the strategy to establish territorial symbioses with multi-circle economy concepts. IREN is a large multi-utility managing water, energy, waste services in regions or so called territories. Multi-utilities serve as the initiator of the sustainable transition in the territories via linking urban services and industrial needs. Establishing local committees enables dialogues with stakeholders and participatory planning of actions in order to gather project proposals from local communities, to promote solutions for improving the environmental and social impact for the territory and to improve the quality of the services provided by the IREN group. One example is the I.BLU Industrial Symbiosis in waste management that develops new circular raw materials such as blu-polymer and bluair. Blu-polymer is an additive for high performance asphalts and bluair is a secondary reducing agent to be applied in blast furnaces and electric arc furnaces as process optimizer. Other examples are the treatment of wastewater for its agricultural reuse at the WWTP in Mancasale and the heat recovery in Turin from CHP power plants and a waste-to-energy plant for district heating via the largest district heating network in Italy.

2.8.5. AquaSPICE: Capitalising the experience of others to achieve a successful symbiosis

Asthanasios Angelis-Dimakis from the Huddersfield University summarized the experience from other projects to achieve successful water symbioses. AquaSPICE aims to reduce water demands, to implement and foster water recycling and to exploit alternative water sources for European process industries. It raises awareness in resources efficiency and delivers solutions for industrial applications via circular, process and digital innovations. The key success factor is based on the symbiotic cooperation between the industries and the water sector. Therefore, AquaSPICE analysed the aspects for success of industrial symbioses in different projects. Those

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were: industrial awareness of the benefit of such a symbiosis as well as the acceptability of the recovered product and the demand for it. A query showed that industrial awareness exists already, but the instruments to implement such a symbiosis are missing. Product acceptability is also affected by the public knowledge and its willingness to support such schemes. Here, communication, dissemination, training and social awareness are still needed.

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3. Summary and conclusion

In the frame of the project Ultimate, eight workshops were conducted by the cross-cutting technology group leaders for water recycling, material recovery and energy recovery as well as in cooperation with the “stakeholder engagement” work package. In these workshops, the concepts of the case studies were discussed at an early stage of the project together with experts from other Horizon2020 projects such as NextGen, Smart-Plant, Run4life, Sea4value, Digital-water.city, Fiware4water, Water2Return and Aquaspice. In addition, the partners from our sister projects B-WaterSmart, Water Mining, Rewaise and Wider Uptake had been invited to share their opinion with us and to identify possible synergies for cooperation.

In general, we learned that we should plan our Ultimate solutions with a technological flexibility in order to conduct trials which simulate a critical state of the investigated processes and which allow the project participants to follow new “crazy” ideas.
In terms of the WSIS, we identified the most important success factor to be the commitment and willingness to act together in order to “make it happen”. Therefore, a common goal is necessary, success stories as motivation to act together and a charismatic person serving as an initiator to spread and start ideas among the partners. Another important success factor is an open and evidence-based communication to convince people and to gain their trust. Based on this, we conclude that this is also true for a project consortium involving multiple WSISs. Hence, the continuation of our workshops, which focus mainly on the development and optimisation of our technologies, is seen as a crucial step towards the successful project execution to inform and involve all project partners even those, who are not directly involved case study specific tasks. Furthermore, the technology evidence base (Kleyböcker et al. 2021a; https://mp.uwmh.eu/teb/) will contribute to an open and evidence-based communication about the outcomes of our project and spread the successful circular economy solutions in Europe.

Our technological workshops were mainly dedicated to three topics: water reclamation, energy recovery and material recovery. The water reclamation meetings revealed interesting insights about membrane and adsorption technologies and showed, that there is still a demand for research in terms of the development of new membrane materials, the optimisation of membrane properties and their configurations. Regarding adsorption technologies, we learned that they can be more energy efficient than a standard reverse osmosis. In general, the adsorption technology is very versatile in terms of inorganic and organic pollutants removal from water. However, adsorbent characteristics and properties have a great impact on the pollutant's removal selectivity and efficiency. Therefore, the adsorption technologies can be used in two ways: to remove pollutants from wastewater and to recover materials from the regeneration solutions.

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In terms of energy recovery, we discussed biogas technologies, heat recovery and the increase in energy efficiency via digitalisation. In general, a way to increase energy efficiency at a wastewater treatment plant is to avoid over-aeration and hence, to maintain a demand-driven aeration process. Therefore, digitalisation is necessary. However, a model can be only as good as the quality of its used data is. Thus, reliable sensors and regular maintenance of those are mandatory. Hence, data validation and reconciliation as well as its quality control are crucial.
We learned that biogas technologies involved in wastewater treatment can contribute to a lower CO_2 footprint of a WWTP. Hereby, methane recovery from effluents of anaerobic reactors is an important treatment step to avoid high methane losses. In combination with excess low grade heat reuse, the CO_2 footprint can be further decreased. A possible point of application is for example the reuse in an ammonia air stripping process to remove and recovery nitrogen from wastewater.
If excess heat is available from a nearby industry for example, high temperature - aquifer thermal energy storage (HT-ATES) systems can be a good option to substitute fossil energy needed for heating purposes. Hereby, the efficiency of an HT-ATES increases with its size and better isolating properties of the upper subsurface of the storage.

In terms of nutrient recovery, different innovative technologies have been successfully implemented and applied for wastewater, sludge and kitchen waste such as advanced biodrying and composting, bioelectrochemical systems and ultra-low flush toilets coupled with (hyper-)thermophilic anaerobic digestion. Within Ultimate, different technologies are under investigation to recover nutrients from greenhouse, distillery and brewery wastewaters that refer to similar topics such electrodialysis, electrostimulated anaerobic digestion systems and struvite recovery. The main barriers for the implementation of such concepts were related to regulatory gaps, the need of increasing social acceptance and market competition.
The recovery of value-added compounds can bring multiple advantages: removing of components which are harmful for a specific treatment, obtaining marketable products, allowing for the reuse of a residual/out of specification material. Recovery of value-added compounds usually require the implementation of different treatment steps to be implemented in existing plants. Both laboratory and pilot tests are a key step for the implementation of a value-added compound recovery process. The quality of the final product is fundamental for the market accessibility; specific treatment steps are usually necessary to reach an adequate quality. The legislation is fundamental for the recognition of a recovered material as product, if it is generated by a waste (end-of-waste).

The workshops will continue throughout the project, since they revealed to deliver valuable information for the participants and identified important topics for further cooperation and discussion among the Ultimate partners and the other projects.

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Hence, further workshops are planned for the following topics in cooperation with the other work packages:

- Legal risk assessments of the Ultimate solutions and policy gaps (in cooperation with WP2 and WP4)
- Lessons learned from the installation and start-up of the pilot plants (in cooperation with WP5)
- Technical risk assessments of the Ultimate solutions and potential for replication of the concepts (in cooperation with WP2 and WP5)
- Chemical risk assessment of the products as well as their reuse and marketability (in cooperation with WP2 and WP5)

The EU-added value of the workshops results in a synergetic networking between Ultimate and its sister projects B-WaterSmart (GA 869171), Water Mining (GA 869474), REwaise (GA 869496) and Wider Uptake (GA 869283). In addition, those projects learned from further progressed projects such as NextGen, Smart-Plant, Sea4value, Run4life, Digital-water.city and Fiware4water, Routes, Res-urbis, Water2Return, Sludge4.0 and BioKS. The case study leaders profit from the lessons learned and discussions about their concepts in order to set up their demo cases properly. This will contribute to the successful implementation of thoughtful Ultimate solutions and provide useful results for new approaches and best practices of the Ultimate solutions within symbioses clusters (D1.3, D1.4, and D1.5) and for the technology evidence base (TEB, D1.7). The collection and open access presentation of the technologies in this evidence base will support decision makers and investors to gain a fast overview of the opportunities and proven concepts of circular economy. Together with the Marketplace (D5.5), the TEB will severely contribute to the transition from a linear to a circular economy in Europe.

Ultimate promotes technologies that are in line with the ambitions of the European Green Deal (European Commission 2019) and its Action Plan for Circular Economy (European Commission 2020) to reduce strongly our greenhouse gas emissions, to provide clean water, to maintain healthy soil, make industry resilient and produce cleaner energy. The TEB presents technologies that can be applied in the frame of the Regulation (EU) 2020/741 on minimum requirements for water reuse, the Regulation (EU) 2019/1009 laying down rules on the making available on the market of EU fertilising products and the Directive (EU) 2018/2001 on the promotion of the use of energy from renewable sources.

The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

4. References

European Commission (2019). Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions. The European Green Deal COM/20197640 final (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52019DC0640) accessed on Feb. 8th 2022.

European Commission (2020). Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions. A new Circular Economy Action Plan for a cleaner and more competitive Europe COM/2020/98 (https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1583933814386&uri=COM:2020:98:FIN) accessed on Apr. 11th 2022.

EU (2011/10) Commission Regulation (EU) No 10/2011 of 14 January 2011 on plastic materials and articles intended to come into contact with food Text with EEA relevance. (https://eur-lex.europa.eu/eli/reg/2011/10/oj/eng) accessed on Apr. 18th 2022

EU (2018/2001) Directive of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32018L2001&qid=1630937219623) accessed on Feb. 8th 2022

EU (2019/1009) Regulation of the European Parliament and of the Council of 5 June 2019 laying down rules on the making available on the market of EU fertilising products and amending Regulations (EC) No 1069/2009 and (EC) No 1107/2009 and repealing Regulation (EC) No 2003/2003 (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32019R1009) accessed on Feb. 8th 2022

EU (2020/741) Regulation on minimum requirements for water reuse (https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32020R0741&from=EN) accessed on Feb. 8th 2022

Kleyböcker, A., Naves Arnaldos, A., Bruni, C., Fatone, F. (2021a). Technology Evidence Base Concept and Integration. D1.6 ULTIMATE project (GA 869318).

Kleyböcker, A., Bruni, C., Naves Arnaldos, A., Casas Garriga, S., Fantone, F., van den Broeke, J., Iossifidis, D., Gimenez Lorang, A., Sabbah, I., Pidou, M., Reguer, A., Lundgaard, L., Bendix Larsen, S. (2021b). Assessment of baseline conditions for all case studies. D1.1 Ultimate project (GA 869318).

Kleyböcker, A., Lienen, T., Kasina, M., Westphal, A., Teitz, S., Eichinger, F., Seibt, A., Wolfgramm, M., Würdemann, H. (2017). Effects of heat shocks on biofilm formation and the influence on corrosion and scaling in a geothermal plant in the North German Basin. Energy Procedia, 125, 268–272.

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Otten, C., Dassler, B., Teitz, S., Iannotta, J., Eichinger, F., Seibt, A., Kuhn, D., Würdemann, H. (2021). Interactions between the calcium scaling inhibitor NC47.1B, geothermal fluids, and microorganisms – results of in situ monitoring in the Bavarian Molasse Basin (Germany) and accompanying laboratory experiments. Adv. Geosci., 54, 217-227.

Westphal, A., Lerm, S., Miethling-Graff, R., Seibt, A., Wolfgramm, M., Würdemann, H. (2016). Effects of plant downtime on the microbial community composition in the highly saline brine of a geothermal plant in the North German Basin. Appl. Microbiol. Biotechnol. 100, 7, 3277-3290.

The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

Annex1-8 are attached as extra files:

Annex 1: Presentations – Membrane technologies

Annex 2: Presentations – Adsorption technologies

Annex 3: Presentations – Biogas technologies

Annex 4: Presentations – Heat recovery

Annex 5: Presentations – Nutrient recovery

Annex 6: Presentations – Material recovery

Annex 7: Presentations – Digitalisation

Annex 8: Presentations – Success secret of WSIS

The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

Annex 1: Presentations – Membrane technologies

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ULTIMATE
WATER SMART INDUSTRIAL SYMBIOSIS

CTG meeting:

Membrane technologies for water and resource recovery

When: 25 November 2020 (10-12h)

Where: Online meeting **Unirse a reunión de Microsoft Teams**

10:00 **Opening and Welcome** Sandra Casas (EUT)

10:10 **Near zero liquid discharge systems in the petrochemical industry** Sandra Casas (EUT)

10:20 **Filtration and small bioreactor platform for wastewater reuse in the food industry** Dimitri Iossifidis (GtG)

10:30 **AnMBR and RO for water recovery in the beverage industry** Marc Pidou, (Cranfield Univ)

10:40 **Ultratight UF in fit-for-purpose water treatment systems in the biochemical industry.** Leo Vredenbregt (X-Flow)

10:50 **Nextgen Synergies: space technology for water reuse in a Dutch brewery.** Ralph Lindeboom (Semilla)

11:10 **Watermining Synergies: Pilot System for Water, Salt and Energy recovery from urban wastewater.** Maria Kyriazi (NTUA)

11:20- Open discussion

11:30 - Closure

ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

Online seminar
Membrane technologies

S.Casas, A.Kleyböcker, F.Fantone, C.Bruni, R.Serena

November, 25th 2020

Ultimate (June 2020 – May 2024):

Industry water-utility symbiosis for a smarter water society

- Promotion, establishment and extension of **Water Smart Industrial Symbioses**
- Development and demonstration of **innovative technologies** for symbioses
- **Assessment** of the technologies and development of **digital „support tools“**
- Development of **new business models** towards marketability

9 Symbioses between:

Industrial sectors

- Agro-food
- Beverage
- (Petro)chemical
- Biotech

Service providers

- Municipal utility
- Multi-industry utility
- Specialized SME
- Water services provider

Coordinator: KWR

9 Case Studies

27 Partners

37 Technologies

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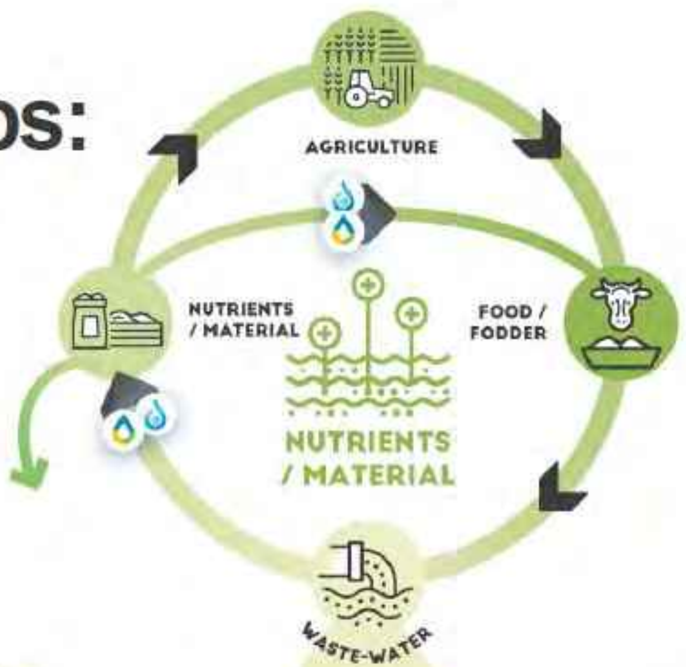
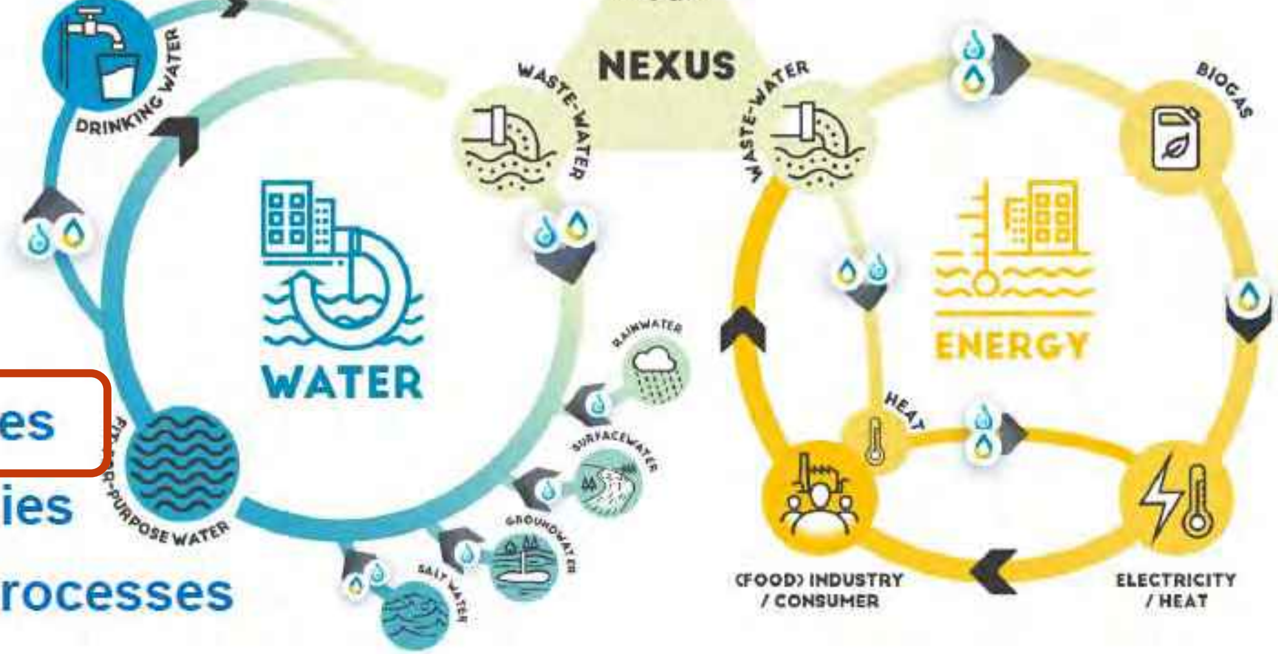
3 Cross-cutting Technology Groups: 9 Topics

F. Fatone C. Bruni

UNIVERSITÀ POLITECNICA DELLE MARCHE

- Nutrient recovery
- High added value products
- Metal recovery

eurecat

S. Casas

- Membrane technologies
- Adsorption technologies
- Advanced oxidation processes

A. Kleyböcker

KOMPETENZZENTRUM Wasser Berlin

- Biogas technologies
- Heat recovery
- Digitalization

Coordinator: KWR

9 Case Studies

27 Partners

37 Technologies

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Agenda

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11:30	**Closure**

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ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

Near zero liquid discharge systems in the petrochemical industry

D.Montserrat, X.Martínez, S.Casas

Petrochemical Complex of Tarragona (Spain)

Industrial area that groups several companies **of the chemical and petroleum field.**

it has been considered the most important of this type in Catalonia, Spain and the south of Europe.

More than 30 companies operate in the petrochemical complex focusing on production of chlorine, alkaline salts, oxygen gas, fertilizers, insecticides, fuels, plastics and synthetic essences.

AITASA was created in 1965 to supply water to the complex. In 2012, a water reclamation plant was put in operation to supply industrial water.

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Tarragona symbiosis through AITASA

Drinking water
Non-potable water
Urban Reclaimed water
Demineralized water

Security,
optical fiber,
pipes for transport of products

aitasa — Aguas Industriales de Tarragona S. A. → Petrochemical complex Tarragona

Industrial Wastewater

Synergies in place since 1965

Kms of pipes that make up the network:

Industrial Water: 43.5 Kms. Average diameter: 500 mm
Chlorinated Water: 14 Kms. Average diameter: 200 mm

Distributed industrial water flow: 10 Hm^3 / year

Direct jobs:17

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Camp de Tarragona WRP

Industrial water reclamation for cooling towers, boilers and deminerilized uses

6,8 hm^3/year capacity for urban wastewater reclamation

EDAR Vila-Seca i Salou →
EDAR Tarragona →

Coagulation/floculation & settling (ACTIFLO) | Microfiltration (Discfilter) | Sand filter | Reverse Osmosis (2 passes) | Disinfection

→ Industrial water

Users: REPSOL, BASF, IQA, ERCROS, DOW CHEMICAL, CELANESE, BAYER, etc

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Industrial wastewater treatment

To be commisioned in 2022

Goal: to meet the BREF

1,8 Mm3/h treatment capacity

	BREF CWW + REFINO
Parámetro	NEA-MTD (media anual)
Carbono Orgánico Total (COT)	*33 mg/l*
Demanda Química de Oxigeno (DQO)	*100 mg/l*
Total Sólidos en Suspensión (TSS)	*25 mg/l*
Nitrógeno Total (NT)	*25 mg/l **
Nitrógeno Inorgánico Total (TN_{inorg})	*20 mg/l*
Fósforo Total (P_T)	*3 mg/l*
Compuestos Orgánicos Halogenados Adsorbibles (AOX)	*1 mg/l*
Cromo (expresado como Cr)	*25 µg/l*
Cobre (expresado como Cu)	*50 µg/l*
Níquel (expresado como Ni)	*50 µg/l*
Cinc (expresado como zinc)	*300 µg/l*
Índice de Hidrocarburos	*2,5 mg/l*
plomo (expresado como Pb)	*0,03 mg/l*
cadmio (expresado como Cd)	*0,008 mg/l*
mercurio (expresado como Hg)	*0,001 mg/l*
Benceno	*0,050 mg/l*

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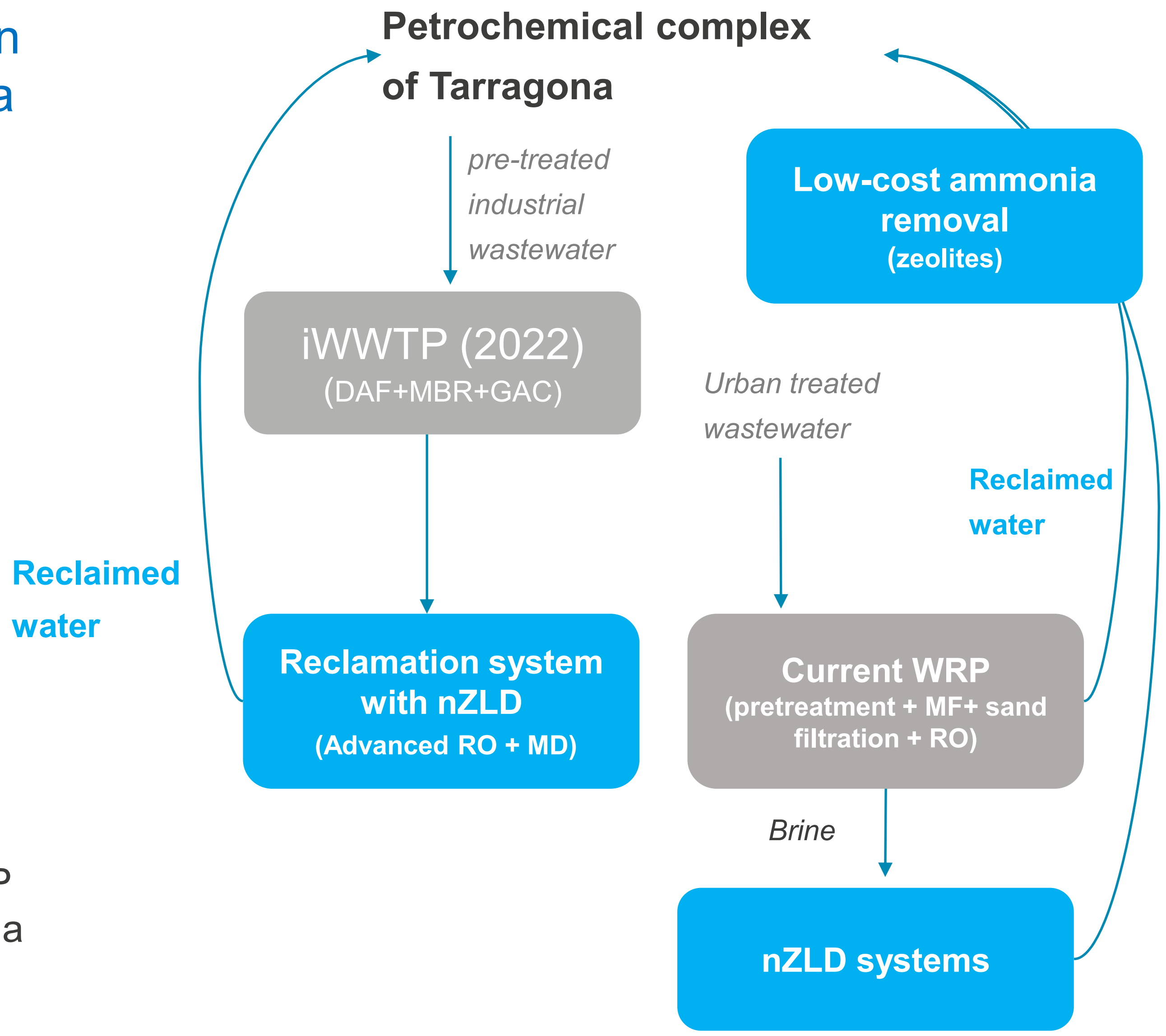
WATER - Task 1.2.1

Increasing reclaimed water availability in the petrochemical complex of Tarragona

Partners:

eurecat Centre Tecnològic de Catalunya

aitasa Aguas Industriales de Tarragona S. A.



OBJECTIVE:

Increase reclaimed water availability for the complex by 20%:

→ Defining a tertiary treatment with nZLD technologies from the future iWWTP

→ Increase water recovery of the current WWRP with nZLD technologies. Remove the ammonia with low-cost technologies (zeolites).

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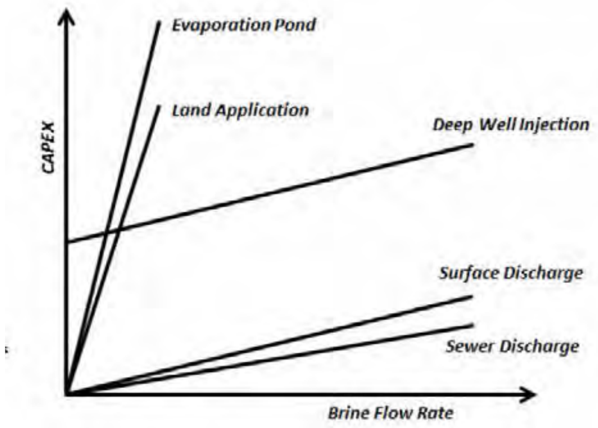
nZLD systems

Optimize water production and minizimize wastes through brine treatment

Brine → liquid solution with high salinity (TDS > 35000 mg/L)



ZLD schemes: hindered by high costs… nZLD can be interesting to minimize volume

Brine → Concentration → Crystallization → Salt

Concentration:
Electrodialysis EDR
Reverse Osmosis RO
Membrane Distillation MD
Forward Osmosis
Evaporation (MSF, MCV)

60-80% Water recovered

Crystallization:
Evaporation
Membrane Crystallization
Solar ponds
Advanced Solar Evaporation

Water

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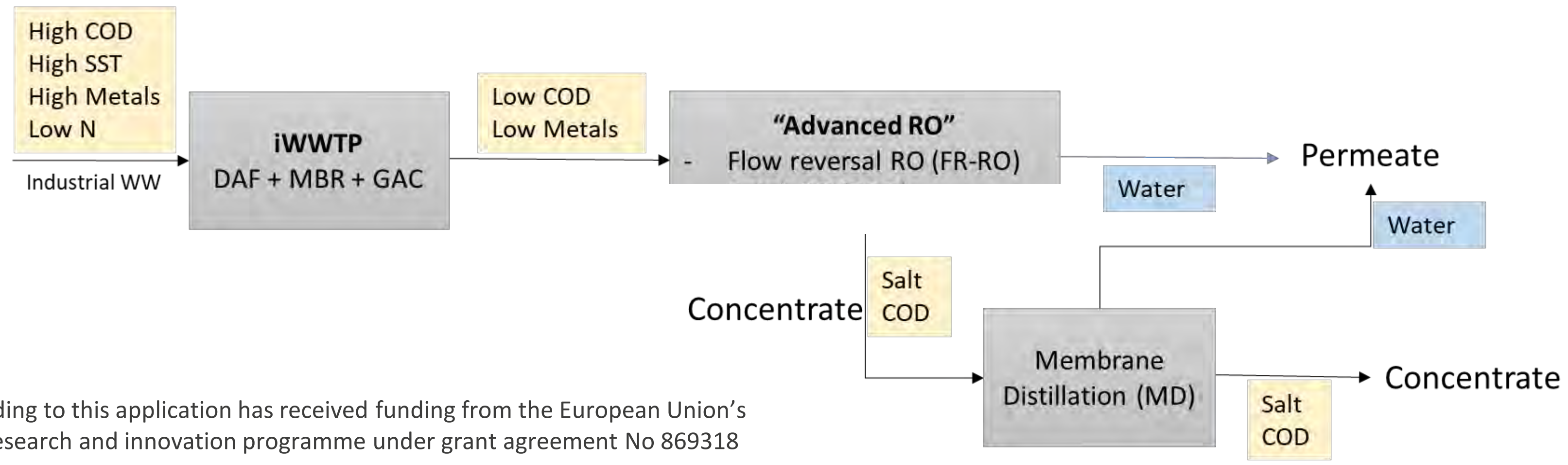
nZLD concentration

Benefits and limitations of different technologies used in ZLD systems modified (Tong and Elimelech, 2016).

Tech.	Benefits	Limitations	Energy kWh_e/m^3	References
MVC	High salinity limit >200,000 mg/L	High capital and operational costs	20–25, 28–39 (a)	(Mickley, 2008b; Burbano and Brandhuber, 2012; McGinnis et al., 2013; Charisiadis, 2018)
RO	Energy-efficient	Limited salinity; scaling	2–6, 1.5–2.5 (b)	(Elimelech and Phillip, 2011; Al-Karaghouli and Kazmerski, 2013; Charisiadis, 2018)
MD	High salinity limit >200,000 mg/L	Low flux and recovery; limited area of application	40–45, 22–67 (b)	(Schwantes et al., 2018; Al-Obaidani et al., 2008; Charisiadis, 2018)
FO	High salinity limit >200,000 mg/L; requires low-grade heat; less fouling	Low flux at high salinity; reverse solute flux; limited use	21 (a)	(McGinnis et al., 2013; Haupt and Lerch, 2018; Oasys Water, 2017; Li et al., 2017)
ED/EDR	Salinity limit >100,000 mg/L; less fouling	High energy consumption	7–15 (a)	(Korngold et al., 2009; Loganathan et al., 2016; Turek et al., 2005; Tufa et al., 2015)

Tech; Technologies, (a) energy consumption kWh_e/m^3 of feed water; (b) energy consumption kWh_e/m^3 of product water.



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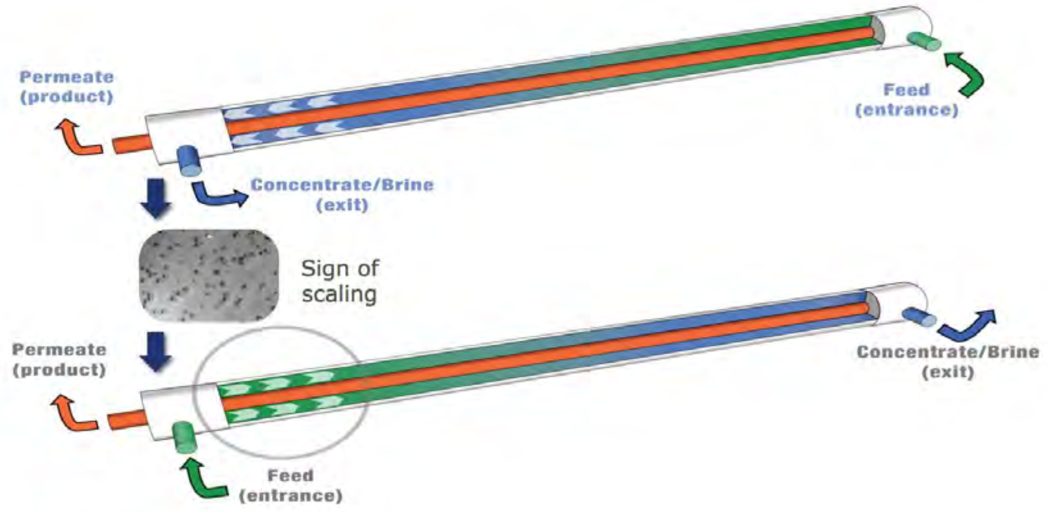
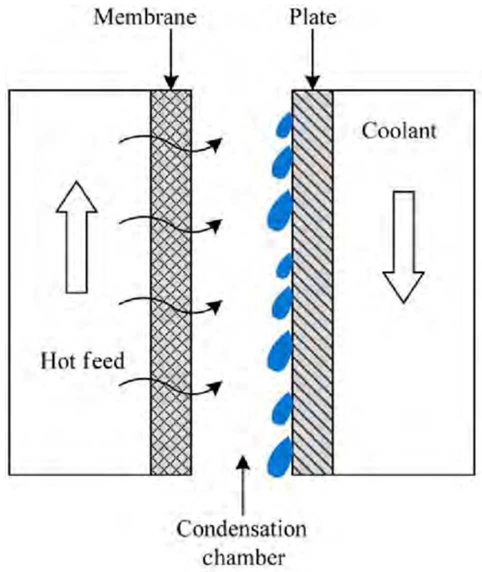
nZLD technologies proposed in CS1

Flow reversal RO (FR-RO)



Membrane distillation



- Inhibits and prevents mineral scaling (no anti-scaling required)
- Switches connection of feed and concentrate before supersaturated solutions can precipitate from the concentrate onto the membrane.
- Reduction of volume disposal up to 60% compared to RO.

- Thermally driven process in which only vapor molecules are able to pass through a porous hydrophobic membrane. The driving force of this process is the vapor pressure differential between both sides of the membrane.
- MD can also be used in conjunction with other separation processes (UF or RO) , is competitive for desalination of brackish and seawater, is an effective process for organic and heavy metal removal from aqueous solutions.

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FR-RO

Desalination 485 (2020) 114462

Contents lists available at ScienceDirect

Desalination

Application of feed flow ... industrial wastewaters

Di Tang[a,b], Jie Song[c,d], Adrian ...

[a] Environmental Process Modelling Centre, Nanyang En... 639798, Singapore
[b] School of Civil and Environmental Engineering, Nanya...
[c] Shanghai Environmental Protection Key Laboratory on ... Engineering, East China University of Science and Techn...
[d] Shanghai Institute of Pollution Control and Ecological ...

Desalination 308 (2013) 63–72

Contents lists available at SciVerse ScienceDirect

Desalination

journal homepage: www.elsevier.com/locate/desal

Self-adaptive feed flow reversal operation of reverse osmosis desalination

Han Gu, Alex R. Bartman, Michal Uchymiak, Panagiotis D. Christofides, Yoram Cohen *

Department of Chemical and Biomolecular Engineering and Water Technology Research Center, University of California, Los Angeles, 420 Westwood Plaza, Chemical Engineering Offices, Boelter Hall 5531, Los Angeles, CA 90095, USA

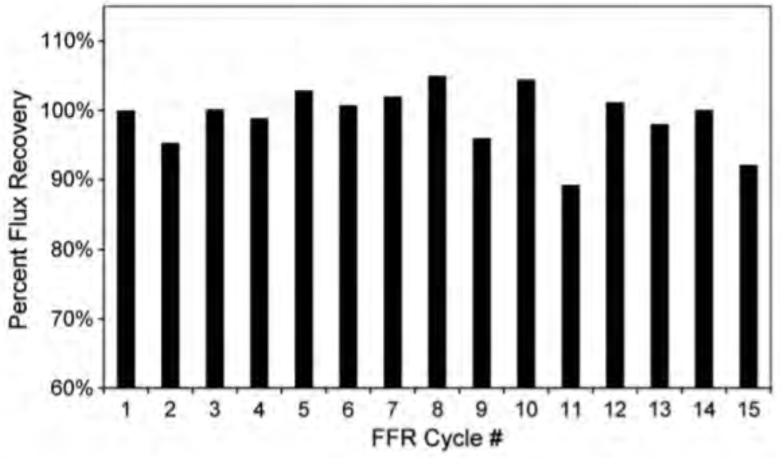

Fig. 10. Percent recovery for the tail element (PV6) permeate flux for the series of FFR cycles for Test #2 (69% recovery for period of 88 h, $SI_{gm} = 2.76$; Table 3).

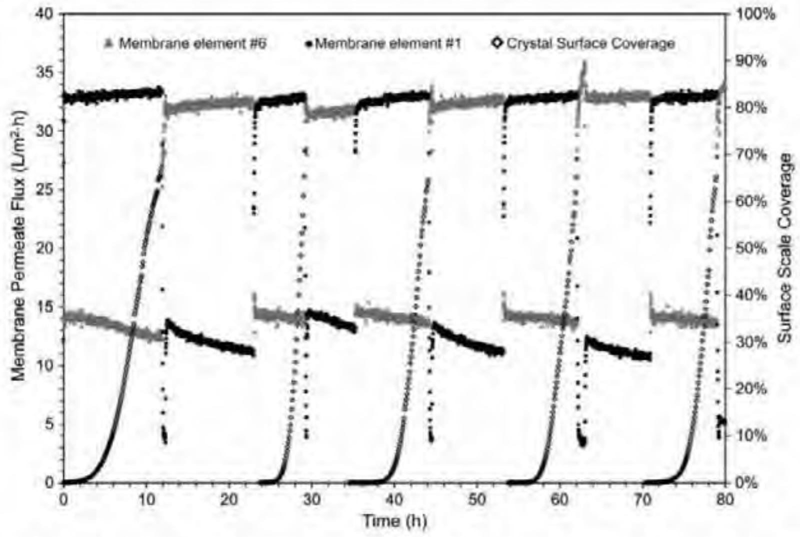

Fig. 12. Permeate flux (normalized) for membrane elements PV1 and PV6 during NFF and FFR periods, along with percent surface crystal coverage in the MeMo cell monitored area (M3 operation at 81% recovery with $SI_{gm} = 3.45$, with the FFR trigger set to 65% surface scale coverage in the MeMo monitored area, Test #3, Table 3).

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MD

Source: Chapter 4: Membrane Distillation. Thermal Solar Desalination, Elsevier Ltd. (2016)

DCMD

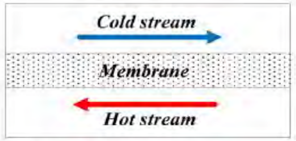

Figure 4.3 Direct contact membrane distillation.

SGMD

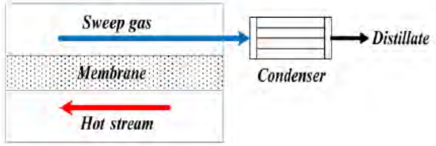

Figure 4.5 Sweep gas membrane distillation.

AGMD

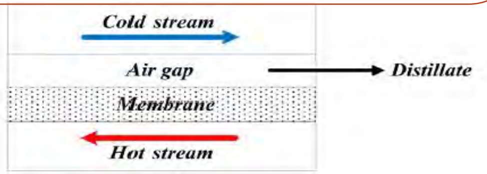

Figure 4.4 Air gap membrane distillation.

VMD

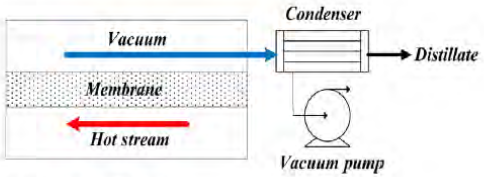

Figure 4.6 Vacuum membrane distillation.

Selection of MD:

- **Operation modes**

- **Materials available for membranes**

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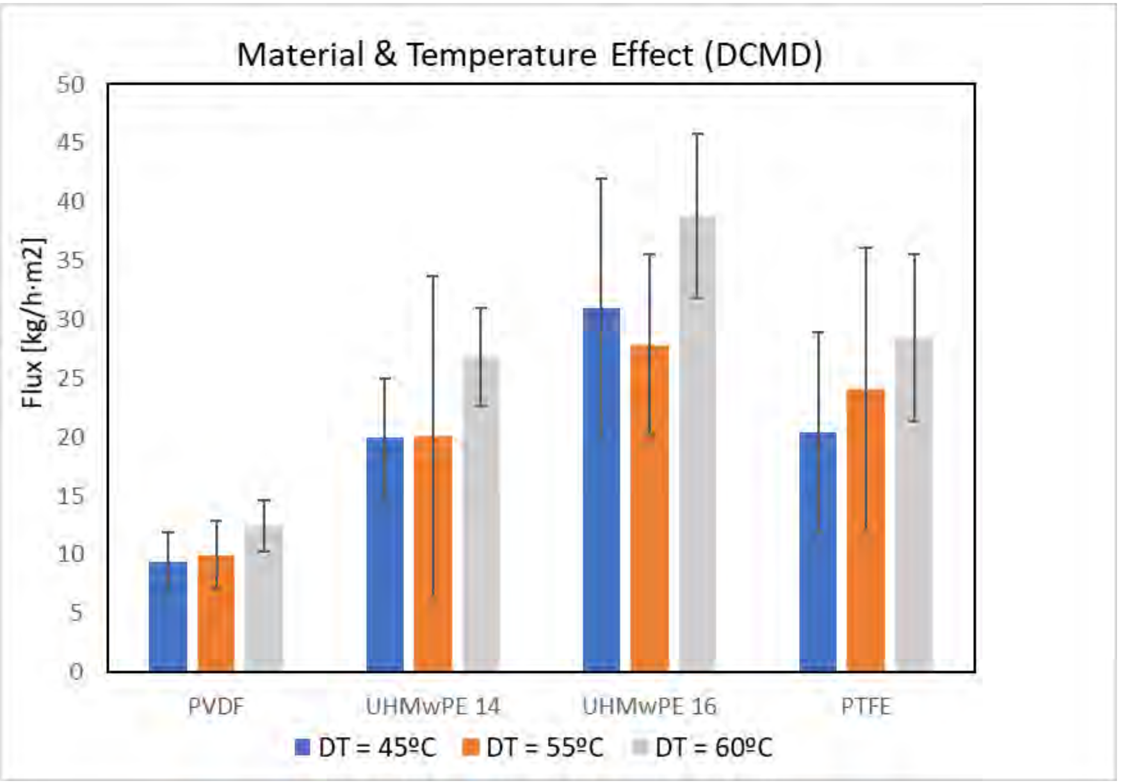
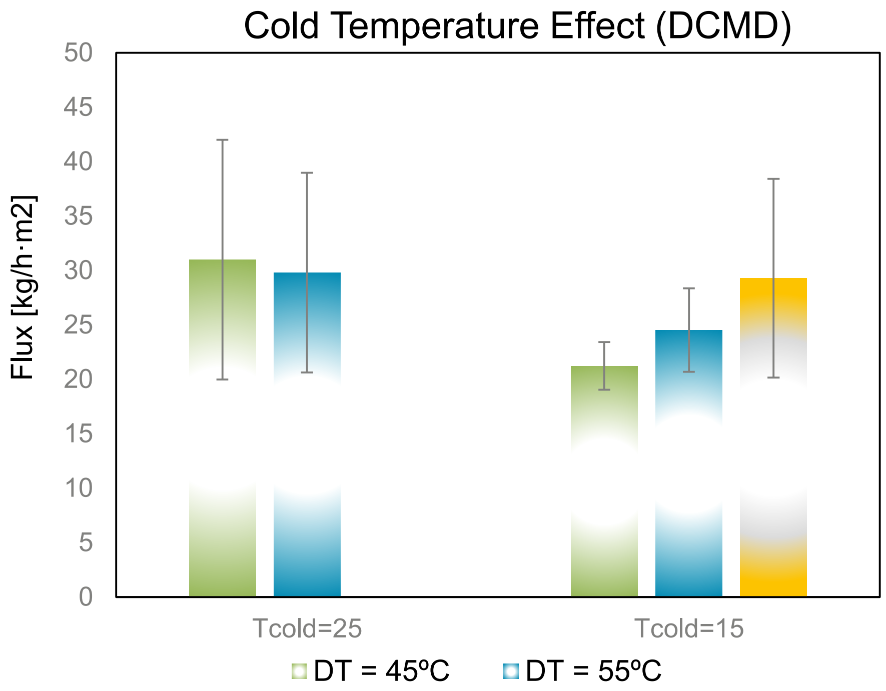
MD preliminary results

UHMwPE16 material is the most promising material for the application

Tests with syntethic brine (35 g/L – 50 mS/cm)





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Next steps in CS1

		2020							2021												2022											
		6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
Internal milestones:		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Review of historical operation and quality data of the site. Definition of extra campaigns required. Analysis of samples.	EUT																															
Sampling and analysis for extra analitical campaigns and collection of data for baseline	AIT																															
Set-up experimental plan and laboratory equipment	EUT																															
Definition of requirements for reuse	AIT																															
Trials of proposed technologies at bench scale. Optimitzation of the system	EUT																															
Site adaptation	AIT																															
Definition of prototype for construction	EUT																															
Prototype construction and installation	AIT																															
Operation of prototype and optimization	AIT																															
Prototype follow-up and monitoring	EUT																															
Evaluation of results and integration of water sources	EUT																															

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Conclusions

nZLD Systems will be evaluated in CS1 of ULTIMATE with a focus on:

- Increasing water availability at least 20% more than conventional Systems (conventional RO)
- Reduce fouling and scaling in membrane treatments (RO)
- Evaluate MD and FR-RO for brine concentration and optimize their operation (estimate OPEX of the system)

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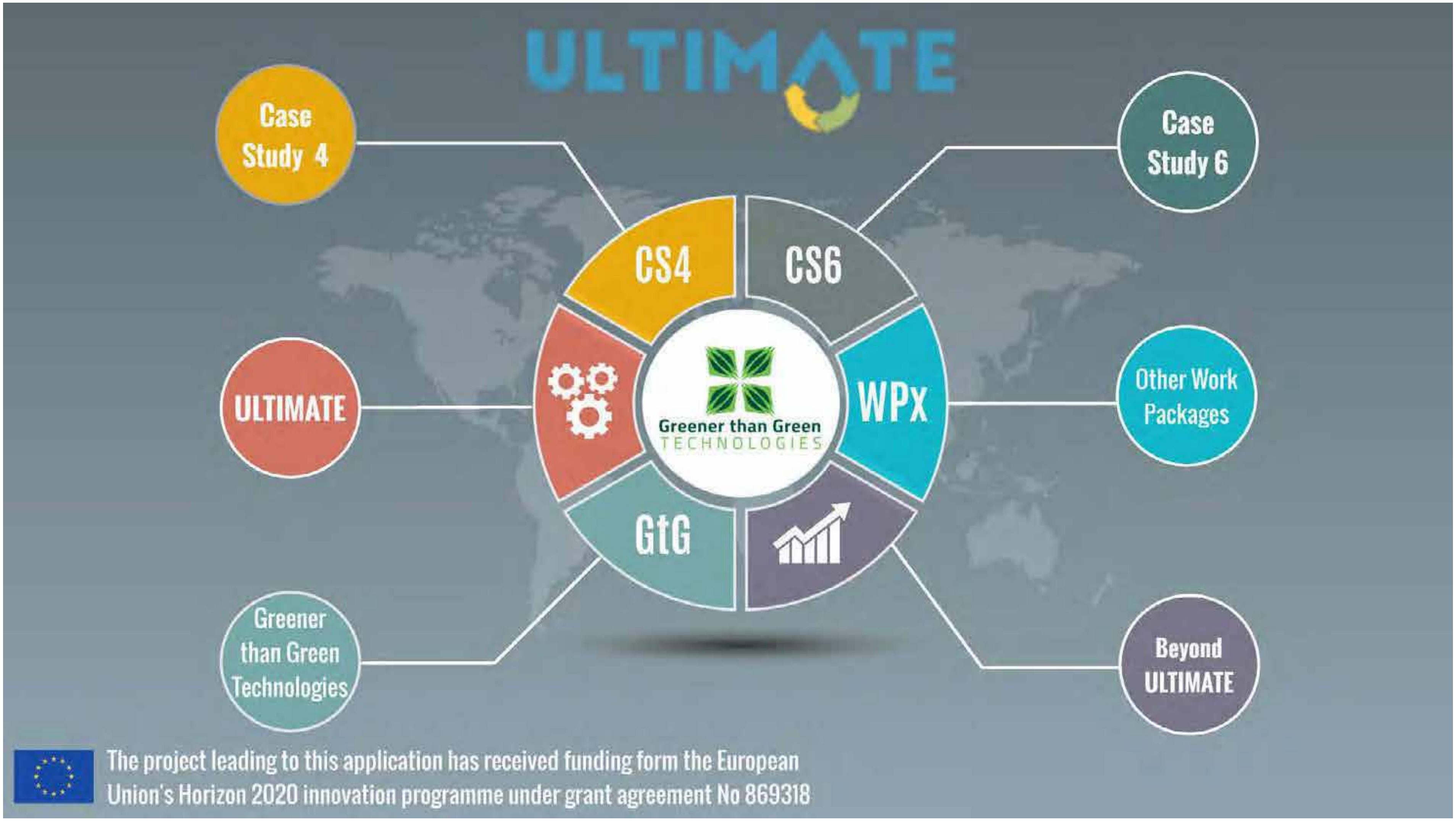
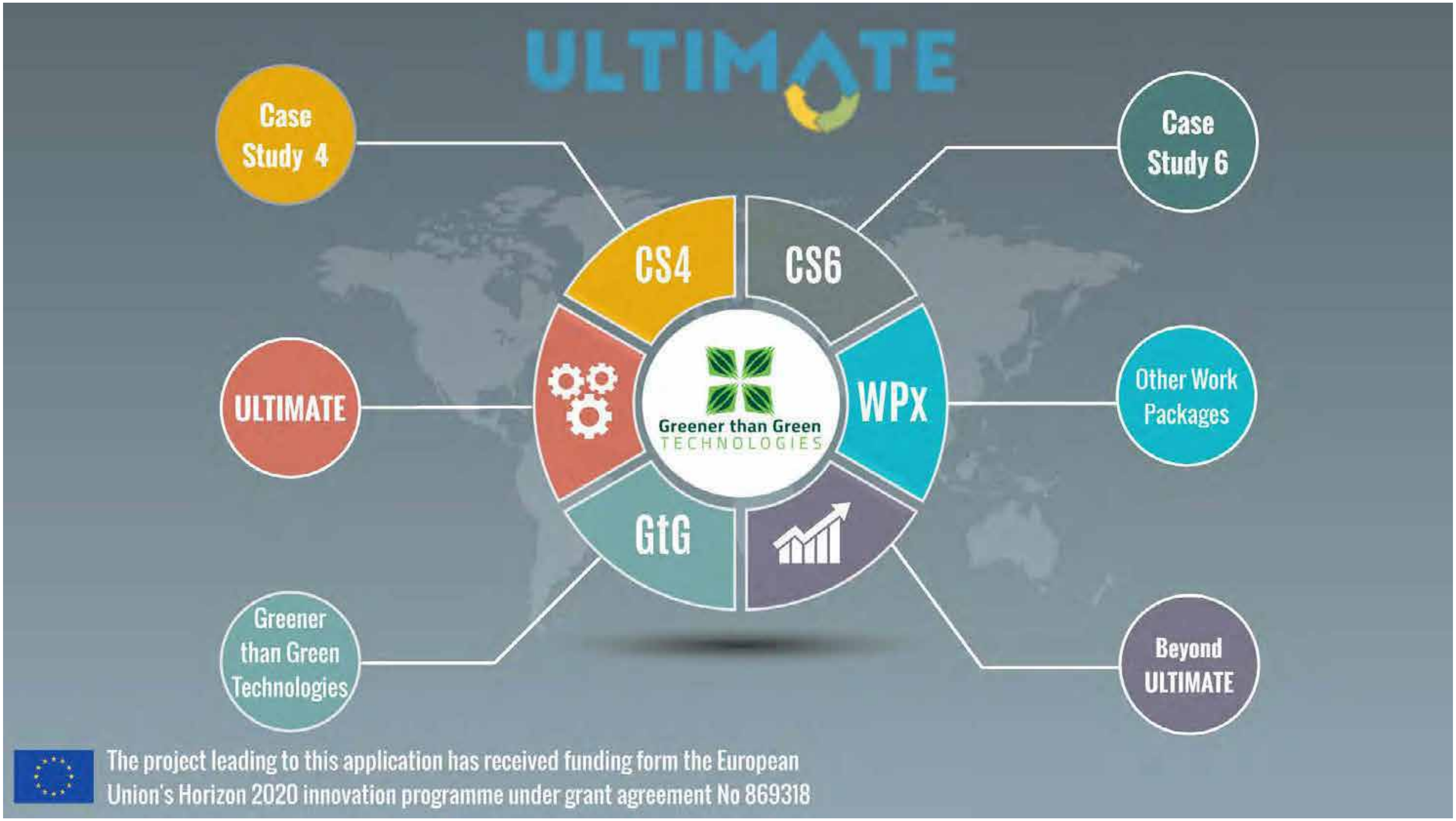

ULTIMATE
Case Study 4
Case Study 6
CS4
CS6
ULTIMATE
Greener than Green TECHNOLOGIES
WPx
Other Work Packages
GtG
Greener than Green Technologies
Beyond ULTIMATE
The project leading to this application has received funding form the European Union's Horizon 2020 innovation programme under grant agreement No 869318


ULTIMATE
Case Study 4
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ULTIMATE
Other Work Packages
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Beyond ULTIMATE
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The team
Greener than Green Technologies
Greener than Green Technologies SA (GtG)
is active in R&D and marketing of disruptive water and wastewater remediation technologies and methodologies for the circular usage of water providing valuable tools for the transition of industries and communities towards a circular economy model, taking a step closer to a circular economy. In cases where high interest and value added compounds are present in the waste, these can be reclaimed, purified and reused, minimising production cost, or can be commercially exploited, thus, turning waste into a resource.
Established in 2014, we are start-up company that sprung out of pioneering university research. Our research efforts are funded by private capital as well as EU grants and we continuously seeking synergies in both the industrial and research partners. Since 2019 we are marketing and promoting in Greece and the wider southeastern European area novel and innovative environmental technologies.
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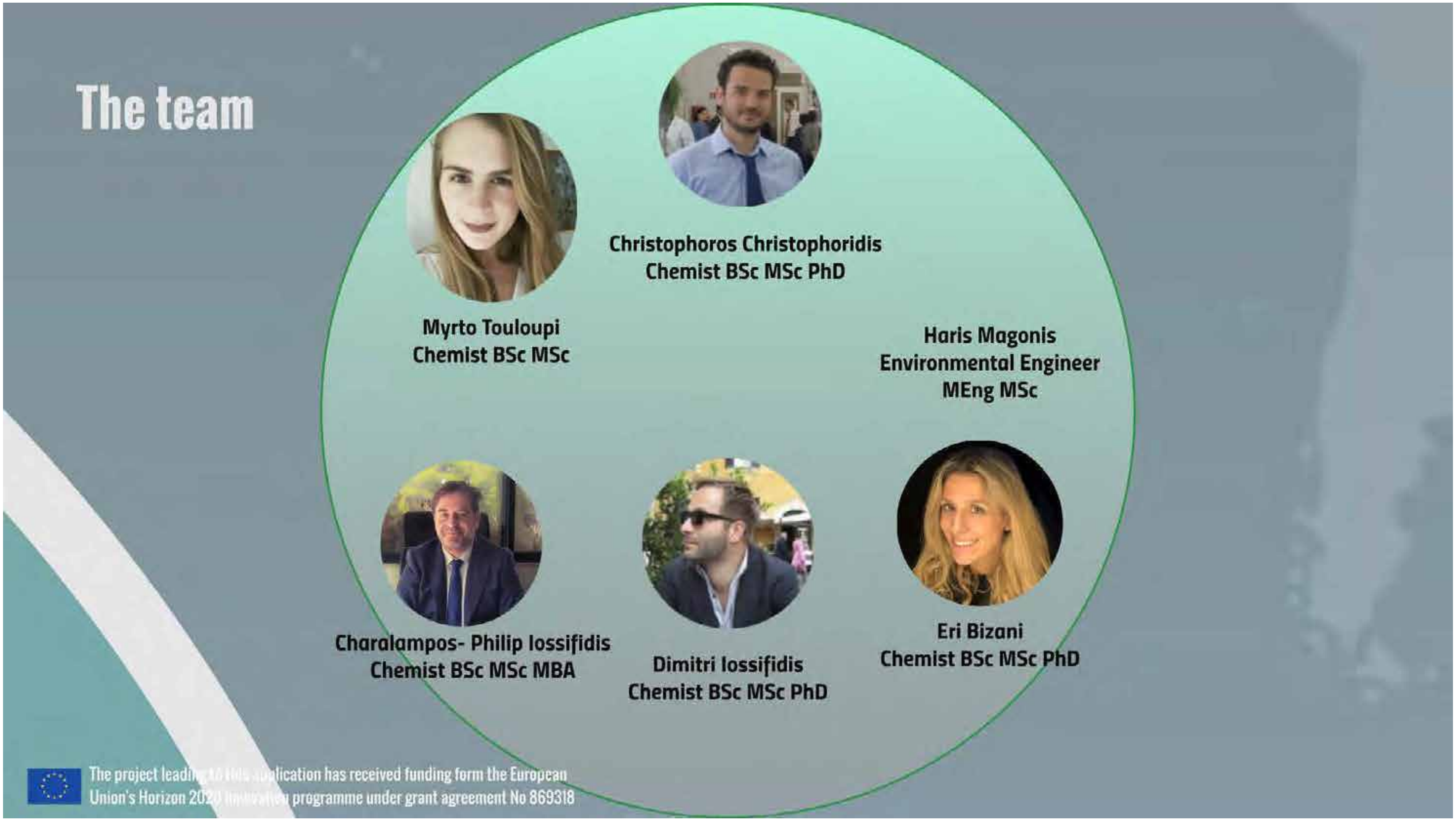
The team
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Environmental Engineer
MEng MSc
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Chemist BSc MSc PhD
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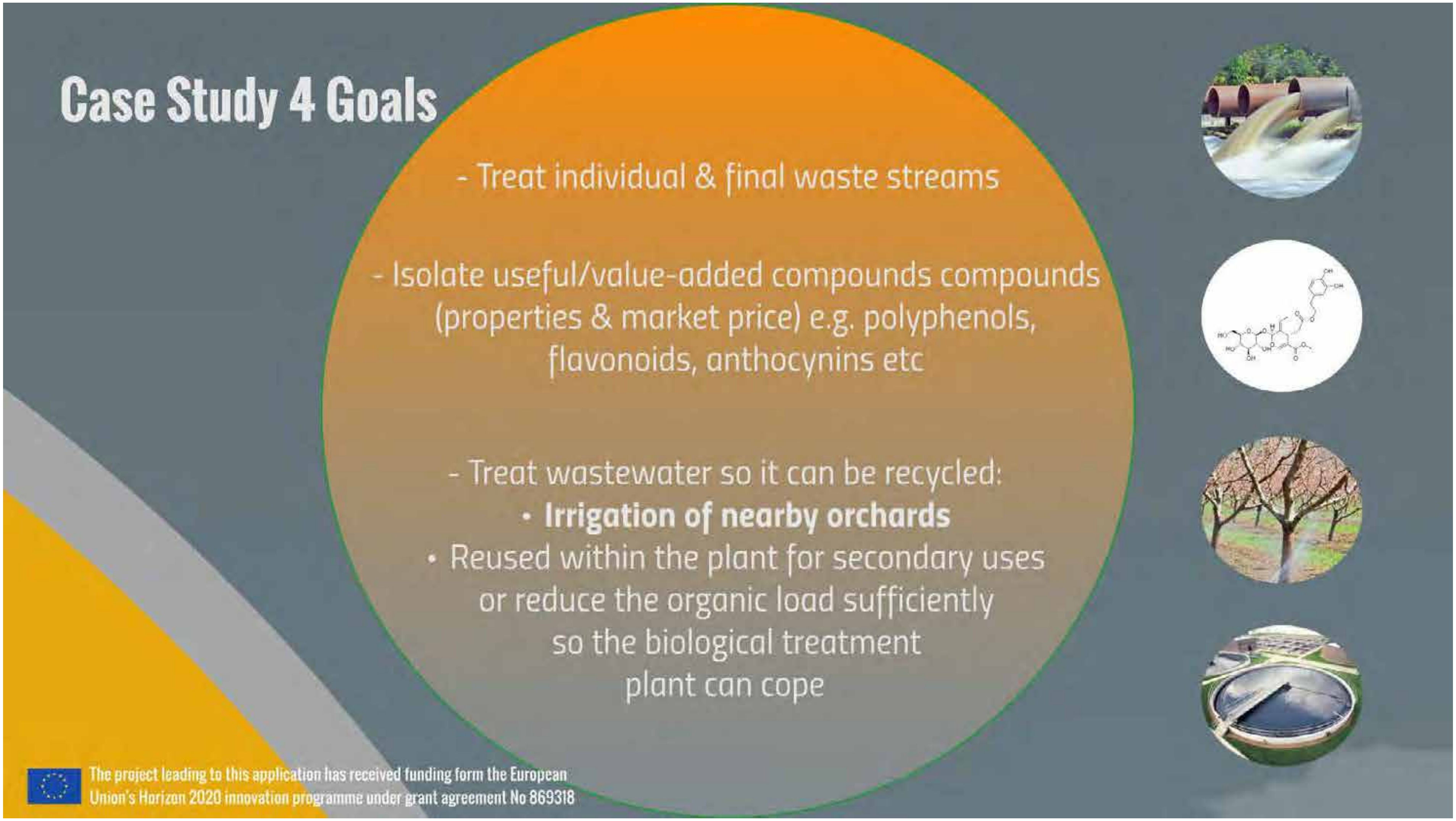
Case Study 4
- Fruit processing industry
- Nafplio, Eastern Peloponese, Greece
- High water demand puts pressure in the aquifer
-Seasonality puts strain on the local biological treatment plant
- Under-performing biological treatment plant, leads to higher waste removal cost
Goals
The Unit
Value-added compound extraction
AOP
SBP
Greener than Green TECHNOLOGIES
ALBERTA S.A.
Hellenic Fruit Processing Industry
The project leading to this application has received funding form the European Union's Horizon 2020 innovation programme under grant agreement No 869318


Case Study 4 Goals
- Treat individual & final waste streams
- Isolate useful/value-added compounds compounds (properties & market price) e.g. polyphenols, flavonoids, anthocynins etc
- Treat wastewater so it can be recycled:
• Irrigation of nearby orchards
• Reused within the plant for secondary uses or reduce the organic load sufficiently so the biological treatment plant can cope
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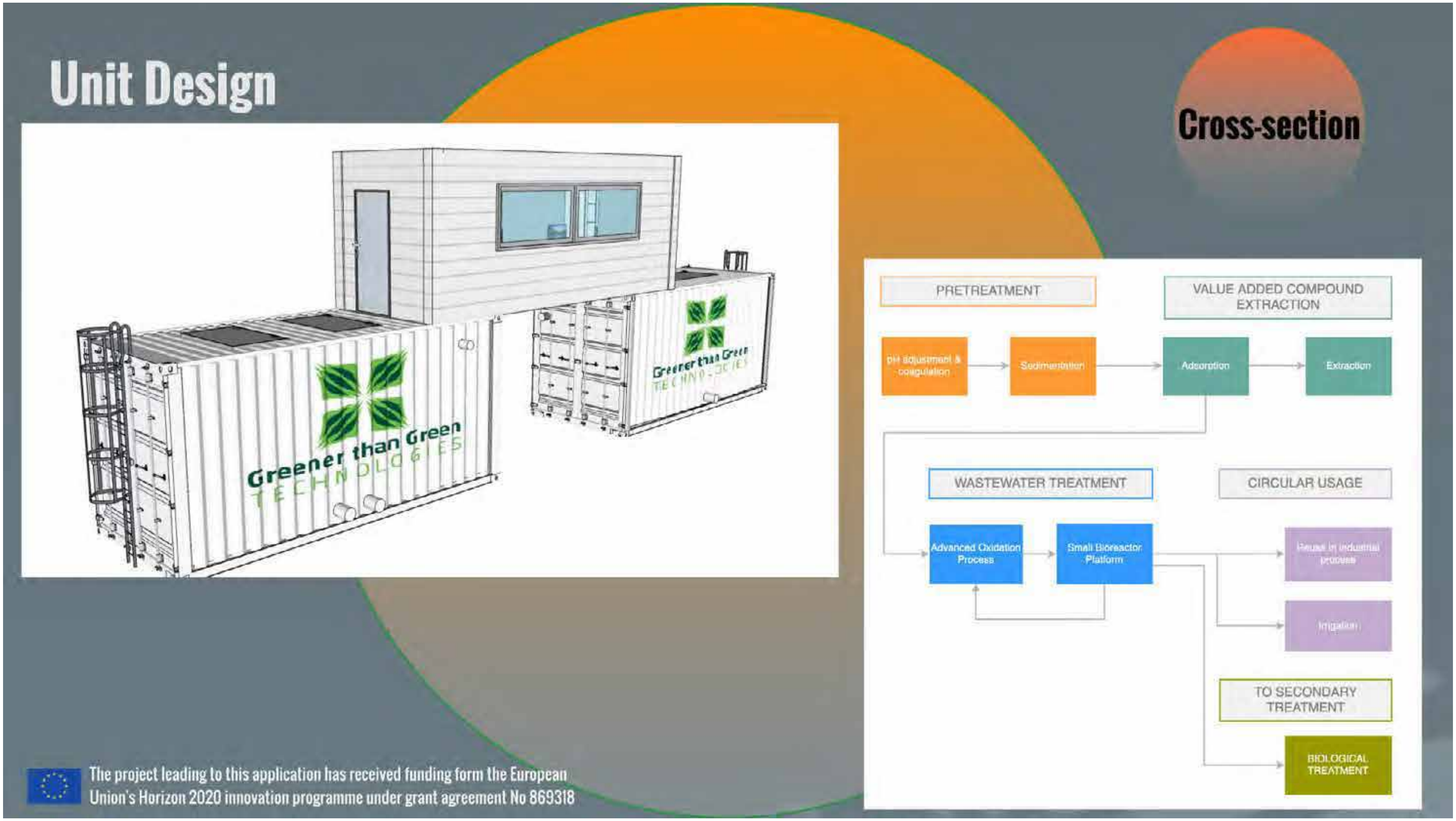
Unit Design
Cross-section
Greener than Green
TECHNOLOGIES
PRETREATMENT
VALUE ADDED COMPOUND EXTRACTION
pH adjustment & coagulation
Sedimentation
Adsorption
Extraction
WASTEWATER TREATMENT
CIRCULAR USAGE
Advanced Oxidation Process
Small Bioreactor Platform
Irrigation
TO SECONDARY TREATMENT
BIOLOGICAL TREATMENT
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Unit Cross-section

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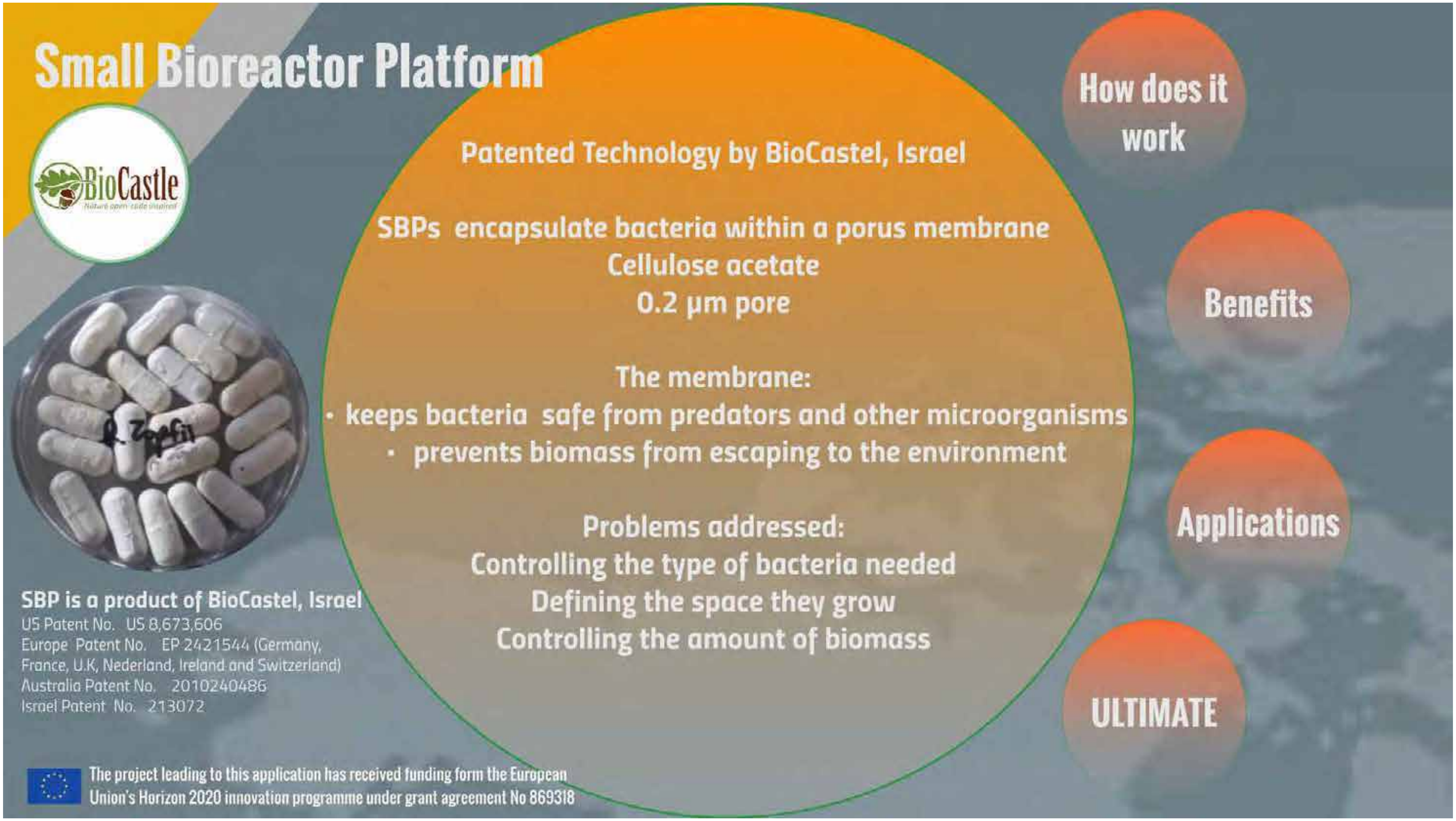
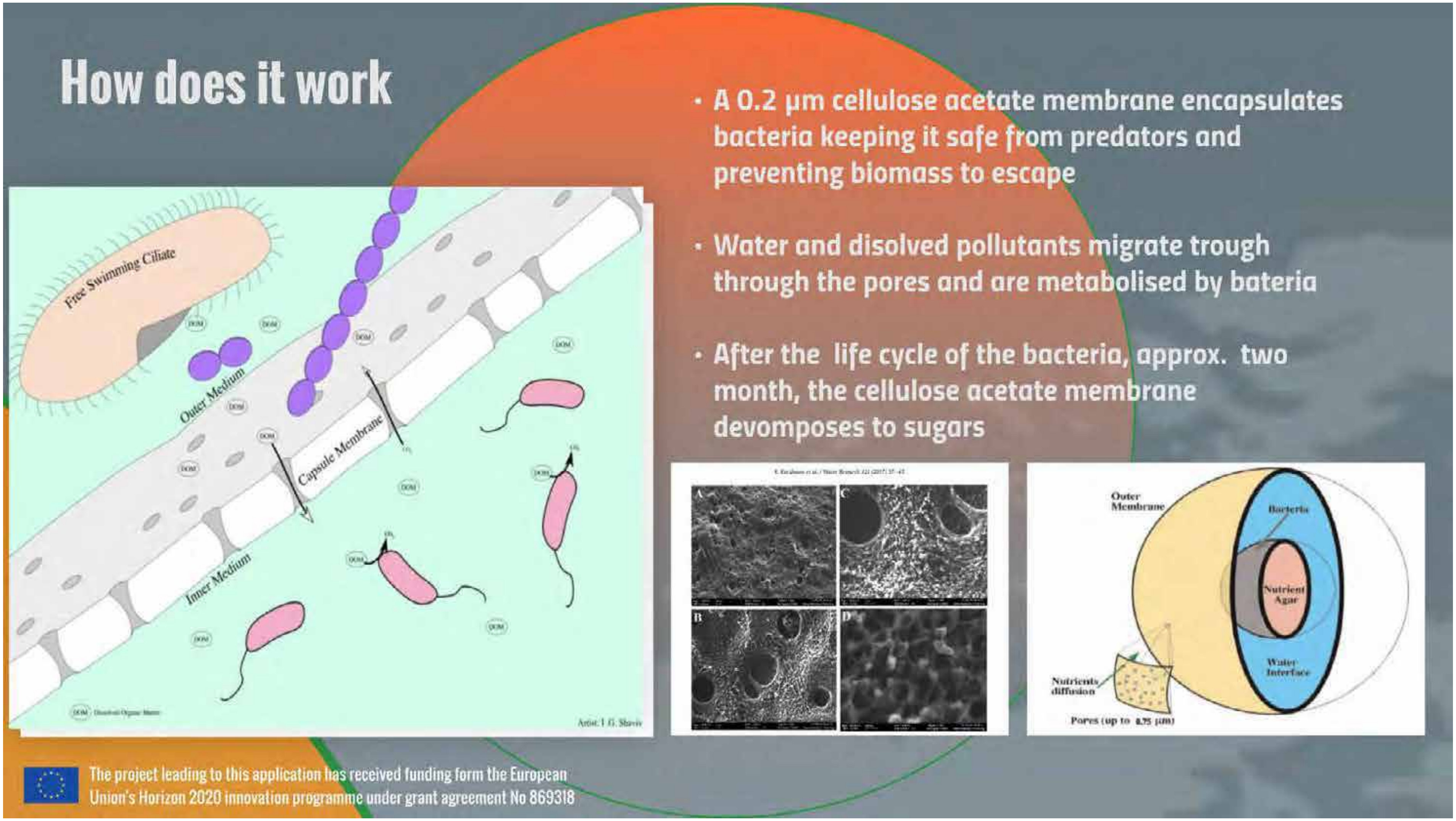

Small Bioreactor Platform
BioCastle
Patented Technology by BioCastel, Israel
SBPs encapsulate bacteria within a porus membrane
Cellulose acetate
0.2 µm pore
The membrane:
• keeps bacteria safe from predators and other microorganisms
• prevents biomass from escaping to the environment
Problems addressed:
Controlling the type of bacteria needed
Defining the space they grow
Controlling the amount of biomass
How does it work
Benefits
Applications
ULTIMATE
SBP is a product of BioCastel, Israel
US Patent No. US 8,673,606
Europe Patent No. EP 2421544 (Germany, France, U.K, Nederland, Ireland and Switzerland)
Australia Patent No. 2010240486
Israel Patent No. 213072
The project leading to this application has received funding form the European Union's Horizon 2020 innovation programme under grant agreement No 869318


How does it work
• A 0.2 µm cellulose acetate membrane encapsulates bacteria keeping it safe from predators and preventing biomass to escape
• Water and disolved pollutants migrate trough through the pores and are metabolised by bateria
• After the life cycle of the bacteria, approx. two month, the cellulose acetate membrane devomposes to sugars
Free Swimming Ciliate
Outer Medium
Capsule Membrane
Inner Medium
Artist: I. G. Shavit
Outer Membrane
Bacteria
Nutrient Agar
Water Interface
Nutrients diffusion
Pores (up to 0.75 µm)
The project leading to this application has received funding form the European Union's Horizon 2020 innovation programme under grant agreement No 869318

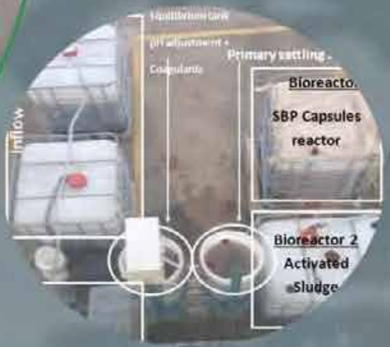
Benefits

SBP technology addresses certain biological treatment problems:

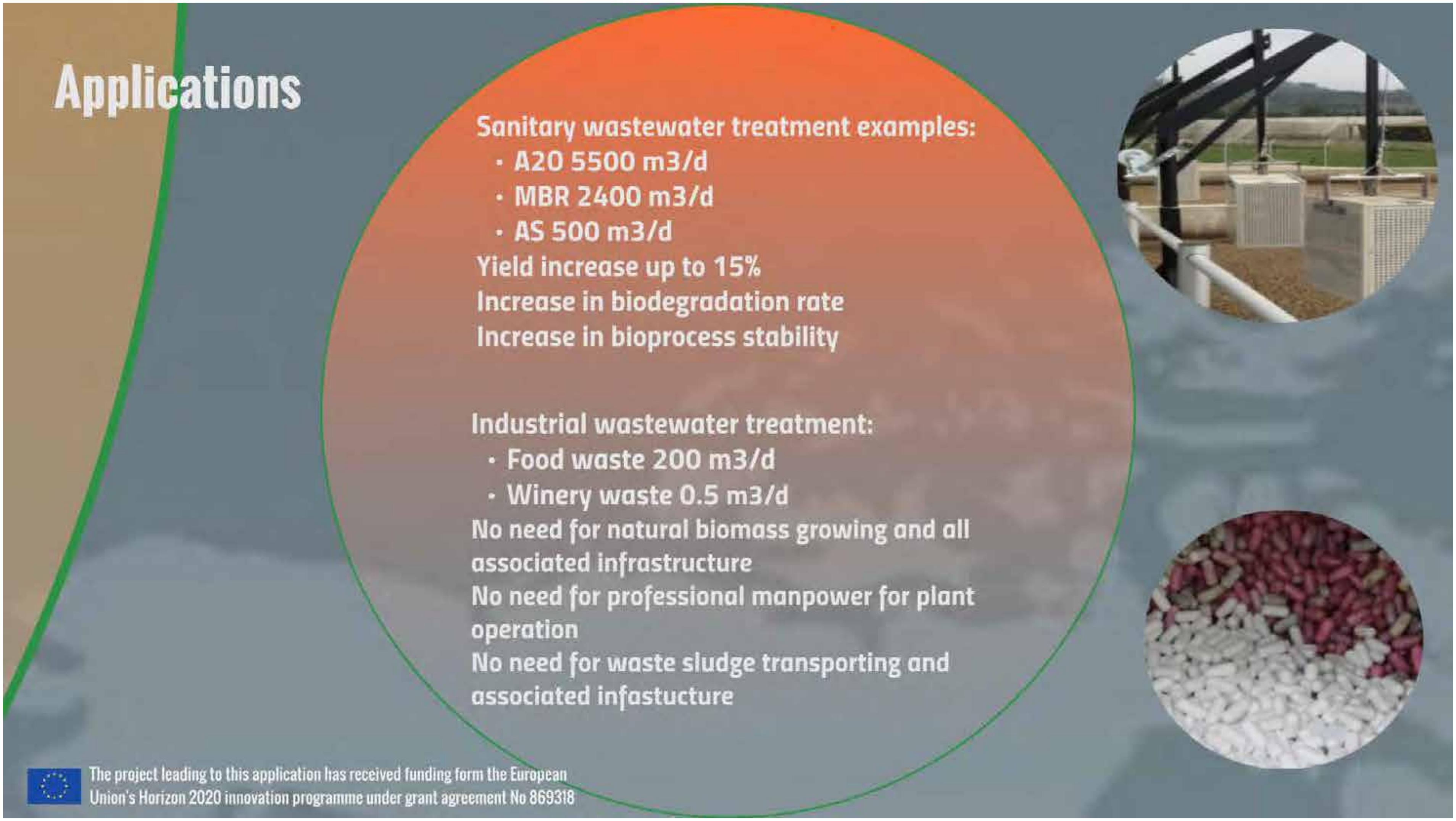
- Control of bacteria type growth
- Control of space bacteria grow
- Control of amount of bacteria

It can be implemented:

- to assist existing biological treatment units to cope with seasonal and unexpected shock load episodes
- to increase capacity with minimal CapEx
- as a small scale standalone solution with out the need of high-cost & extensive infrastructure



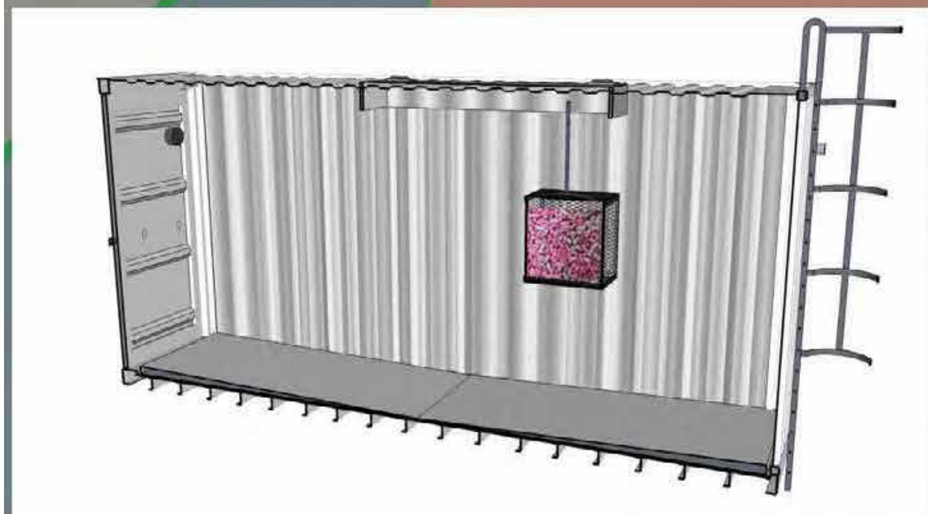
The project leading to this application has received funding form the European Union's Horizon 2020 innovation programme under grant agreement No 869318


Applications
Sanitary wastewater treatment examples:
· A20 5500 m3/d
· MBR 2400 m3/d
· AS 500 m3/d
Yield increase up to 15%
Increase in biodegradation rate
Increase in bioprocess stability
Industrial wastewater treatment:
· Food waste 200 m3/d
· Winery waste 0.5 m3/d
No need for natural biomass growing and all associated infrastructure
No need for professional manpower for plant operation
No need for waste sludge transporting and associated infastucture
The project leading to this application has received funding form the European Union's Horizon 2020 innovation programme under grant agreement No 869318

SBPs application in ULTIMATE

Investigate the synegistic effect of AOP-SBP

Goal: To create a universal treatment methodology for the food processing sector



Treat wastewater rich in compounds with antibacterial properties, e.g. polyphenols

Wastewater from:

- Olive oli mill
- Fruit & vegetable processing and juice production

Future: Phrmaceutical wastewater treatment

The project leading to this application has received funding form the European Union's Horizon 2020 innovation programme under grant agreement No 869318

ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

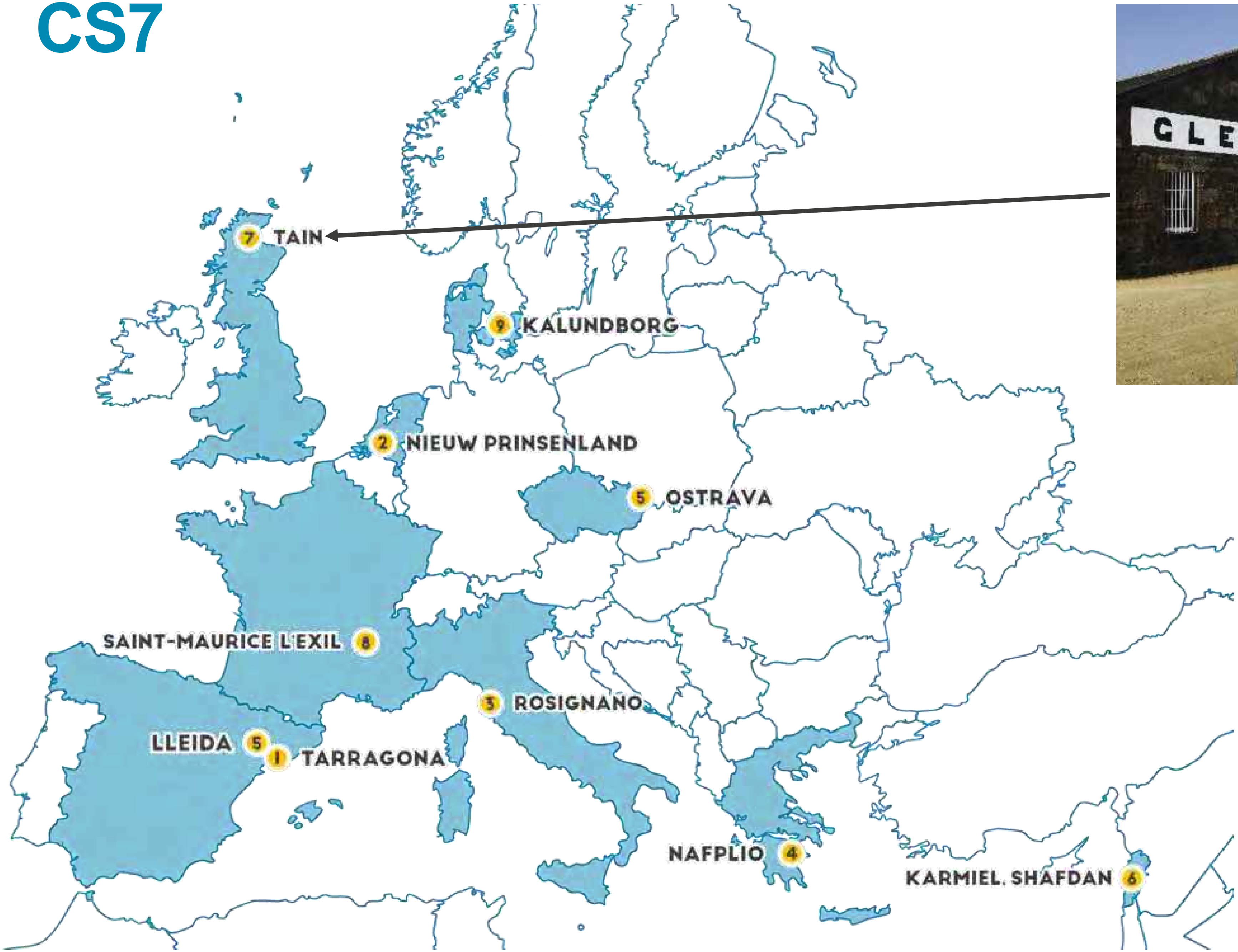
CS7 – Tain (Glenmorangie distillery)

Cranfield University

Aquabio

Meeting: November, 25th 2020

CS7

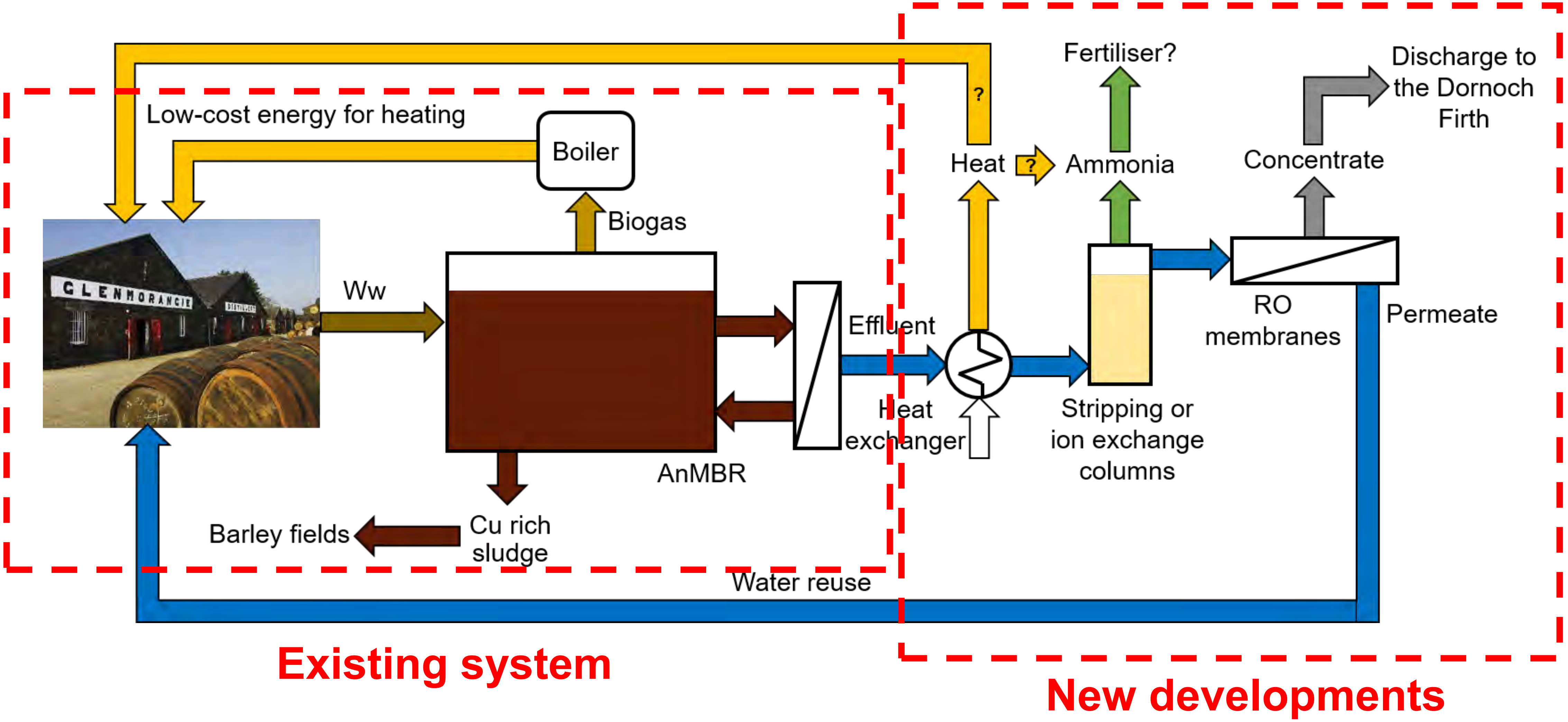


7 TAIN
9 KALUNDBORG
2 NIEUW PRINSENLAND
5 OSTRAVA
SAINT-MAURICE L'EXIL 8
3 ROSIGNANO
LLEIDA 5
1 TARRAGONA
NAFPLIO 4
KARMIEL, SHAFDAN 6

GLENMORANGIE

GLENMORANGIE
THE ORIGINAL

Treatment systems



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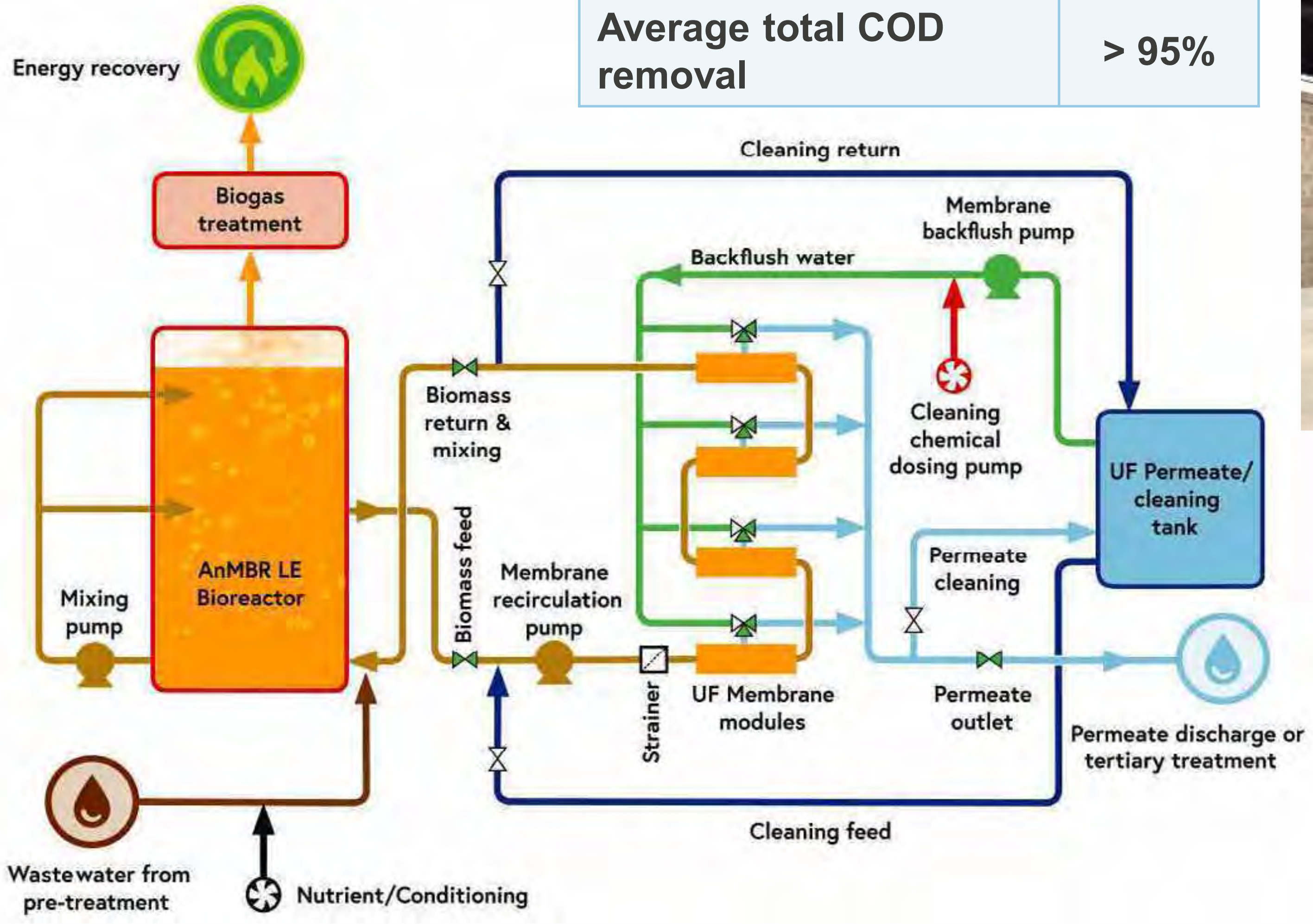
AnMBR LE™

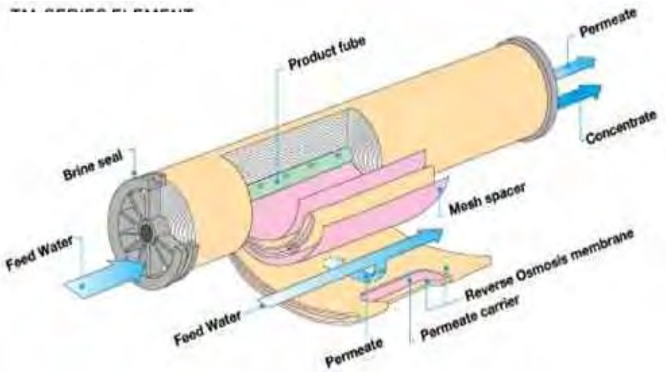
Peak/average AnMBR Feed flow rate (m^3/d)	467/377
Design COD load (kg/d)	14,527
Average total COD removal	> 95%

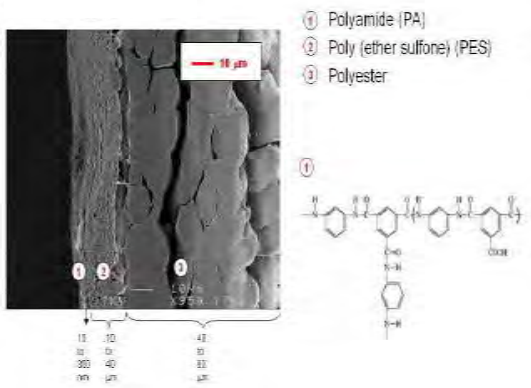


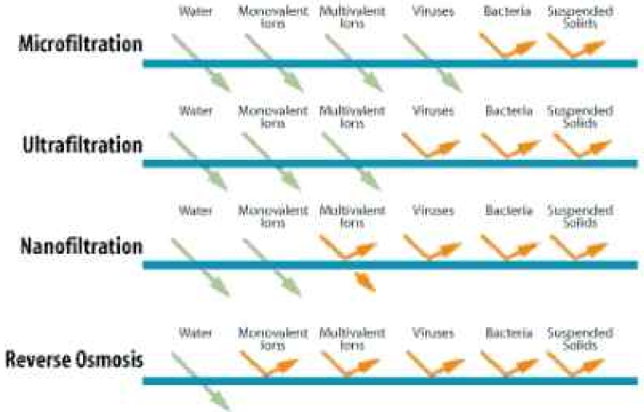
COD (mg/L)	656 (316 – 1454)
SS (mg/L)	3 (0 – 18)
NH_4-N (mg/L)	797 (329 – 1349)
NO_3-N (mg/L)	5 (4 – 8)
PO_4-P (mg/L)	252 (152 – 343)
pH	7.2 (6.4 – 8.0)

The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

Reverse osmosis







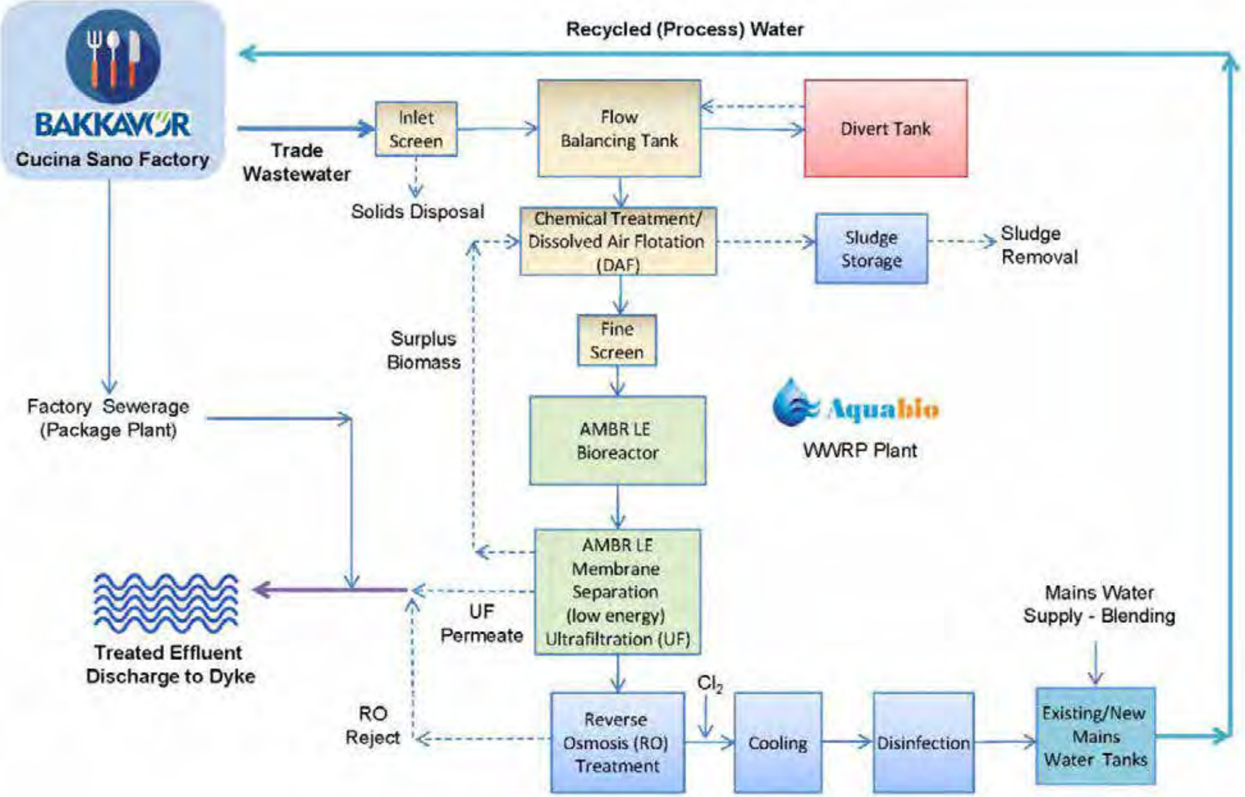
Demonstration of the application:

- Operational performance
- Treatment performance (fit for purpose)
- System integration

The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

Previous experience – food processing

Bakkavor Cucina Sano WWRP Scheme, Boston, Lincolnshire, United Kingdom



Average AeMBR flow rate (m^3/d)	500
Average COD load (kg/d)	3566
Average RO permeate flow rate (m^3/d)	425
Total water recovery for reuse	75-80%

The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

Trials

Operational performance:

- Optimum operation (flux, pressure)
- Fouling formation and cleaning regime
- Recovery rate

Integration (sequence):

- Heat => energy use
- Nutrients => fouling vs concentration

Treatment performance:

- Organics (including trace organic compounds)
- Nutrients
- Metals and other ions
- Microbial contamination
- Concentrate management

Internal milestones: water recovery		2020							2021												2022												2023												2024				
		6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
Wastewater characterisation																																																	
Lab to smale pilot scall trials																																																	
Demo unit design																																																	
Demo unit build																																																	
Demo unit commisioning																																																	
Demo unit peration																																																	

The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

Thank you!

ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

CS9 Kalundborg

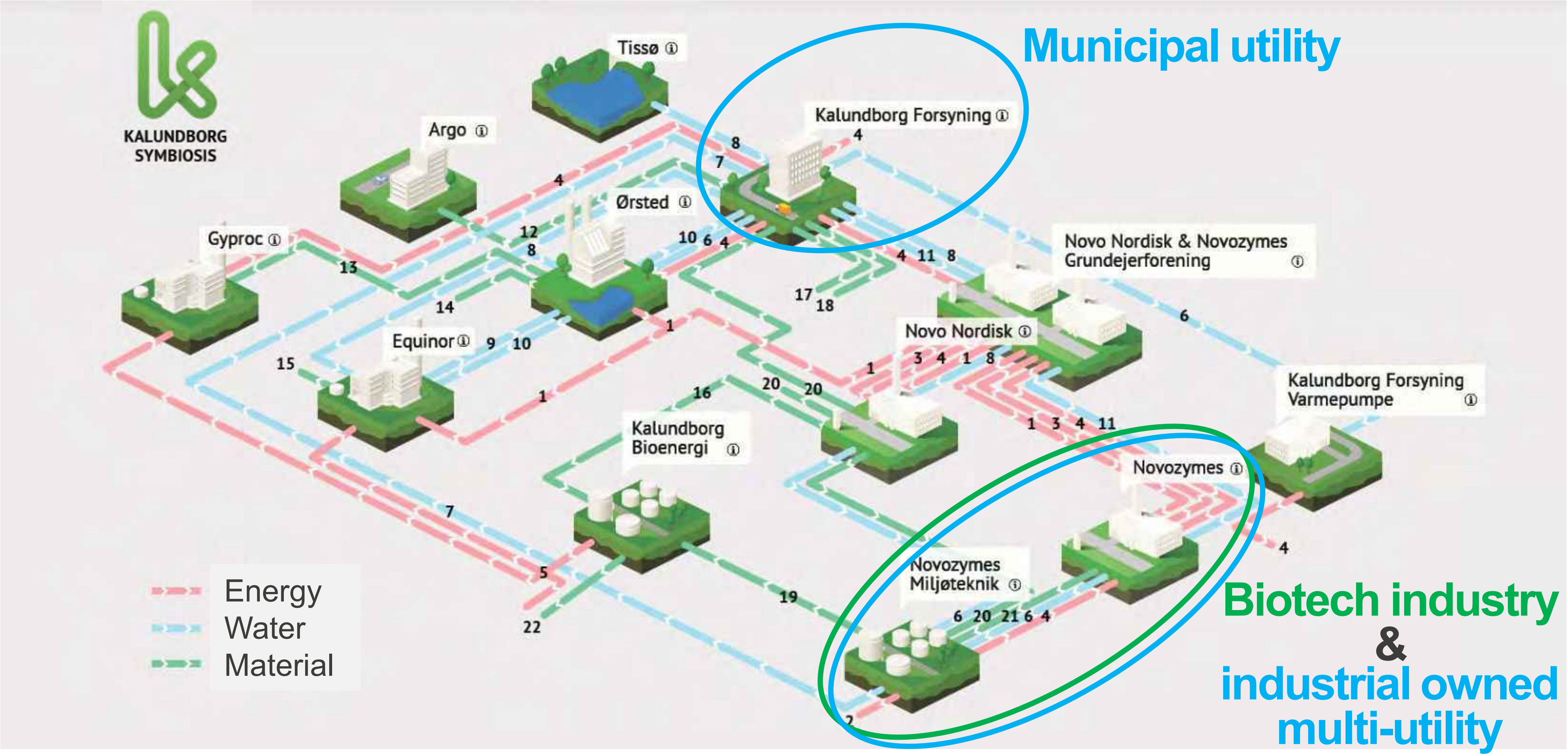
Ultra-tight UF in fit-for-purpose water treatment systems in the biochemical industry

Leo Vredenbregt

PENTAIR X-FLOW

CTG Membranes meeting: 25 November 2020

Kalundborg Symbiosis since 1972:



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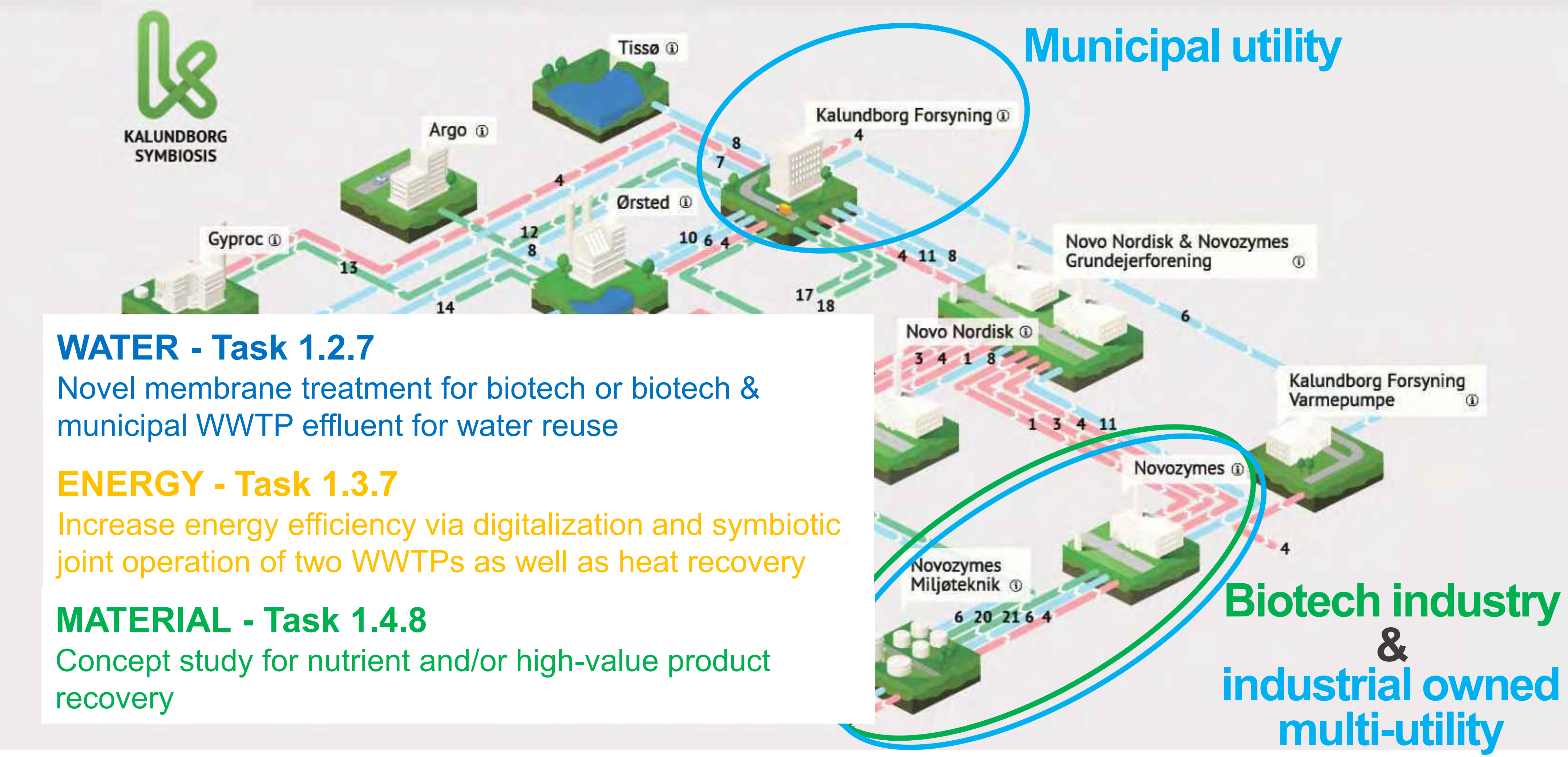
Kalundborg Symbiosis since 1972:



WATER - Task 1.2.7
Novel membrane treatment for biotech or biotech & municipal WWTP effluent for water reuse

ENERGY - Task 1.3.7
Increase energy efficiency via digitalization and symbiotic joint operation of two WWTPs as well as heat recovery

MATERIAL - Task 1.4.8
Concept study for nutrient and/or high-value product recovery

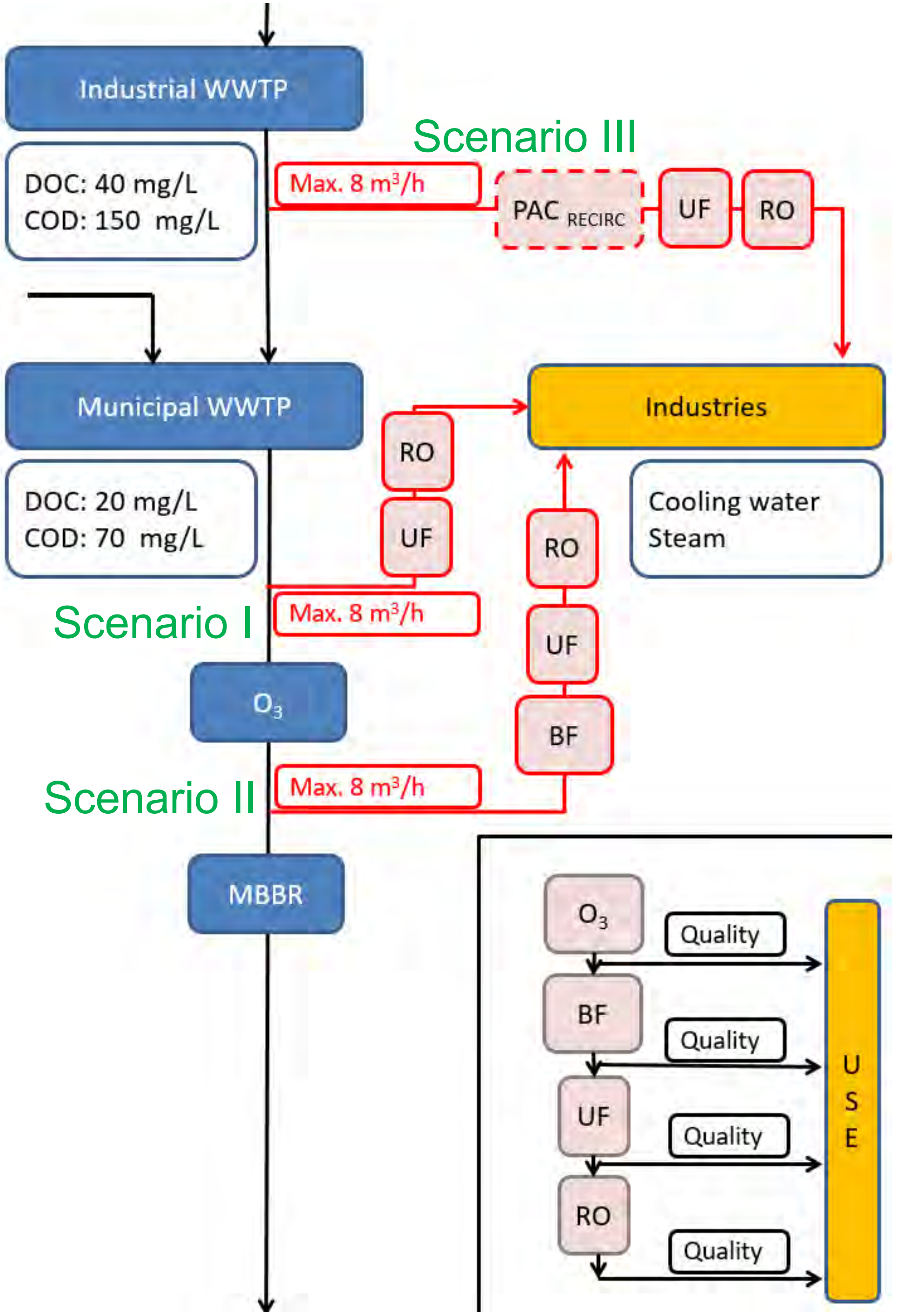
The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

WATER - Task 1.2.7

Novel membrane treatment for biotech or biotech & municipal WWTP effluent for water reuse

Partners:

KALUNDBORG FORSYNING
novozymes Rethink Tomorrow
PENTAIR X-FLOW
KOMPETENZZENTRUM Wasser Berlin



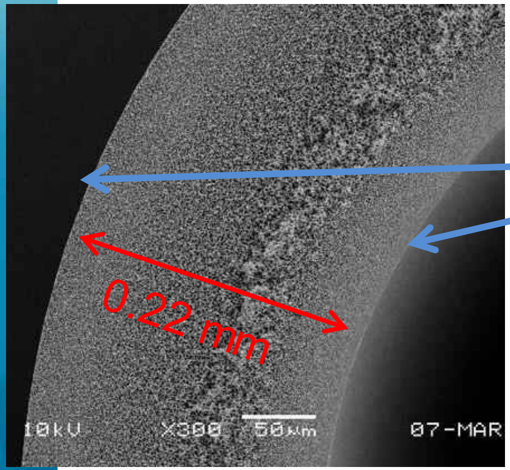
OBJECTIVE:
Production of fit-for-purpose water via:
→ novel (ultra tight) ultra-filtration membrane combined with
→ pre-treatment for wastewater with high-non-degradable organic matter

The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

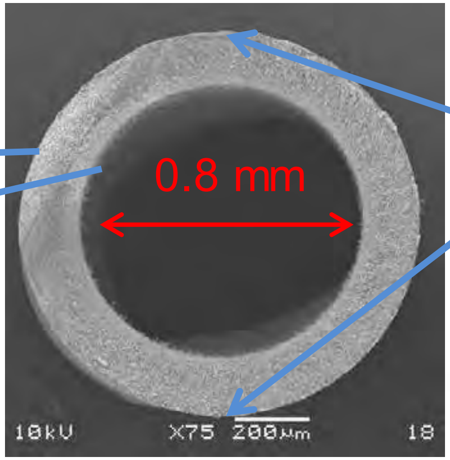
Hollow Fiber Ultrafiltration

PENTAIR X-FLOW

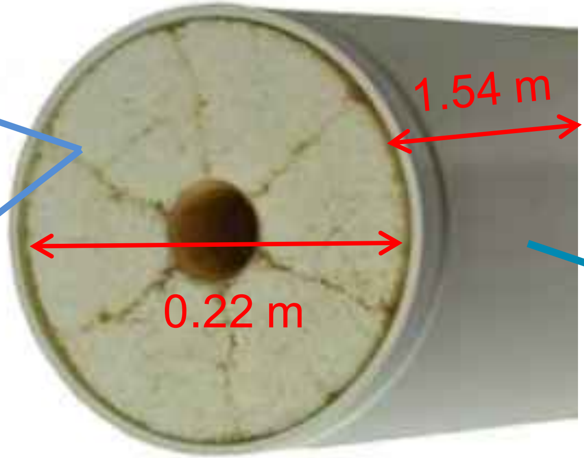
- Hollow fibers: 0.8 mm internal diameter
- Filtration: inside out
- Material: polyvinylpyrrolidone / polyethersulfone
- Module: 0.22 / 1.5 m (diameter / length), 64 / 75 m^2
- > 99.99% virus removal (NSF61 & NSF41)



Fibre wall



Fibre



Module head

Skid with modules

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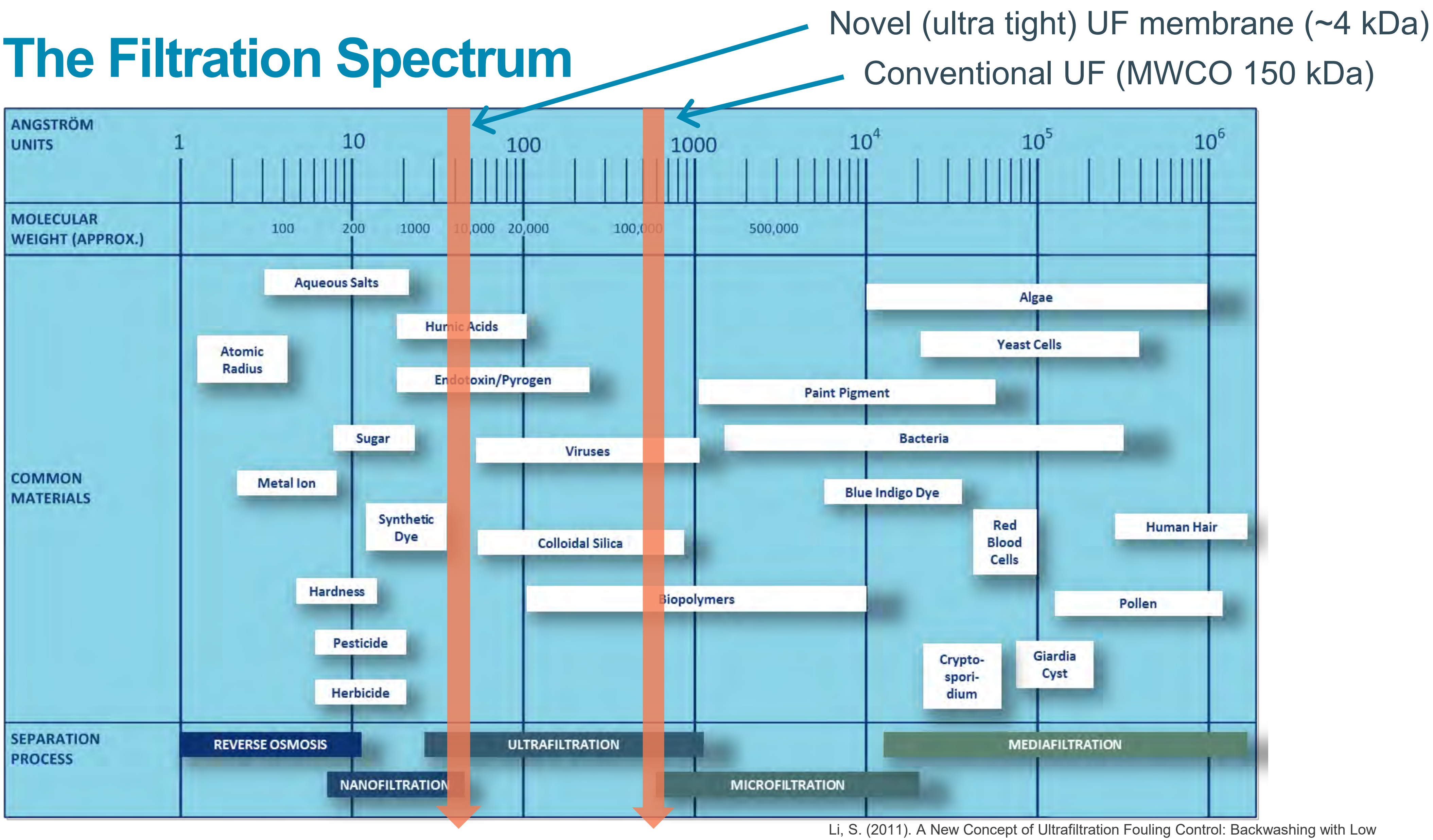
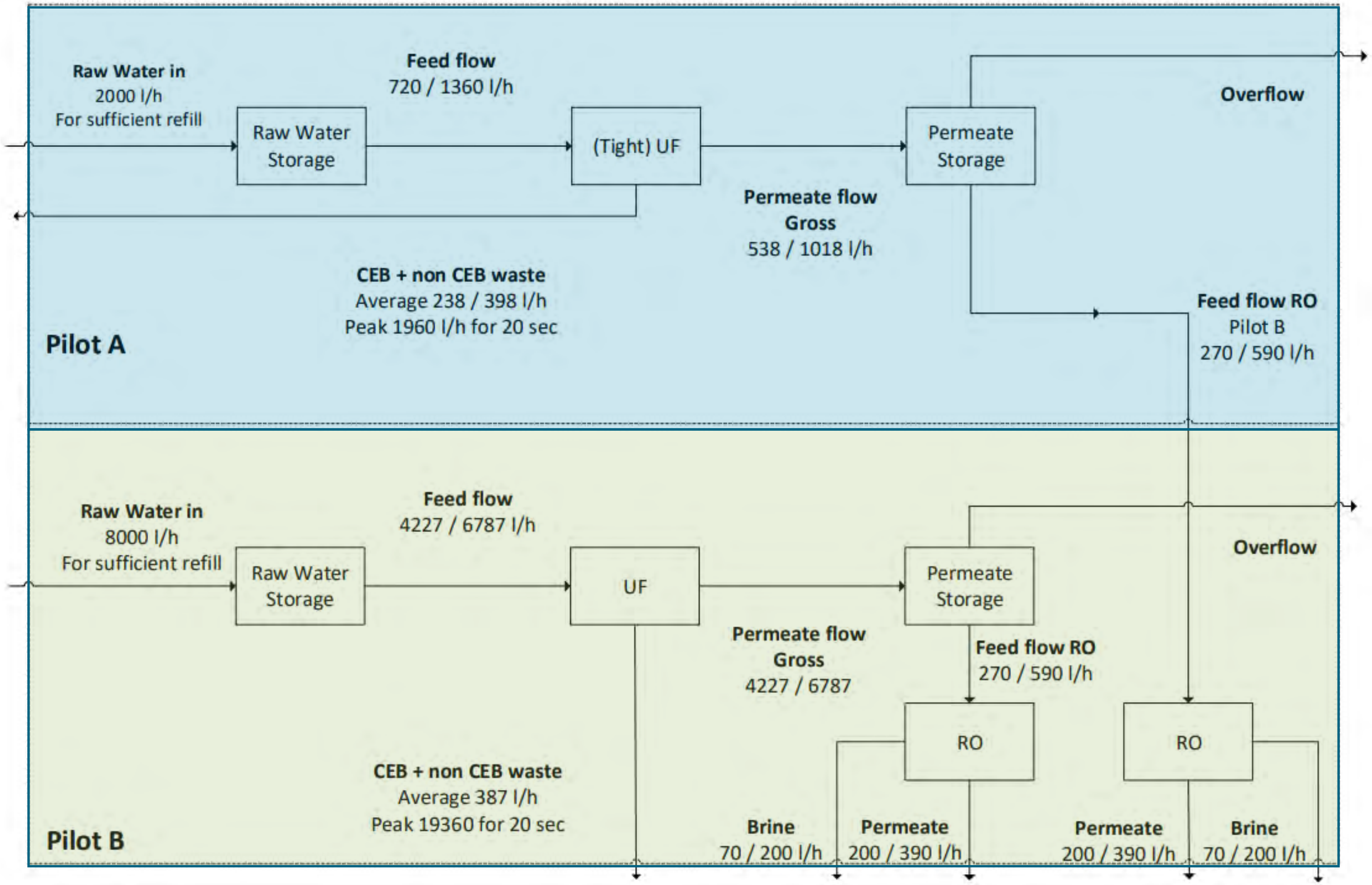
The Filtration Spectrum



Li, S. (2011). A New Concept of Ultrafiltration Fouling Control: Backwashing with Low Ionic Strength Water. Delft, The Netherlands, Technische Universiteit Delft.

The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

Schematic setup pilot plants



- Pilot A:

20 ft container with new tight UF

- Pilot B:

40 ft container with conventional UF and 2 small RO-units

Each RO-unit receives permeate from one of the UF-processes

Li, S. (2011). A New Concept of Ultrafiltration Fouling Control: Backwashing with Low Ionic Strength Water. Delft, The Netherlands, Technische Universiteit Delft.

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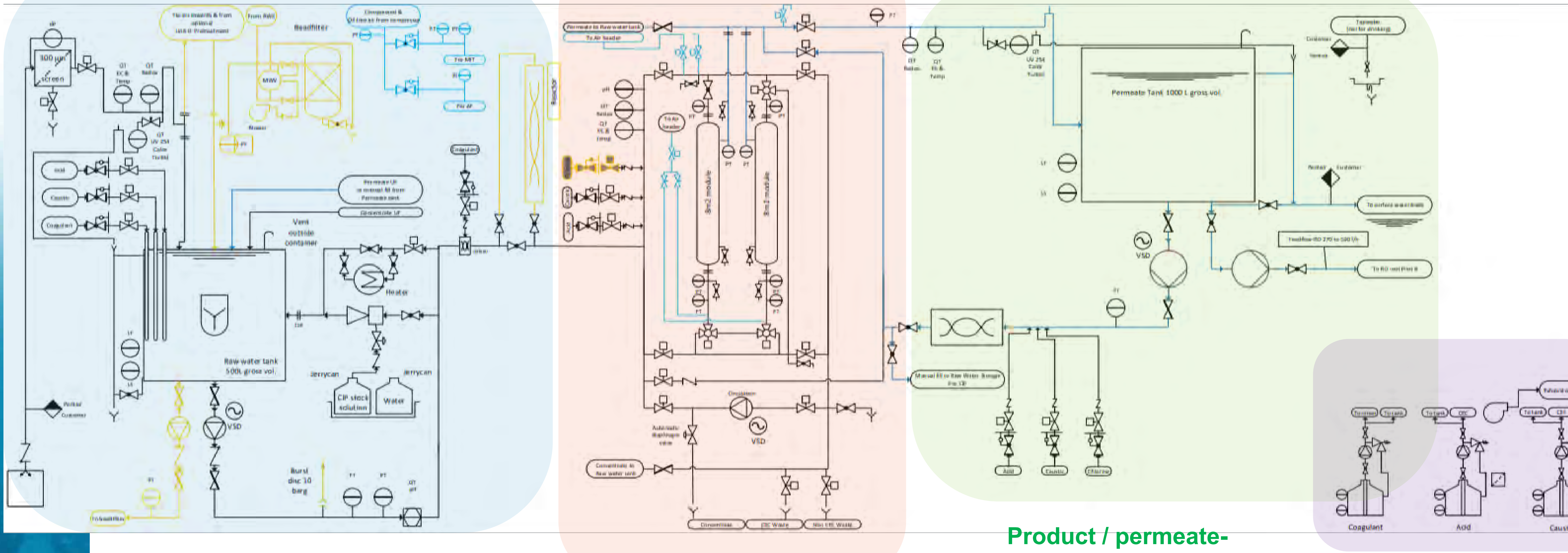
Flow diagram pilot A (tight UF)



Feed-section

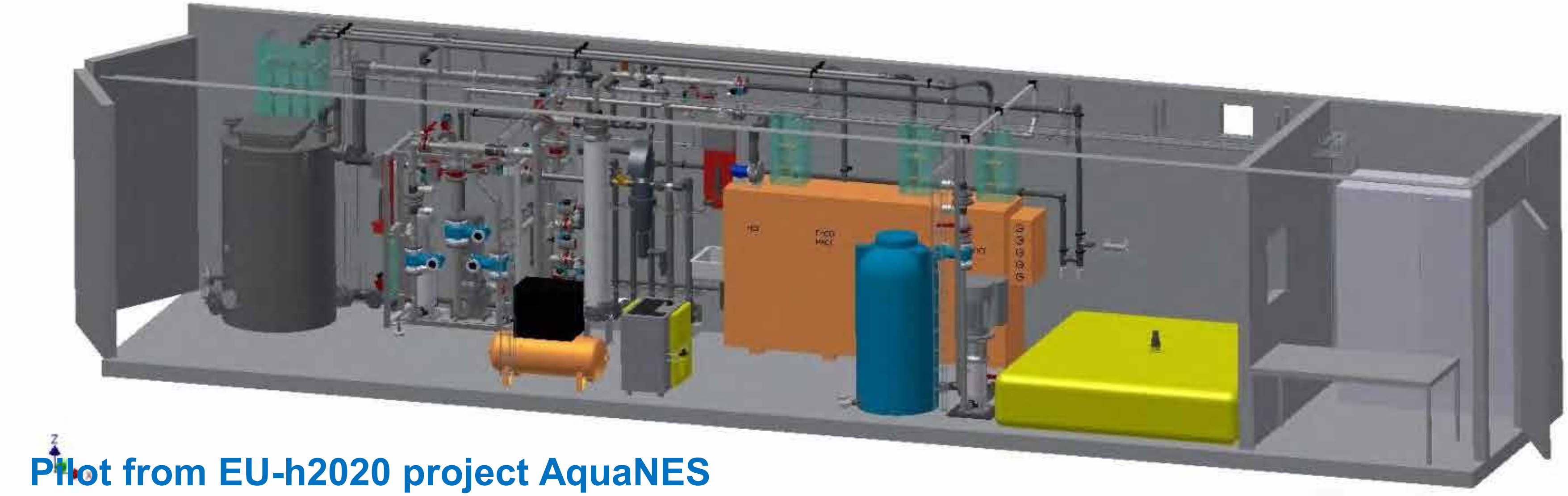
Membrane-section

Product / permeate-section

Chemical cabinet

The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

Pilot B from previous EU-h2020 project will be refurbished



Pilot from EU-h2020 project AquaNES

Containerized (40 feet)

Remote controlled

Full-scale NF or UF module (40-75 m^2)

Variable process settings

Simulation of one full-scale filtration stage

Feed: 0.5 – 6 m^3/h

Panorama-tour: http://showcase24.eu/pano/bwb-tiefwerder.html

The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

9

KPI's proposed (for Task 1.2.7)

KPI proposed	Parameter to be determined
Water yield & reduction of fresh water through reuse of treated wastewater	Inlet and outlet flowrate of the system Recoveries (UF, RO)
Water quality	Removal of specific compounds. Physicochemical and microbiological parameters from inlet and outlet; emerging organic pollutant; nutrient removal (or recovery)
Other parameters to be determined	
Energy consumption	Energy used for the treatment per m^3 obtained Energy used per kg of pollutant removal
Reagents & materials required	Amounts of reagents used for treatment or materials (flocculant, etc.) per m^3 produced and kg of pollutant removed
Wastes produced	Sludge generated (kg per m^3 produced) and brines (m^3 per m^3 produced)

WATER - Task 1.2.7

Parameters to be determined in detail (to be discussed!)

- Physicochemical parameters (temperature, pH, conductivity, O_2, ORP, turbidity, suspended solids/ TDS, UV absorption (254nm), colour (436nm), DOC, TOC, COD, Fe, Mn, hardness, carbonate hardness, Ca, Mg, CO_2, HCO_3, acid capacity, base capacity, total alkalinity, Al, Ba, Cl, K, Na, SiO_2, Sr, F, B, SO_4 – only a selection continuously!)
- Microbiological parameters (pathogenic bacteria, viruses and parasites (e.g. *E. Coli*, *Enterococcus*, somatic coliphages, *Clostridium perfringens* spores/spore-forming sulphate reducing bacteria)), Emerging organic pollutants (depending on existing pollutants)
- Nutrients (NH_4, NO_3, PO_4, TP, BOD_5)
- Performance parameter (flow, pressure, temperature, intervals backwash, chemical cleaning, CIP's)

The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

Planning for testing water reuse (Task 1.2.7)

		2020							2021												2022												2023												2024				
		6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5
Internal milestones: pilot plant		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
UFs (novel & commercial), RO designed	X-Flow																																																
UF’s & RO’s constructed	X-Flow																																																
Commissioning pilots	X-Flow																																																
Transport, installation & commiss. on site	X-Flow																																																
Support pilot process operation	X-Flow																																																
Discussion & support: pilot plant design	all																																																
Preparation of periphery for plant imple-mentation (pipes, electricity, etc)	KAL																																																
Pilot plant implemented and operational	KAL																																																
Scenario I: UF&RO – pilot operation	KAL																																																
Scenario I (UF-RO) - evaluation	KWB																																																
Biofilter (BF): tendering for rental	KAL																																																
Preparation of periphery for plant imple-mentation for scenario II	KAL																																																
Scenario II: O3/BF-UF&RO – pilot operation	KAL																																																
Scenario II (O3-BF-UF-RO) - evaluation	KWB																																																
PAC unit tendering	Novo																																																
Preparation of periphery for plant imple-mentation for scenario III	KAL																																																
Scenario III: PAC - UF&RO – pilot operation	KAL																																																
Scenario III ([w/&w/o PAC]-UF-RO) - evaluation	KWB																																																
Comparison of Scenarios	KWB																																																

The project leading to this application has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 869318

Summerizing some high lights

The project will deliver:

- Insight in the performance of the novel ultra-tight UF membrane (with challenging WWTP effluents)
- Insight in quality of produced water
- Effectiveness of novel UF in protecting the RO is compared with conventional UF
- KPI's will be available to assess the (economic) feasibility for the water treatment steps

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Li, S. (2011). A New Concept of Ultrafiltration Fouling Control: Backwashing with Low Ionic Strength Water. Delft, The Netherlands, Technische Universiteit Delft.

Watermining Synergies: Pilot System for Water, Salt and Energy recovery from urban wastewater

25 November 2020

Maria Kyriazi, National Technical University of Athens
makyriazi@gmail.com

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement 869474.

Larnaca WWTP with numbers

Person Equivalent 100.000

Average Inflow 18.000 m^3/day

Maximum Inflow 27.000 m^3/day

2.500.000 m^3 of water/year

5.000 m^3 of sludge/year

water mining

Problem

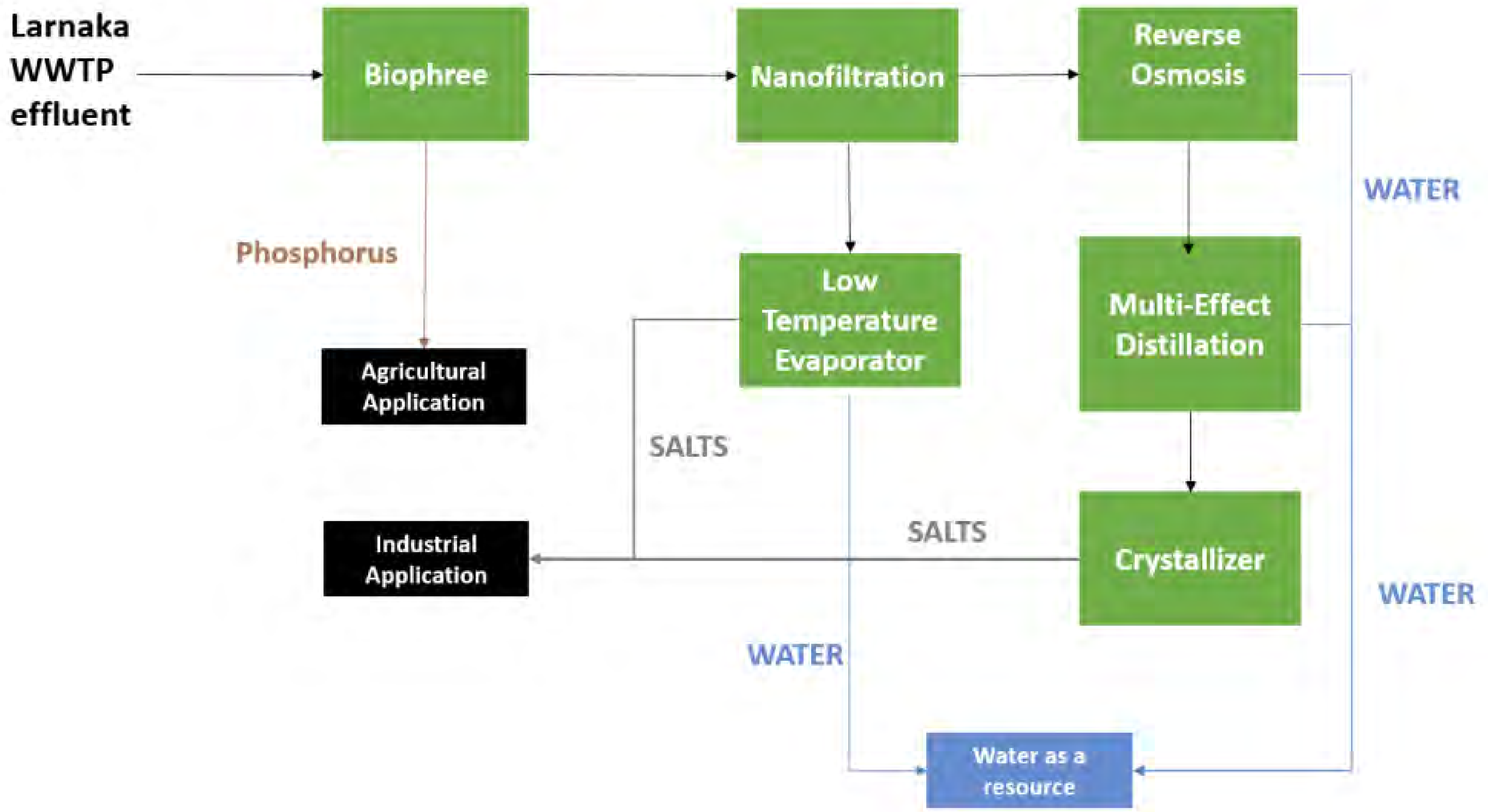
Water of high salinity→ salt accumulation will cause problems to land and cultivations

Pilot Objectives

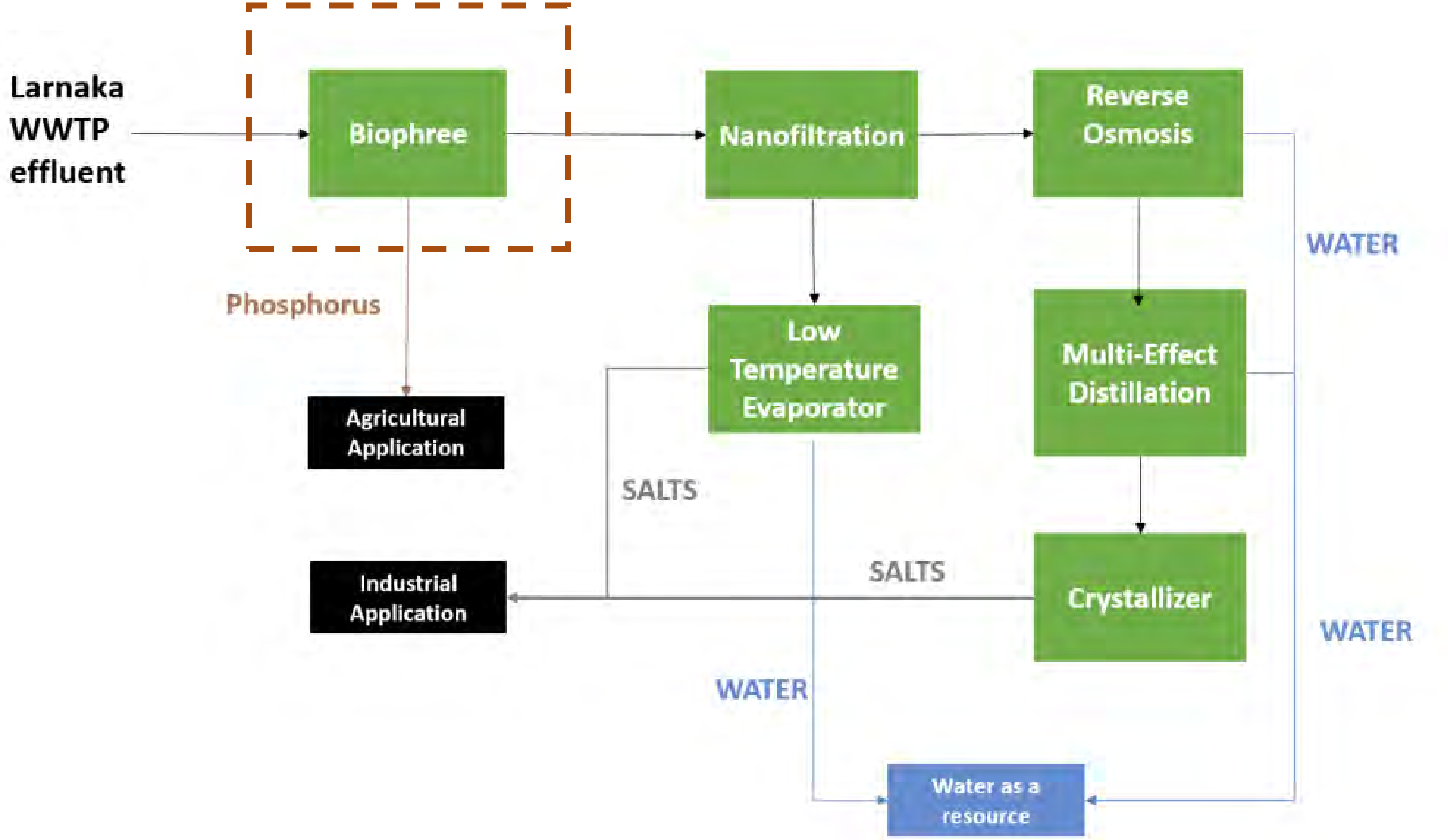
- Ultra low phosphorus concentration in the effluent (<0,05 mg/L)
- Recovery of phosphorus
- Recovery of NaCl
- Recovery of water

water mining

Process flow diagram of pilot



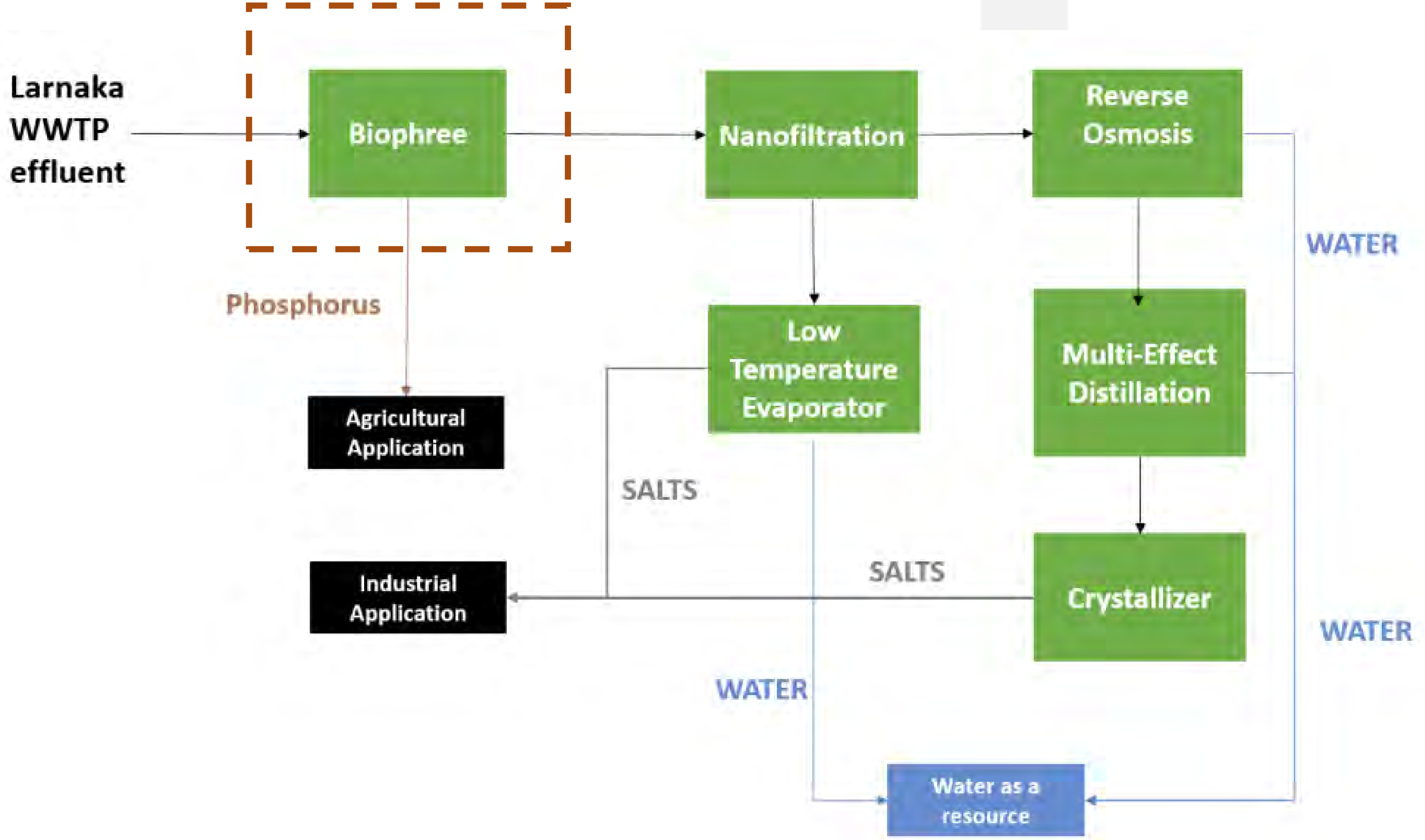
Process flow diagram of pilot



Biophree

- The effluent from the membrane bioreactor will be treated in a pilot scale Biophree installation (capacity 1 m^3/h).
- Biophree will be supported and constructed by WETSUS
- Biophree will absorb the remaining phosphorus in the permeate of membrane bioreactor.
- Phosphorus concentration will be decreased from 0,5 mg/L to 10-40 ppb .
- At these low levels of phosphorus concentration biological growth is limited.
- Reduction of biofouling and prevention of harmful algae growth in the intermediate reservoirs.

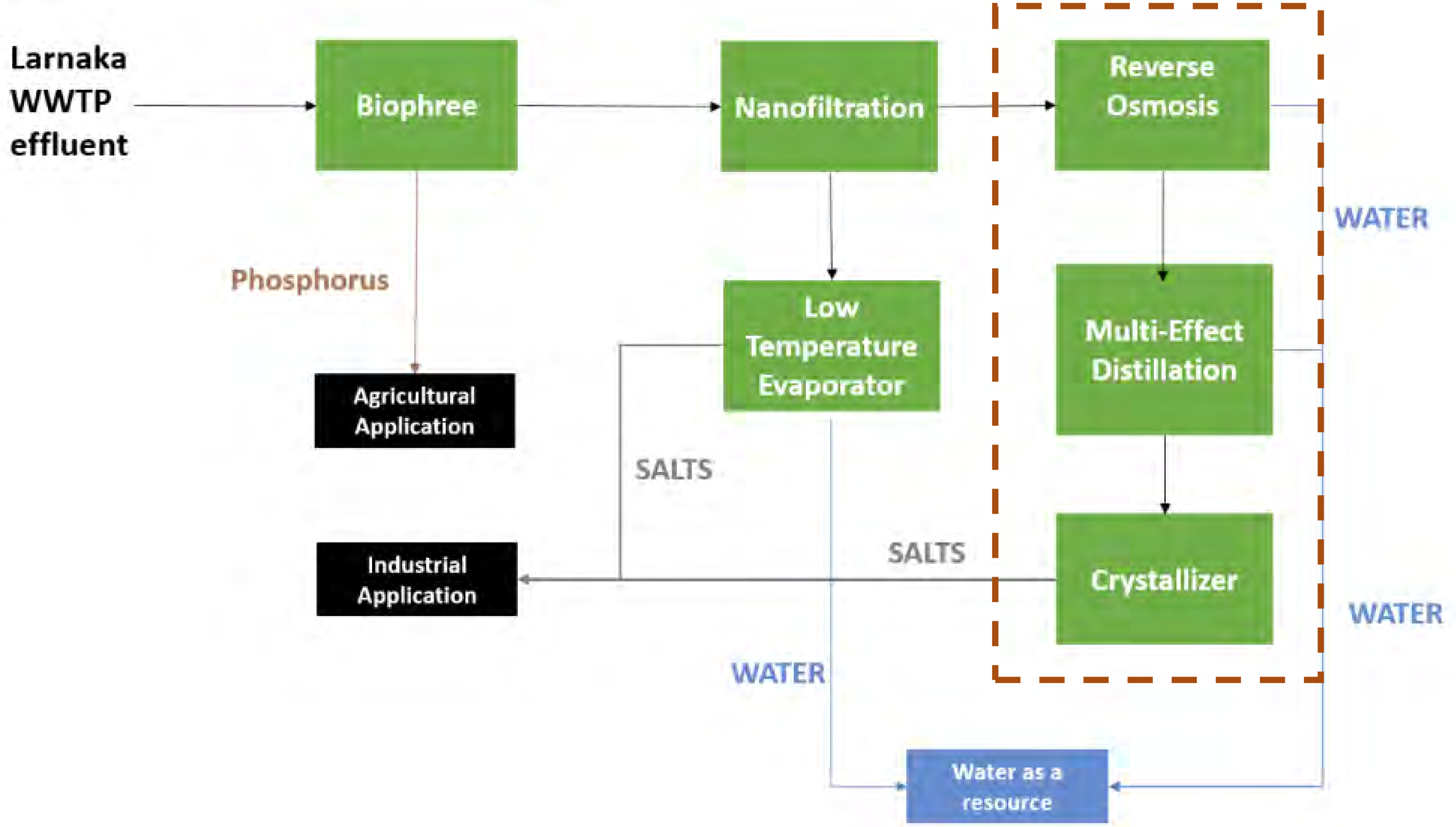
Process flow diagram of pilot



Nanofiltration and Low Temperature Evaporator

- Inflow: the effluent of Biophree ~1 m^3/h
- Separation of Monovalent form divalent ions (Mg and Ca)
- Condensate about 30% →LTE
- LTE recovers salts of Mg and Ca (80mg/L and 150 mg/L).
- LTE works with low temperature for avoiding scaling.
- About 30% of water recovered at this stage.
- Permeate to the next treatment stage.

Process flow diagram of pilot



Reverse Osmosis Multiple Effect Distillation (MED) Evaporator

- RO inflow: the permeate of NF ~0,6-0,7 m^3/h (NaCl~2%)
- Separation of monovalent ions from water ~0,42-0,49 m^3/h of water with low conductivity
- Condensate about 30-40 % →MED (NaCl ~7%)
- MED evaporator will condensate NaCl solution from 7% to about 19% and produce clean water.
- Crystallizer condensate MED effluent (NaCl concentration ~19%) → saturated solution ~26% NaCl
- The saturated solution of NaCl will be used in the chlorination unit.
- Water for irrigation or industrial unit.


GREEK BRINE
EXCELLENCE CENTER

water mining

Renewable Energy

- MED evaporator will be coupled with solar panels.
- Energy needed for the other technologies of system will be produced by photovoltaics in order to minimize environmental footprint of the project and CO_2 production.

Thank you for your attention!!!

Annex 2: Presentations – Adsorption technologies

The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

CTG meeting:

Adsorption technologies in wastewater treatment

When: 31st March 2021 (11-13h)

Where: Online meeting Click here to join the meeting

11:00 h Opening and Welcome. Sandra Casas (EURECAT).

11:10 h ULTIMATE: Removal of ammonia from wastewater by adsorption with zeolites (CS1). Andrea Naves (EURECAT).

11:25 h ULTIMATE: Adoption - extraction methodologies for the extraction of value-added compounds from food-processing wastewater (CS4 y CS6). Dimitri Iossifidis (GREENER THAN GREENER).

11:40 h SMARTPLANT: Removal of key pollutants from wastewater by adsorption: N, P and COD. Ana Soares (CRANFIELD UNIVERSITY).

11:55 h SEA4VALUE: 3D-printed adsorbents for metal recovery. Eveliina Repo (LAHTI UNIVERSITY OF TECHNOLOGY).

12:10 h WATERMINING: BioPhree: Reversible phosphate adsorption for P-removal to ultra-low levels and P-recovery. Demonstrations and perspectives. Wokke Wijdeveld (WETSUS).

12:20 h NEXTGEN: Renewable granular active carbon for removal of organic micropollutants in urban wastewater. Luca Loreggian (Fachhochschule Nordwestschweiz).

12:30 h Open discussion and closure. Sandra Casas (EURECAT).

ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

Adsorption technology webinar

S.Casas, A. Naves

March, 31st 2021

ULTIMATE-Adsorption technology webinar

Please mute your microphone

Use the chat for questions!

Presenters have your presentation open and ready!

Write your name and email in the chat if you want to keep posted or receive presentations of today's meeting!

The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

Ultimate (June 2020 – May 2024):

Industry water-utility symbiosis for a smarter water society

- Promotion, establishment and extension of **Water Smart Industrial Symbioses**
- Development and demonstration of **innovative technologies** for symbioses
- **Assessment** of the technologies and development of **digital „support tools"**
- Development of **new business models** towards marketability

9 Symbioses between:

Industrial sectors
- Agro-food
- Beverage
- (Petro)chemical
- Biotech

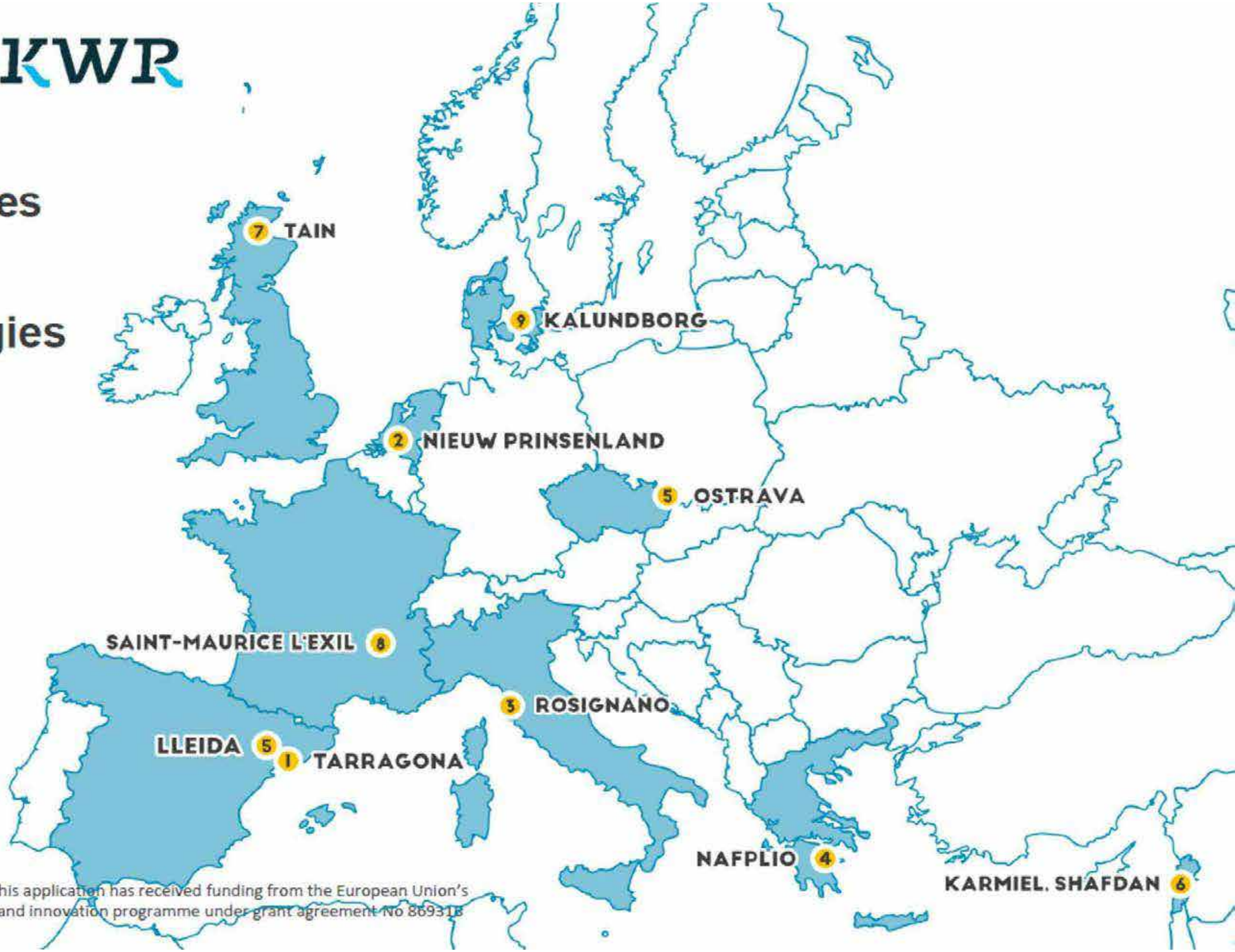
Service providers
- Municipal utility
- Multi-industry utility
- Specialized SME
- Water services provider

Coordinator: KWR

9 Case Studies

27 Partners

37 Technologies



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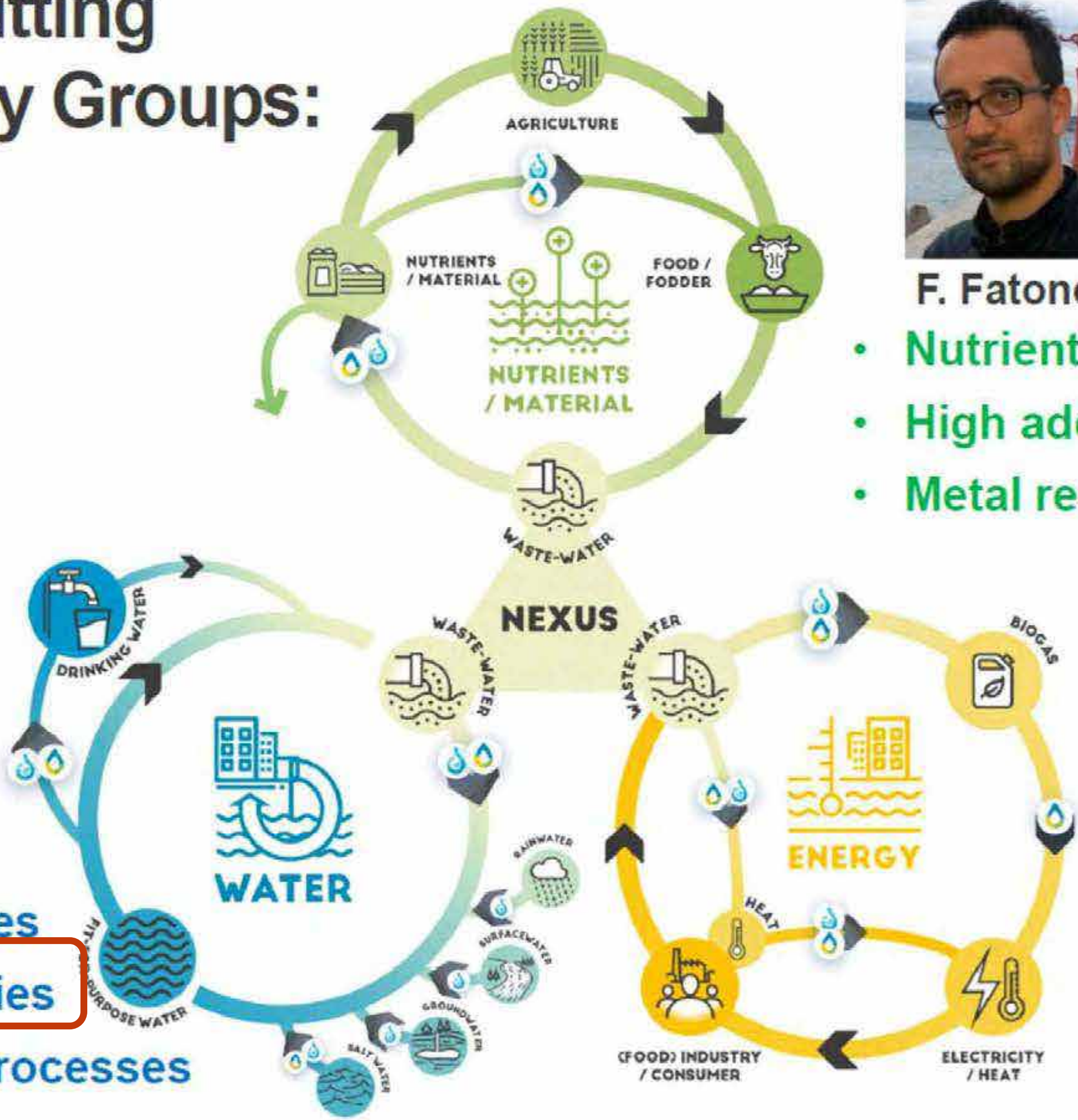
3 Cross-cutting Technology Groups: 9 Topics



F. Fatone C. Bruni

UNIVERSITÀ POLITECNICA DELLE MARCHE

- Nutrient recovery
- High added value products
- Metal recovery

eurecat
Centre Tecnològic de Catalunya


A.Naves S. Casas

- Membrane technologies
- Adsorption technologies
- Advanced oxidation processes

KOMPETENZZENTRUM Wasser Berlin

A. Kleyböcker

- Biogas technologies
- Heat recovery
- Digitalization

Coordinator: KWR

9 Case Studies

27 Partners

37 Technologies

The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

Agenda

11:00 h	**Opening and Welcome.** Sandra Casas (EURECAT)
11:10 h	**ULTIMATE: Removal of ammonia from wastewater by adsorption with zeolites (CS1).** Andrea Naves (EURECAT)
11:25 h	**ULTIMATE: Adsorption - extraction methodologies for the extraction of value-added compounds from food- processing wastewater (CS4 y CS6).** Dimitri Iossifidis (GREENER THAN GREENER)
11:40 h	**SMARTPLANT: Removal of key pollutants from wastewater by adsorption: N, P and COD.** Ana Soares (CRANFIELD UNIVERSITY)
11:55 h	**SEA4VALUE: 3D-printed adsorbents for metal recovery.** Eveliina Repo (LAHTI UNIVERSITY OF TECHNOLOGY)
12:10 h	**WATERMINING: BioPhree: Reversible phosphate adsorption for P-removal to ultra-low levels and P-recovery. Demonstrations and perspectives.** Wokke Wijdeveld (WETSUS)
12:20 h	**NEXTGEN: Renewable granular active carbon for removal of organic micropollutants in urban wastewater**. Luca Loreggian (Fachhochschule Nordwestschweiz)
12:30 h	**Open questions and closure.** Sandra Casas (EURECAT)

The project leading to this application has received funding from the European Union's
Horizon 2020 research and innovation programme under grant agreement No 869318

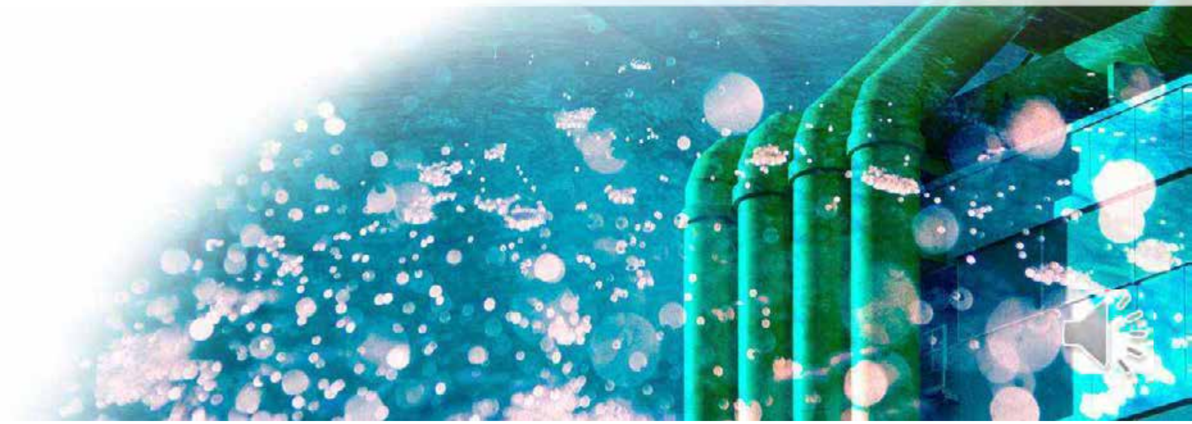
ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

Removal of ammonium from wastewater by adsorption with zeolites (CS1)

D. Montserrat, J.E. Manero (AITASA)

S. Casas, A. Naves (EURECAT)



CS1: Petrochemical Complex of Tarragona (Spain)

AITASA was founded in 1965 to supply water to the Tarragona petrochemical complex.

This industrial area groups several companies **of the chemical and petroleum field.** it has been considered the most important of this type in Catalonia, Spain and the south of Europe.

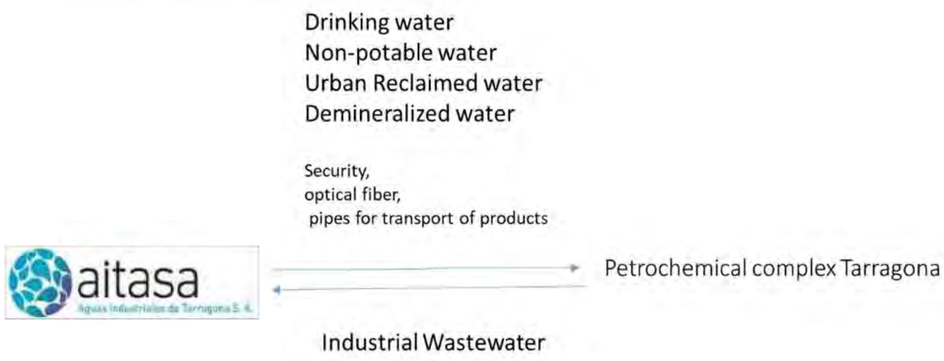
More than 30 companies operate in the petrochemical complex focusing on production of chlorine, alkaline salts, oxygen gas, fertilizers, insecticides, fuels, plastics and synthetic essences.

In 2012, a water reclamation plant was put in operation to supply industrial water and, currently, it is runned by AITASA.

Partners:

eurecat Centre Tecnològic de Catalunya

aitasa Aigües Industrials de Tarragona S.A.



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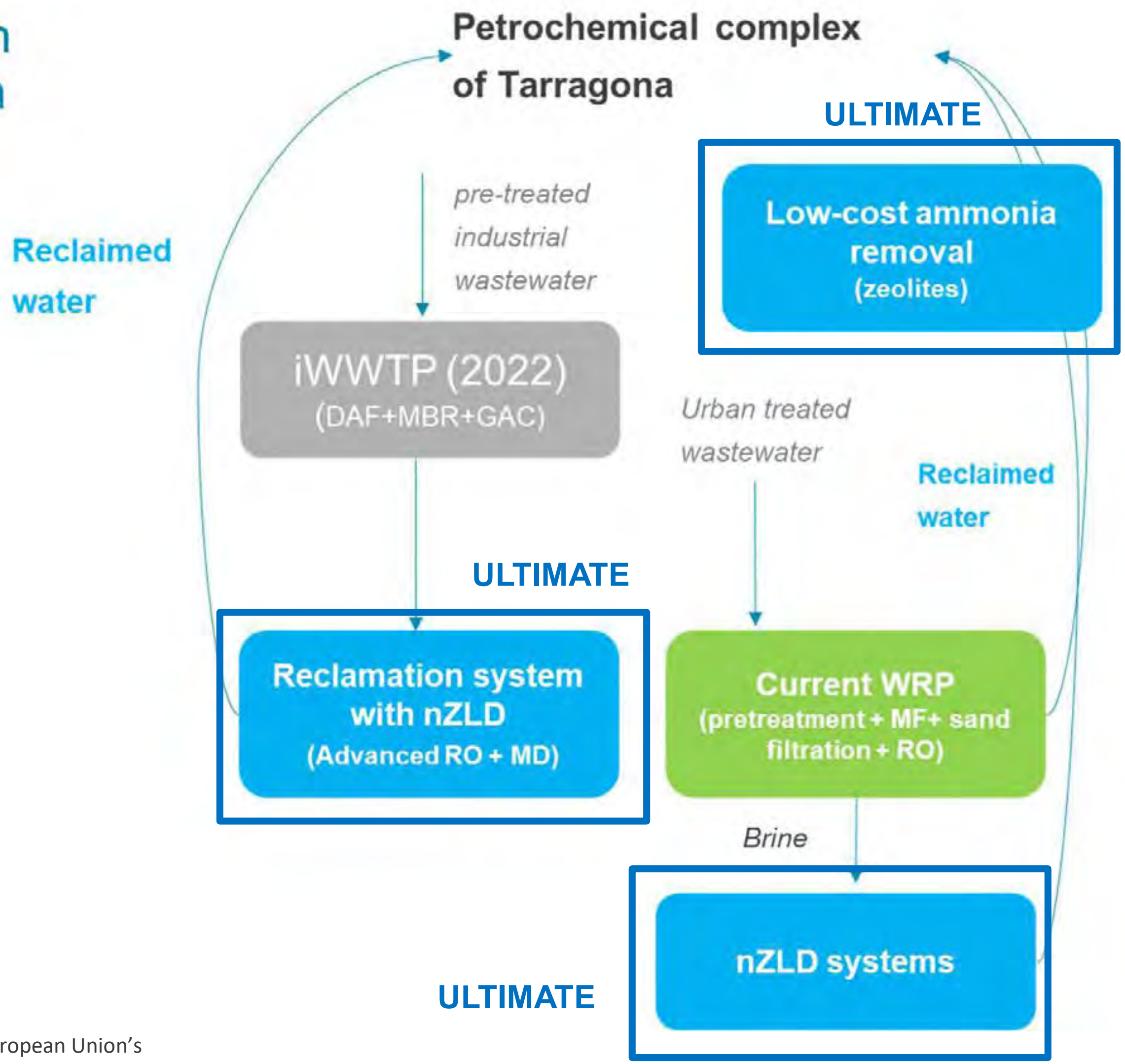
WATER - Task 1.2.1

Increasing reclaimed water availability in the petrochemical complex of Tarragona

OBJECTIVE:
Increase reclaimed water availability for the complex by 20%:

→ **Current WWRP**:
  → Increase water recovery of the current WWRP with nZLD technologies
  → Remove the ammonium with low-cost technologies

→ **Future iWWTP**:
  → Defining a tertiary treatment with nZLD technologies from the future



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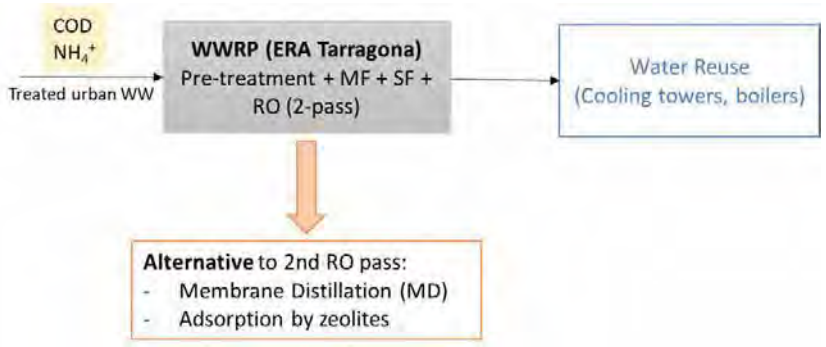
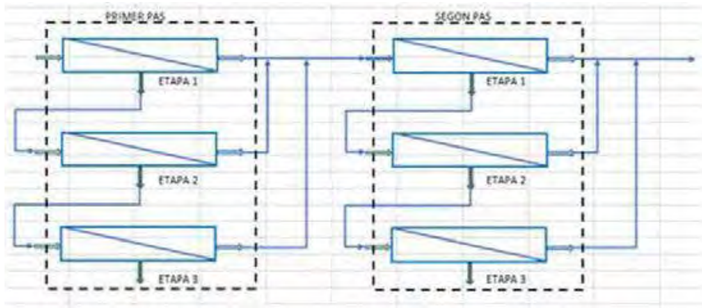
Ammonium removal from wastewater

- Current implemented technology to remove ammonium from water in WRP:
  - AITASA removes ammonium from water by 2-pass RO



AITASA CURRENT AMMONIUM REMOVAL PROCESS (RO)



NH^{+4} inlet (average)	22 mg/L
NH^{+4} outlet (required value)	0.8 mg/L

- Other technologies to remove ammonium from wastewater:
  - Electrodeionization/electrodyalisis
  - Anaerobic oxidation process (biological treatment)
  - Membrane distillation (direct contact membrane distillation DCMD, vacuum membrane distillation VMD, sweeping gas membrane distillation SGMD)
  - Adsorption → Technical-economical feasibility assessment

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Ammonium removal from wastewater by adsorption with zeolites

AMMONIUM ADSORPTION MATERIALS

There are different materials to adsorb ammonium from wastewaters: zeolites, zeolite-like sepiolite, bentonite, bioadsorbents *(Boston ivy leaf powder),* biochar

Adsorbent material	Adsorption capacity
Bioadsorbent *(Boston ivy leaf powder)*	3.3-6.6 mg N/g (15-35ºC)
Sepiolite	0.8-1.5 mg N/g
Biochar (from rice straw)	2.9-4.6 mg N/g (20-50ºC, pH=7.5)
Clinoptilolite (natural zeolite)	8.1-15.2 mg N/g

ZEOLITES CHARACTERISTICS

- **Structure:** zeolites are **crystalline microporous solids** formed by TO_4 tetrahedra (with T being Si, Al, Ge, B… and staying in the tetrahedral position) whose structures contain channels of diameters between 0.3-1.5 nm.
- **Properties:** exceptional physicochemical properties, high functionality, **great adsorption capacity**.
- **Types:** silicate-based materials can be commonly found in volcanic areas, and there are about 45 **natural types.** However, the presence of impurities and the lack of uniformity lead to requiring their processing to avoid limiting their adsorption capacity, which in turn end up leading to the use of **synthetic zeolites**. This tendency to opt for synthetic zeolites widen the number of commercially available structures, and also stimulate the development of tailored adsorption properties by controlling the framework (Si/Al ratio) as well as the extra-framework (use of cations) and other post-synthesis modifications.

APPLICATIONS

Applications for **ammonium removal by adsorption with zeolites**:

- landfill leachates
- livestock wastewaters
- effluents from anaerobic digestion tanks
- livestock manure effluents

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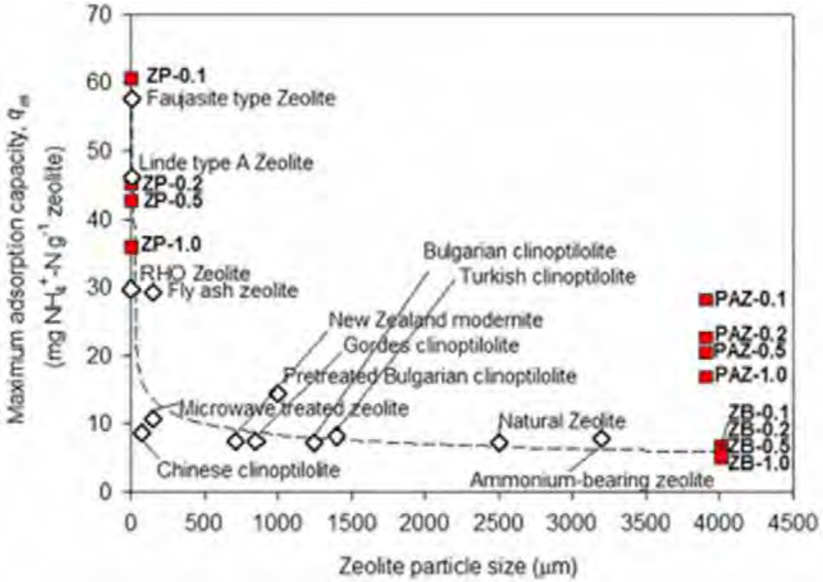
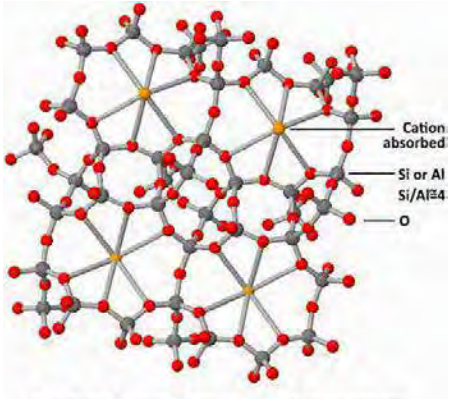
Ammonium removal from water by adsorption with zeolites

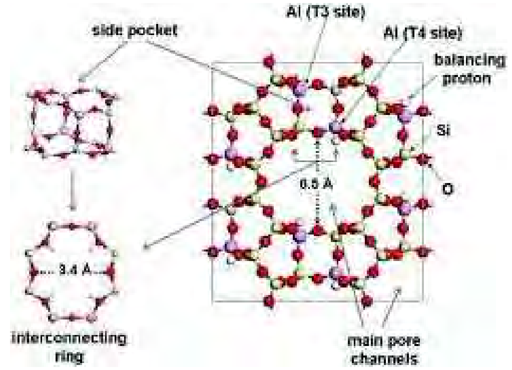
ZEOLITES SELECTION

- Clinoptilolite: $Ca_3(Si_{30}Al_6)O_{72} \cdot 20H_2O$
- Mordenite: $(Na_2,Ca,K_2)_4(Al_8Si_{40})O_{96} \cdot 28H_2O$





The Tetrahedral Framework of Clinoptiloite



Mordenite structure

Zeolite	Crystal framework Si/Al ratio	Crystal structure symmetry	Crystal density[b] (g/cm^3)	Common ion-exchanged forms	Pellet density (g/cm^3)	Bulk density (g/cm^3)	Nominal pore opening (A)
A	0.7–1.2	Cubic	1.52	Na,K,Ag, Mg,Ca	1.20	0.72	3,4,5
X	1.0–1.5	Cubic	1.47	Na,Li, Ca,Ba	1.05	0.65	7.5(NaX) 10.0(CaX)
Mordenite (small port)	4.5–5.0	Orthorhombic	1.83	Na,H,Ca	1.39	0.88	4
Chabazite	1.6–3.0	Trigonal	1.67	Na,Ca	1.16	0.73	4.9
Clinoptilolite	4.2–5.2	Monoclinic	1.85	K,Ca	—	—	3.5
Silicalite	very high	Orthorhombic	1.79	none	—	—	5.3

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Ammonia removal by adsorption with zeolites

BENCH SCALE TESTS

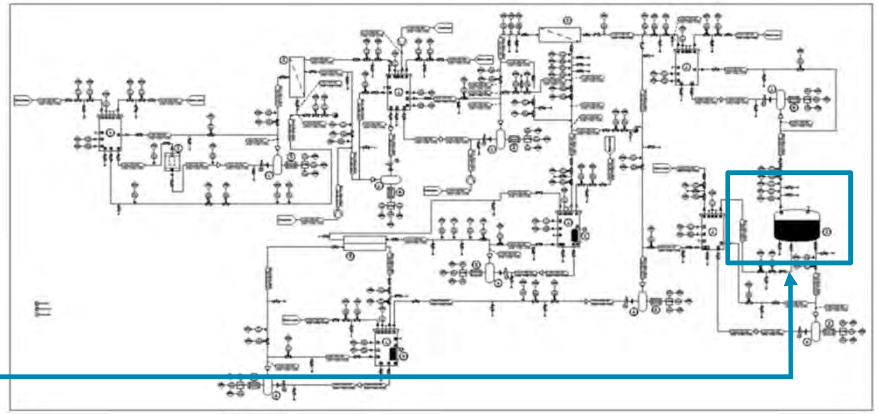
- **Experimental plan at bench scale:**
  - Zeolite type
  - Zeolite granulometry
  - Water flow rate (hydraulic time)
  - Bed length
  - pH
  - Zeolite regeneration cycle (NaCl)

Experimental set-up

- **Optimization of the operational parameters and adsorption performance (breakthrough curve)**

- **Design zeolite adsorption column to be implemented at pilot plant scale**

P&ID FOR CS1 PILOT PLANT



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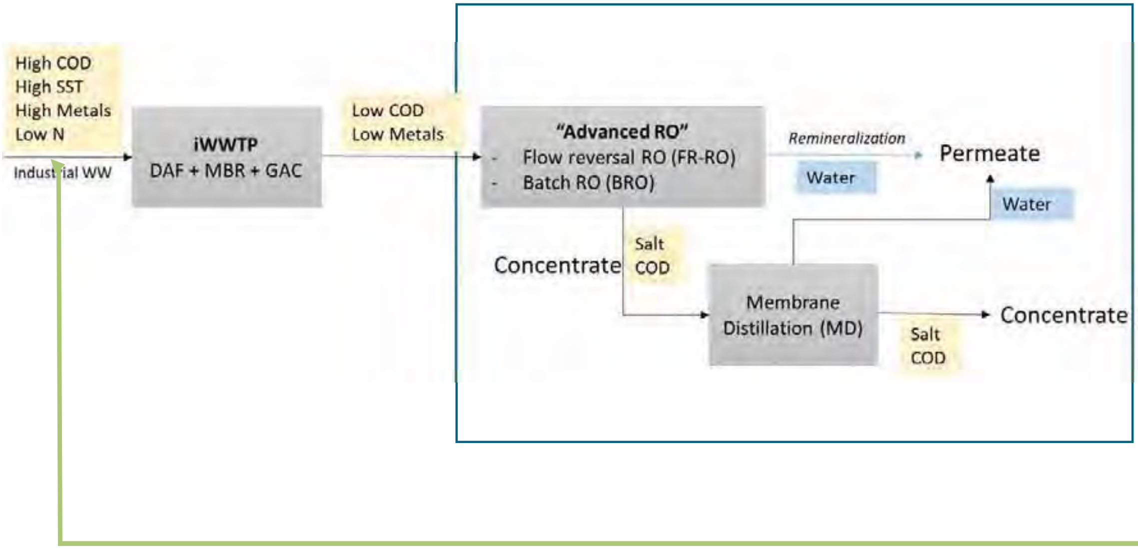
Ammonia removal by adsorption with zeolites

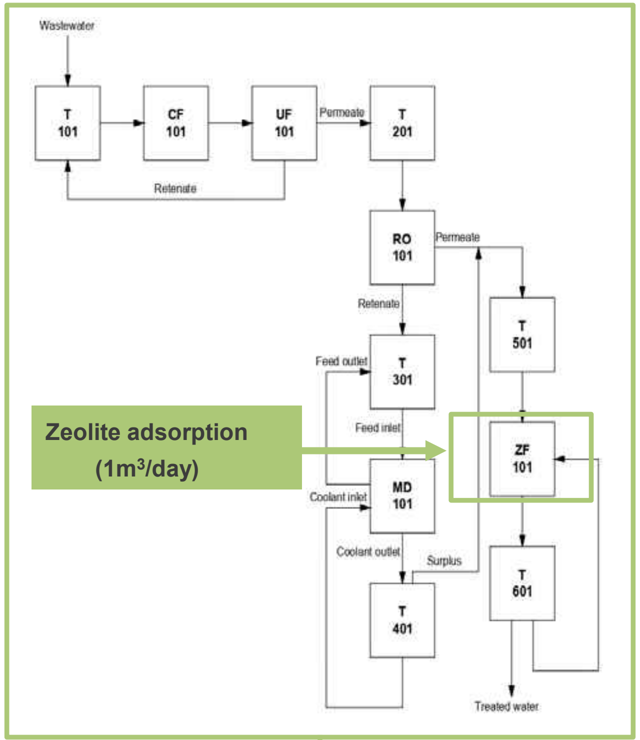
PILOT PLANT SCALE TESTS

Only one pilot plant will be built and it will include all the technologies to be tested in CS1.

ULTIMATE: Proposed WWRP scheme to maximize water recovery (near ZLD)



PILOT PLANT PROCESSES SCHEME



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Next steps in CS1

TIMING

		2020							2021												2022												2023												2024				
		6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5
ULTIMATE CS1 Internal milestones:		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
Review of historical operation and quality data of the site. Definition of extra campaigns required. Analysis of samples.	EUT																																																
Sampling and analysis for extra analitical campaigns and collection of data for baseline	AIT																																																
Set-up experimental plan and laboratory equipment	EUT																																																
Definition of requirements for reuse	AIT																																																
Trials of proposed technologies at bench scale. Optimitzation of the system	EUT																																																
Site adaptation	AIT																																																
Definition of prototype for construction	EUT																																																
Prototype construction and installation	AIT																																																
Operation of prototype and optimizatin	AIT																																																
Prototype follow-up and monitoring	EUT																																																
Evaluation of results and integration of water sources	EUT																																																

Trials at bench scale with real water from the AITASA WRP

Trials at pilot plant scale when the pilot is installed at the industrial site

Technical-economical feasibility assessment

The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

Conclusions

Ammonium adsorption by zeolites will be evaluated in CS1 of ULTIMATE with the aim of:

- Assess its technical and economic feasibility as an alternative technology to current 2 pass-RO in the current Water Reclamation Plant.

The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

Thank you!

Sandra Casas, Andrea Naves

Sandra.casas@eurecat.org

Andrea.naves@eurecat.org

Removal of key pollutants from wastewater by adsorption: N, P and COD

Professor Ana Soares

Ion exchange processes for nutrient removal

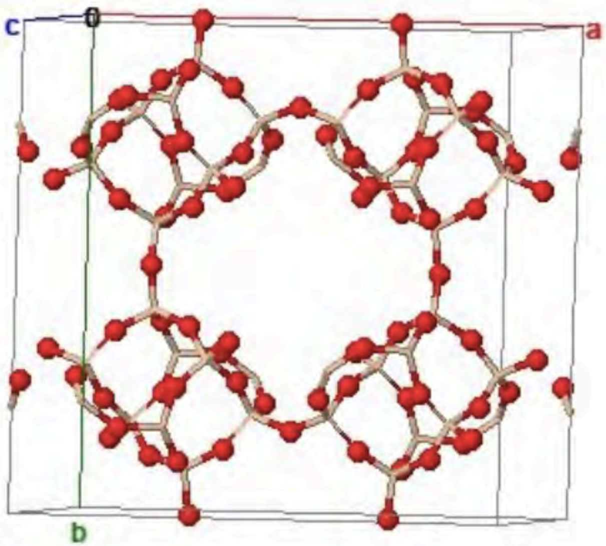
10 m^3/day
P removal 5 min contact time
N removal 10 min contact time

Ammonia **removal:**
Zeolite-N
Exchange of ammonia with potassium or sodium

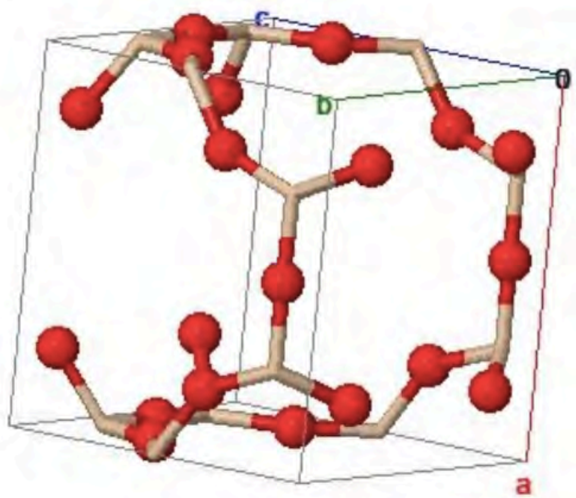
Phosphorus removal: hybrid anion exchange
Adsorption of P to iron nanoparticles. Can be reversed by an increase in pH

Zeolites

Clinoptilolite

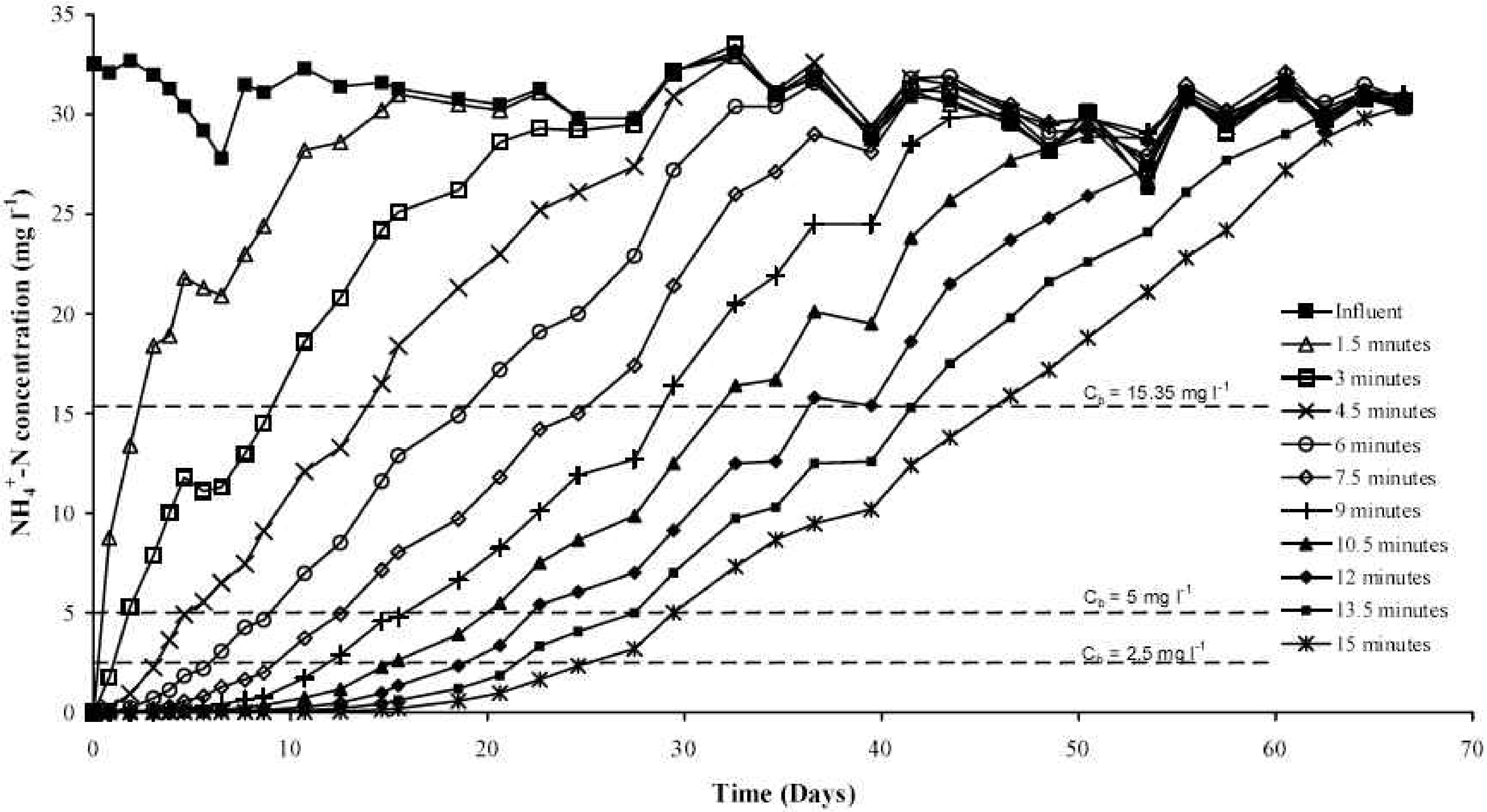


Zeolite-N



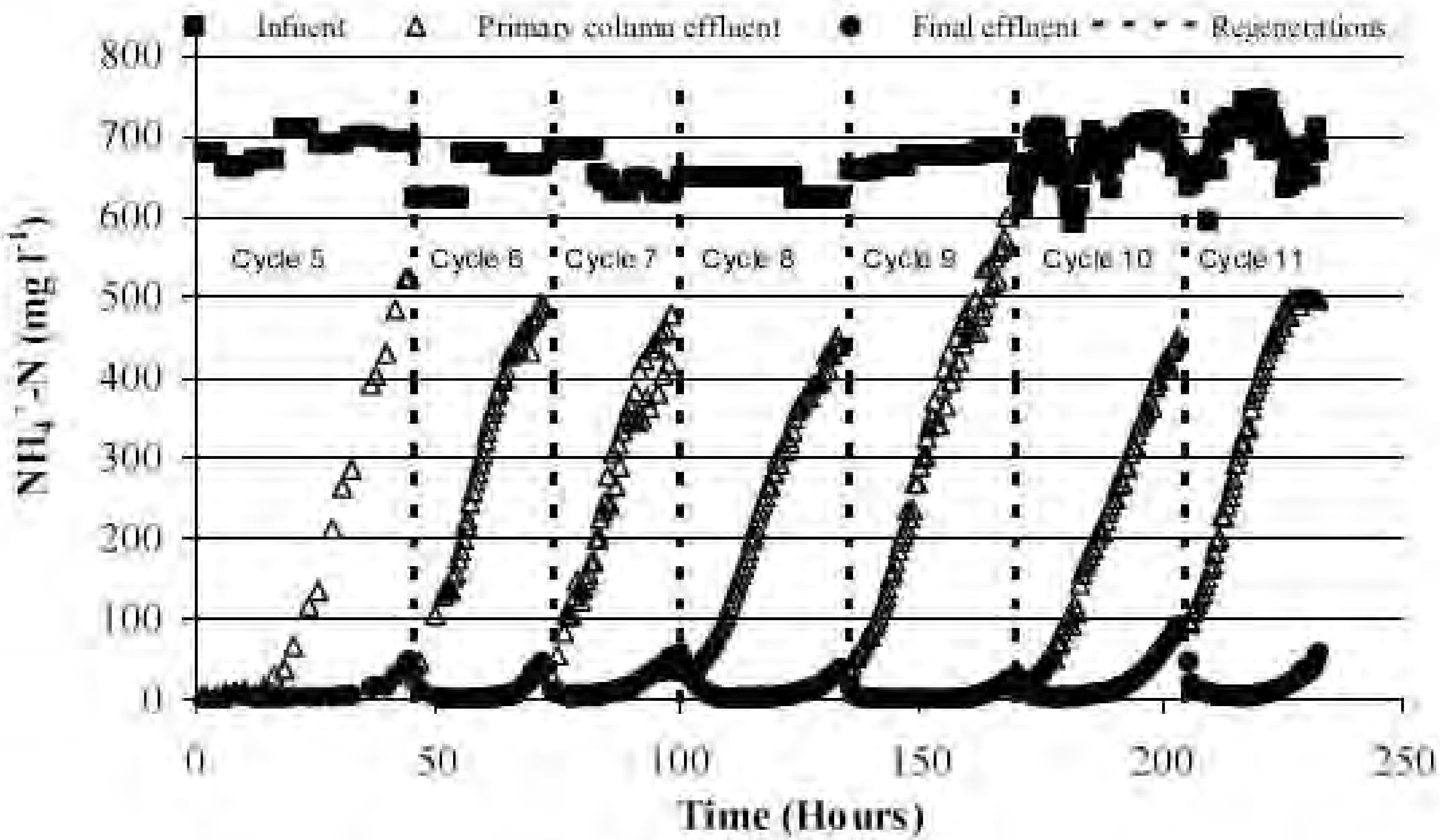
Zeolite-N

Breakthrough time is dependent on EBCT – this example is for a raw wastewater of ~30 mg/L of NH_4



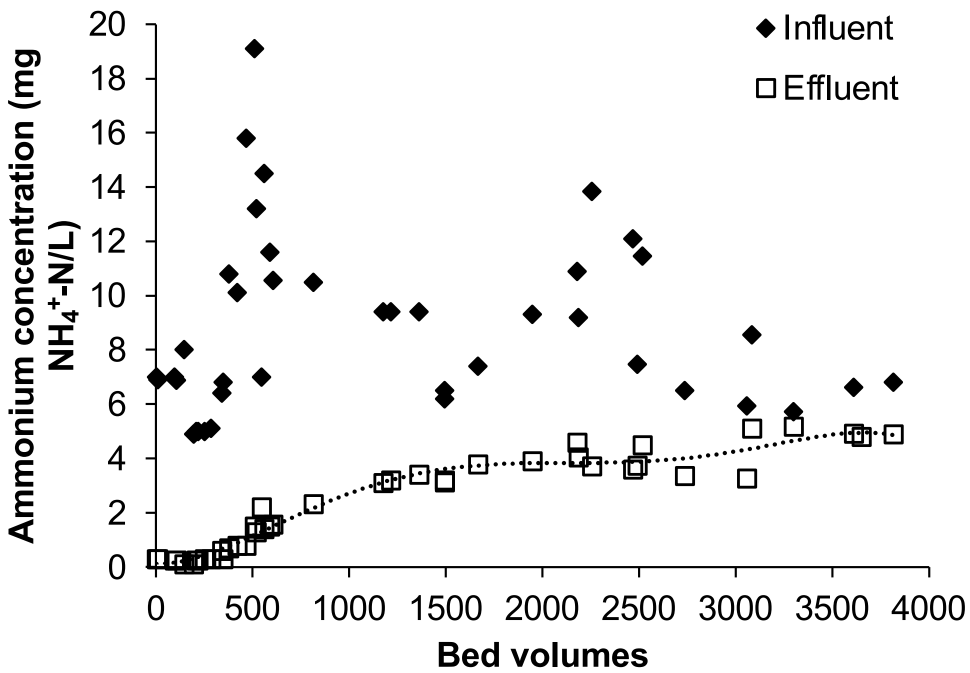
A. Thornton, P. Pearce, S.A. Parsons. Ammonium removal from digested sludge liquors using ion exchange. Water Res., 41 (2007), 433-439

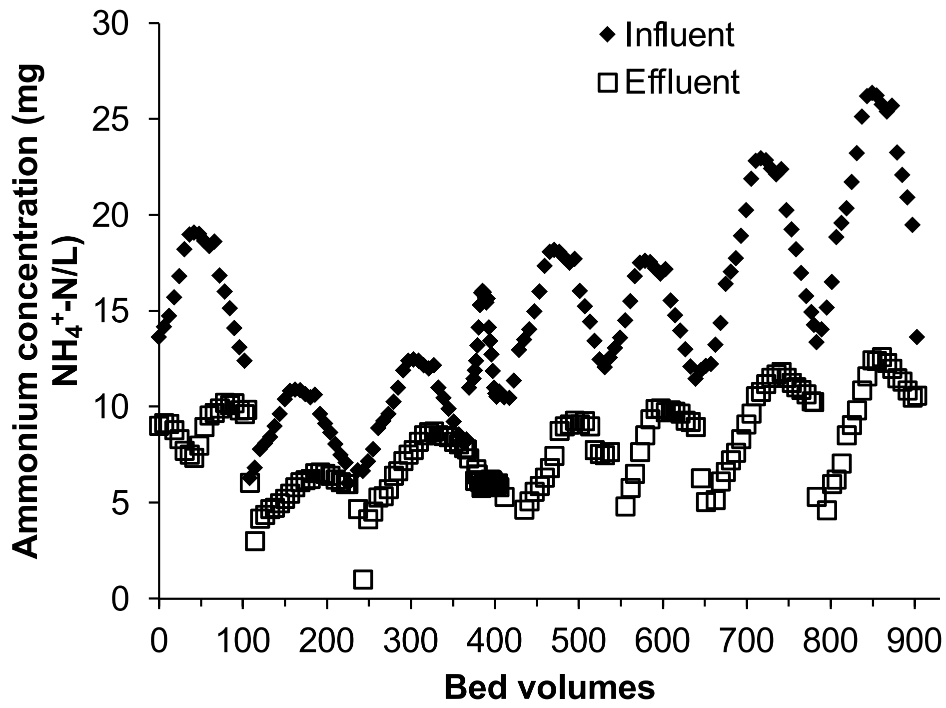
Process developed for sludge liquor treatment is very effective



A. Thornton, P. Pearce, S.A. Parsons. Ammonium removal from digested sludge liquors using ion exchange. Water Res., 41 (2007), 433-439

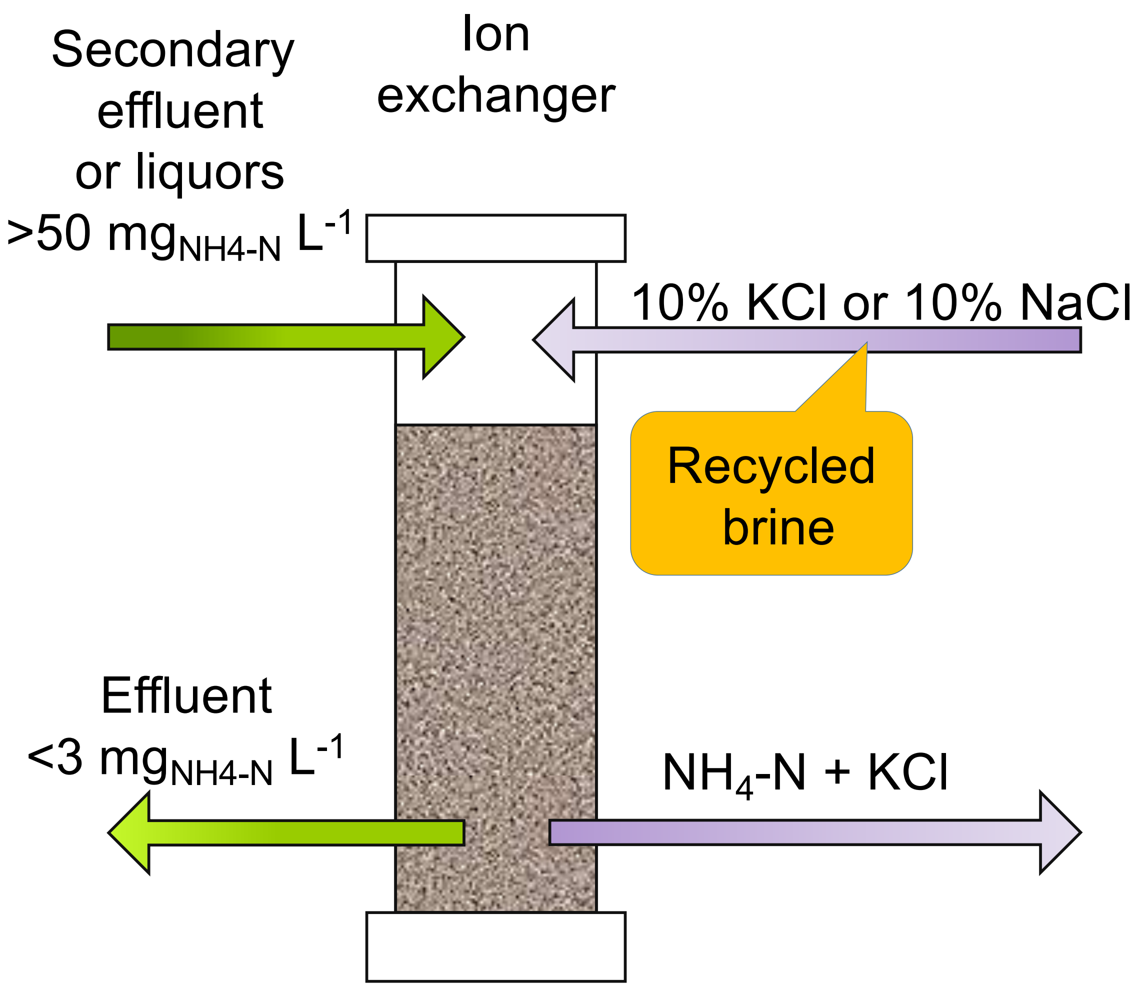
Process developed for tertiary treatment

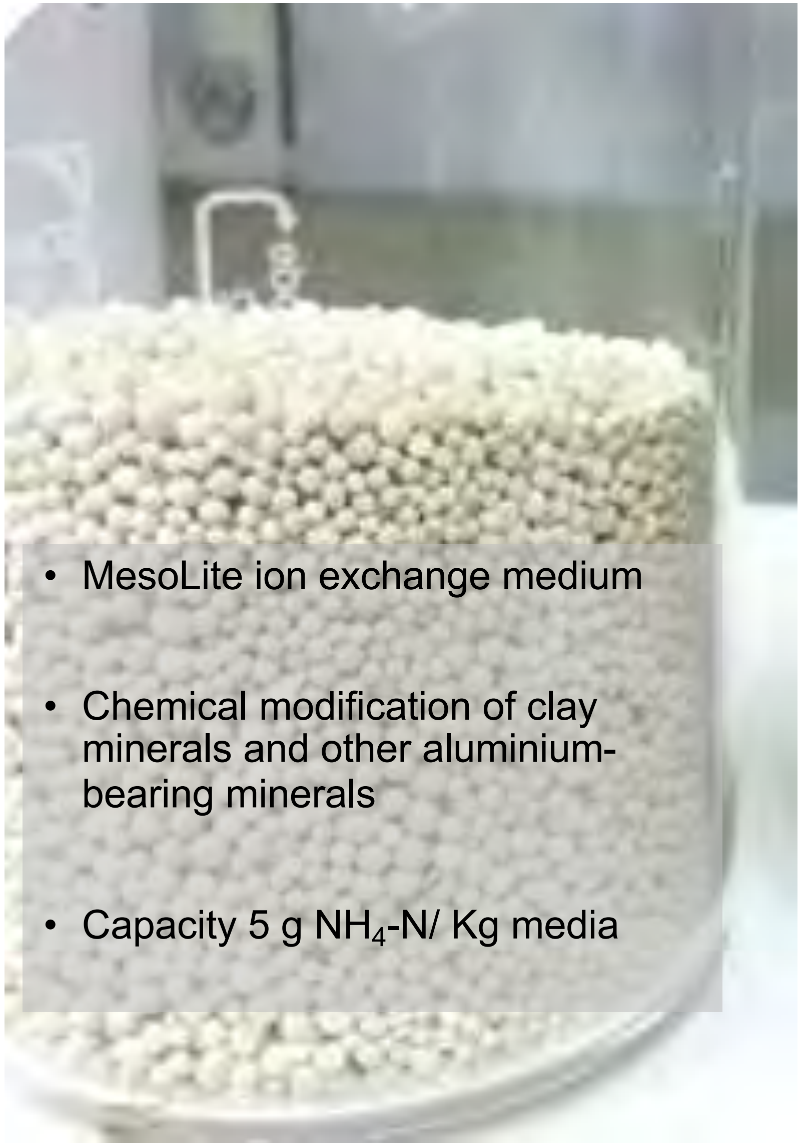




Guida S, Conzelmann L, Remy C, Vale P, Jefferson B, Soares A. 2021. Resilience and life cycle assessment of ion exchange process for ammonium removal from municipal wastewater. Science of the Total Environment. https://doi.org/10.1016/j.scitotenv.2021.146834

But what about the brine?



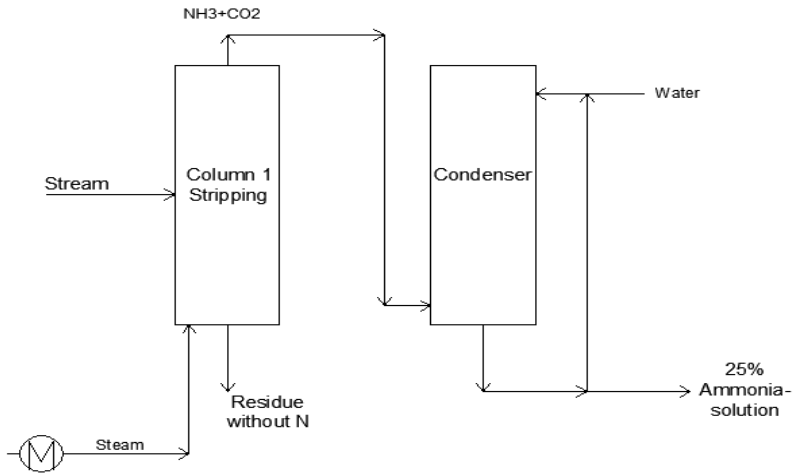


- MesoLite ion exchange medium
- Chemical modification of clay minerals and other aluminium-bearing minerals
- Capacity 5 g NH_4-N/ Kg media

Regenerant and ammonia recovery using commercial products

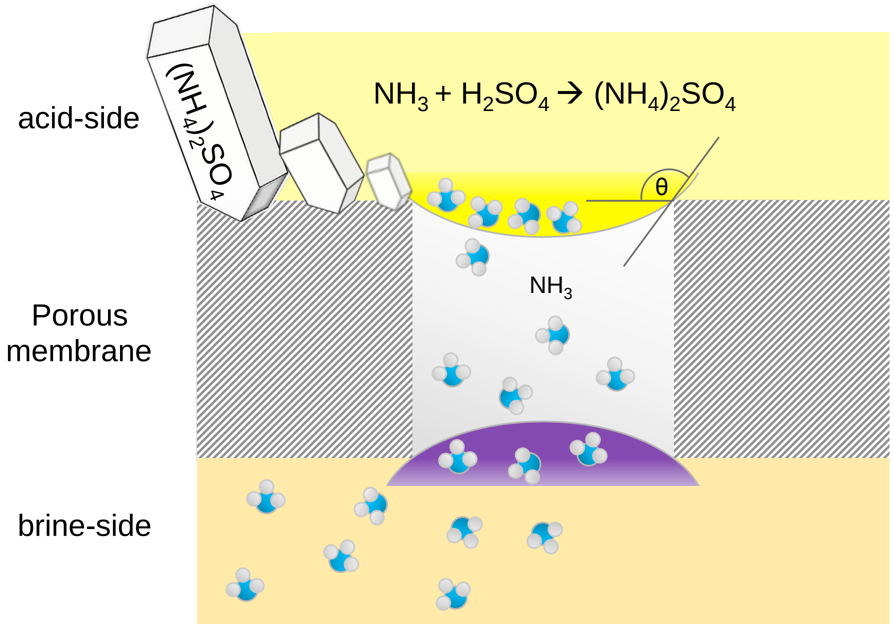
Supported by the Horizon 2020 Framework Programme of the European Union

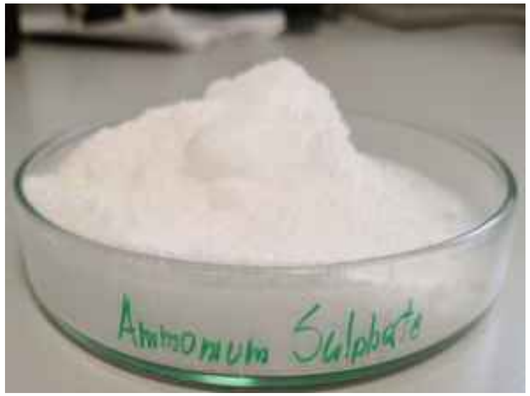
Ammonia steam stripping process



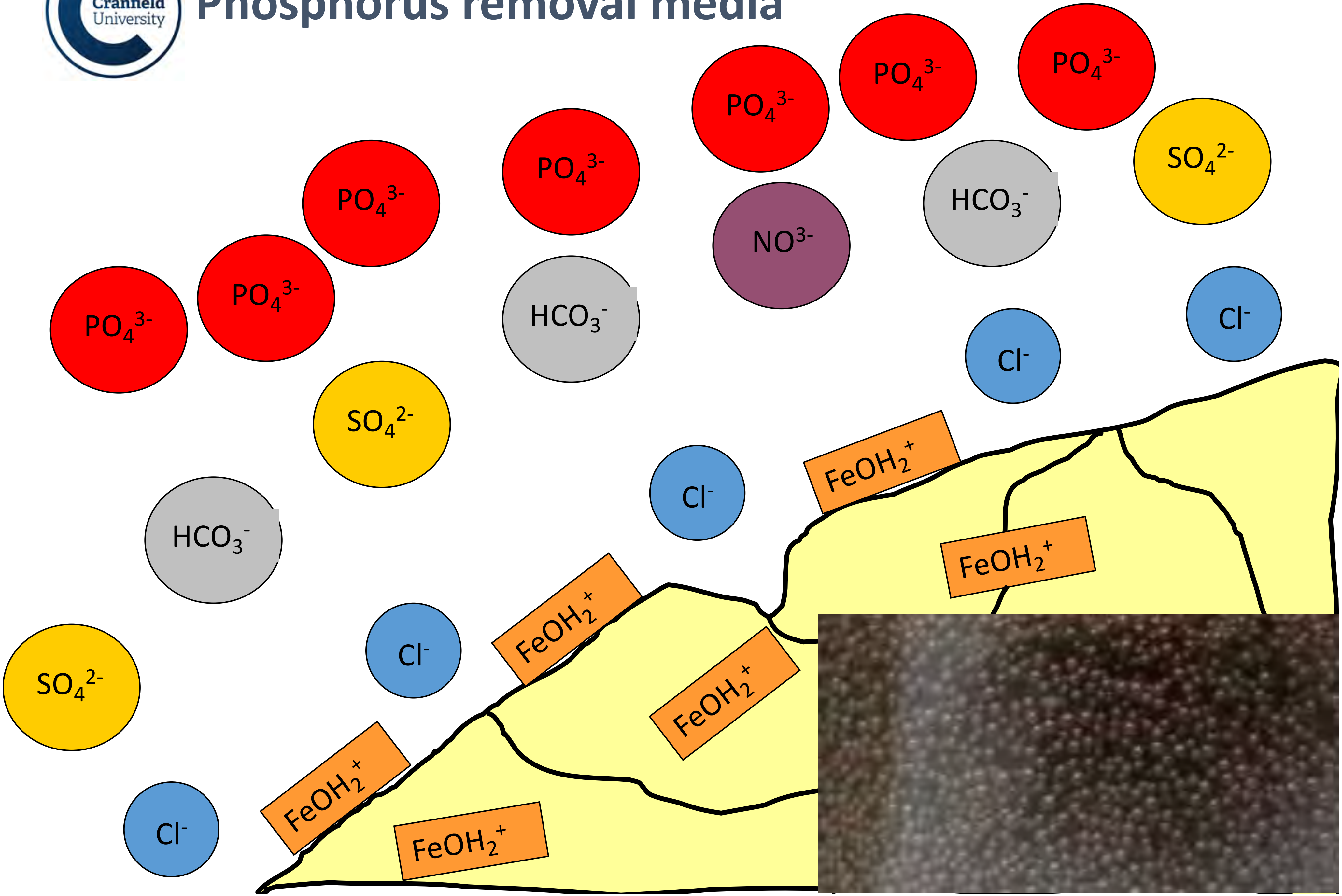
Ammonia water (25%)

Hollow fibre membrane contactor



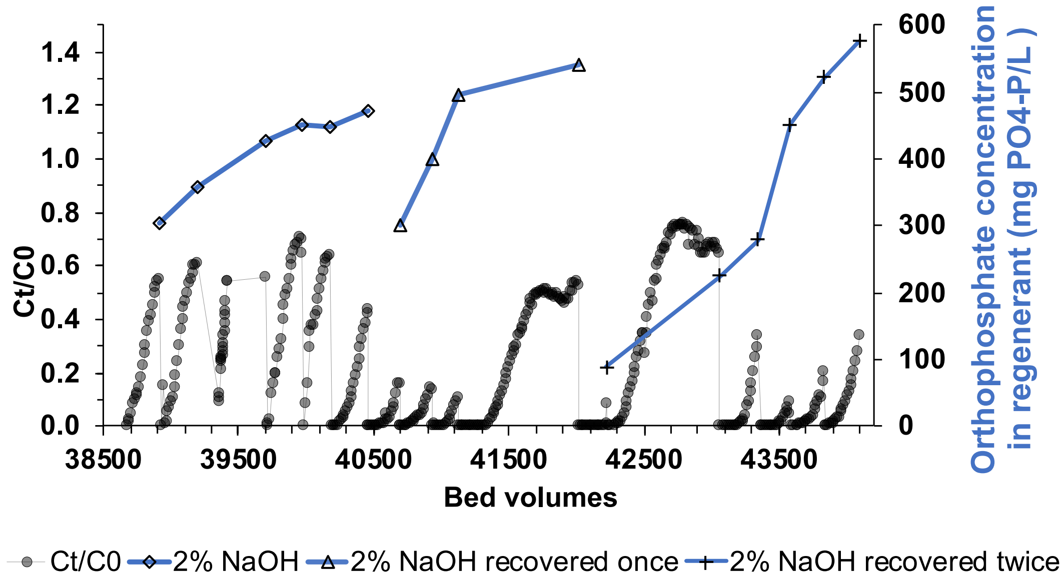


Phosphorus removal media



Cranfield University

Operation of the phosphorus removal IEX



-The HAIX removed an average of 6 mg PO_4-P /L to >0.3 mg PO_4-P/L, within 430 bed volumes
-To manage the regenerant (NaOH 2%) efficiently, this was reused up to 8 times, reaching 785 mg PO_4-P/L
-Process was stable over 2- year operation, although some carbon fouling was observed

Recovered products

CaOH Impurity	Result (µg/g)
Cadmium	<12.5
Copper	42.5
Lead	4
Mercury	<0.125
Zinc	77.5
Non-ionic surfactants	<500
Bis(2ethylhexyl)phthalate	<25
Bisphenol A	<2.5
Nonylphenol	<25
PAHs	<0.05
Tributyltin	<0.05

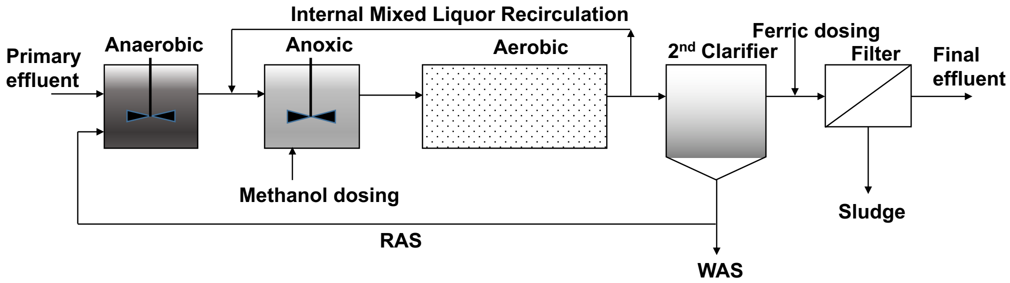
Up to 30% COD removal

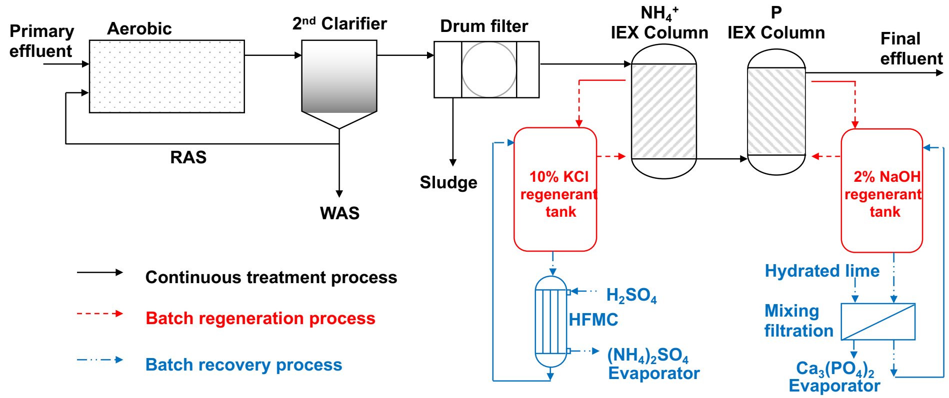
Guida S, Rubertelli G, Jefferson B, Soares A. 2021. Demonstration of ion exchange technology for phosphorus removal and recovery from municipal wastewater. Submitted.

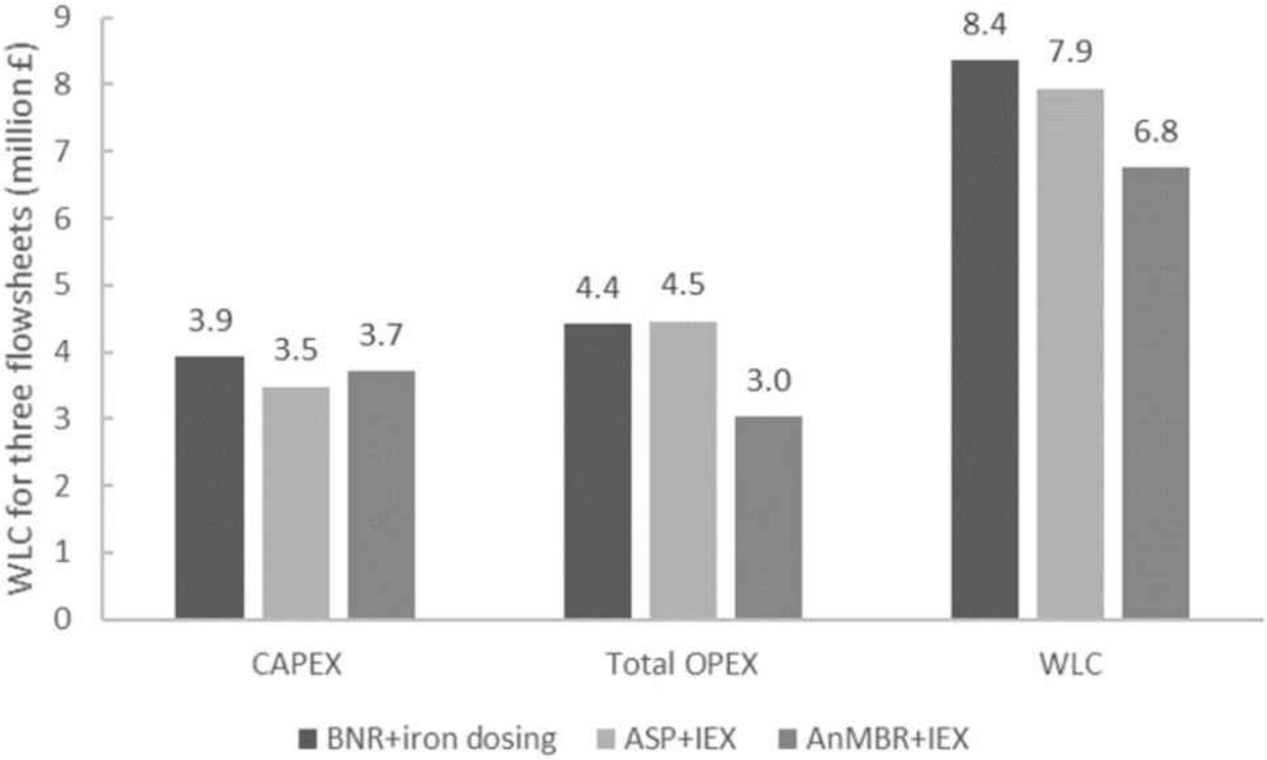
SMART-Plant

Supported by the Horizon 2020 Framework Programme of the European Union

A resource recovery strategy can have economic (and environmental) benefits







Huang H, Guida S, Jefferson B, Soares A. 2020. Evaluation of performance and economics of ion exchange processes for ammonia and phosphorus removal and recovery from municipal wastewater. NPJ Clean Water. 30:7

H2020 NEXT-GEN

Spernal (UK)

Waste Water Treatment Plant

Circular solutions for

Wat **Material** **Energ**

Waste water plant serving the town of Redditch (Birmingham, UK): 92.000 PE

Spernal WWTP serves as Severn Trent Water's "Resource Recovery and Innovation Centre" where emerging technologies compatible with a low energy, circular economy approach will be evaluated.

A multi-stream test bed facility was constructed in 2019 and this will incorporate **an anaerobic membrane bioreactor (AnMBR) to be commissioned in Summer 2020. The AnMBR will also comprise a membrane degassing unit to recover dissolved methane and ion exchange processes to recover nitrogen and phosphorus from the effluent.**

AnMBR combines several benefits such as:

- no aeration energy for removal of Chemical and Biological Oxygen Demand (COD/BOD)
- low sludge production and hence reduced downstream sludge treatment costs
- biogas production (production of electricity/heat
- pathogen and solids free effluent which can be re-used in a number of applications (e.g.: farming and industrial use).

Relevant sectors

Agriculture **Domestic sector** **Energy sector**

Lead partners

Cranfield University

Resource recovery and innovation centre

Cranfield
Water

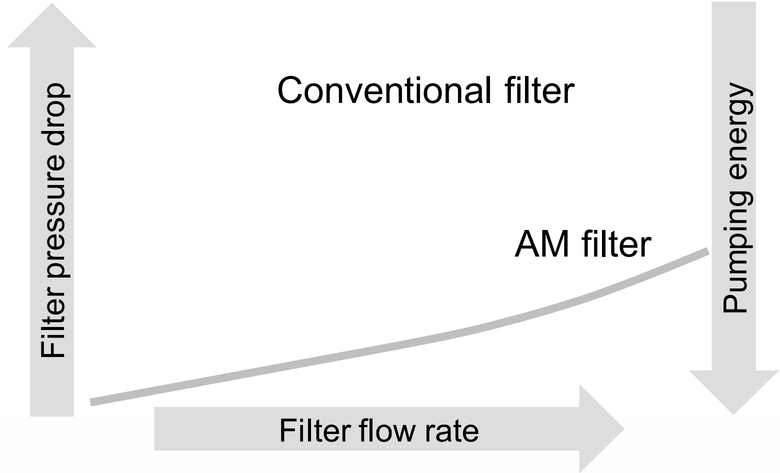
Thank You

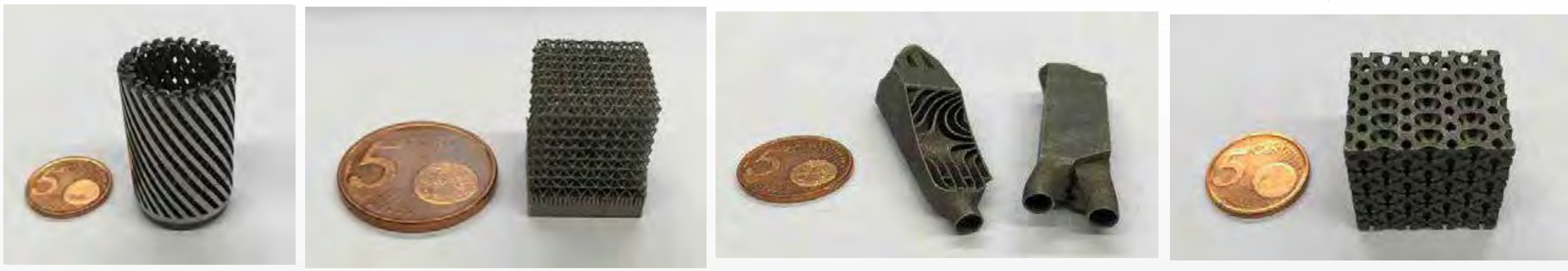
3D Printed Adsorbents for Metal Recovery

Assoc. Prof. Eveliina Repo
LUT University
Separation Science
LENS

Why 3D-printing?

- Porosity and geometry can be optimized
- Fluid channels and holes can be aligned with fluid flow when turbulence decreases → pressure drop decreases and less energy is needed for pumping.
- These kind of structures are possible to manufacture only with 3D-printing (additive manufacturing, AM).

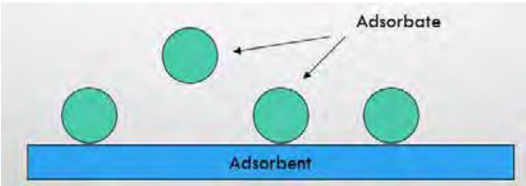




Designs by LUT Laser

AM in the production of adsorbents/scavengers

- Adsorption is based on the interactions between the surface and species in the liquid or gas phase



- Limited by the amount of active sites on the surface (surface area), diffusion, reaction kinetics etc.
- AM offers possibility to optimize the shape, size, and flow properties → enhancing interactions

Design by LUT Laser

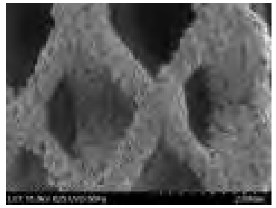
LUT University

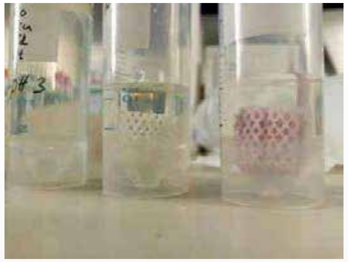
Our premilinary experiments:
Gold recovery by 3D-printed nylon adsorbents

Test solution (pH 3)	After adsorption
Co 2.9 ppm	Co 2.9 ppm
Au 7.3 ppm	**Au 0.2 ppm**
La 36 ppm	La 36 ppm
Pt 6.7 ppm	Pt 6.5 ppm
Pd 6.0 ppm	Pd 5.7 ppm

Test solution (pH 5)	After adsorption
Co 4.9 ppm	Co 4.9 ppm
Au 6.6 ppm	**Au 0.4 ppm**
La 62 ppm	La 62 ppm
Pt 6.0 ppm	Pt 5.9 ppm
Pd 6.4 ppm	Pd 6.0 ppm

Selective laser sintering

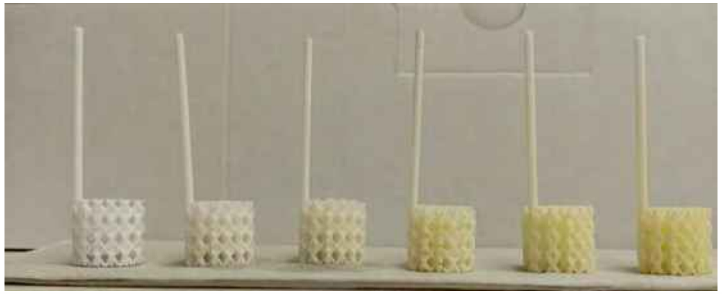




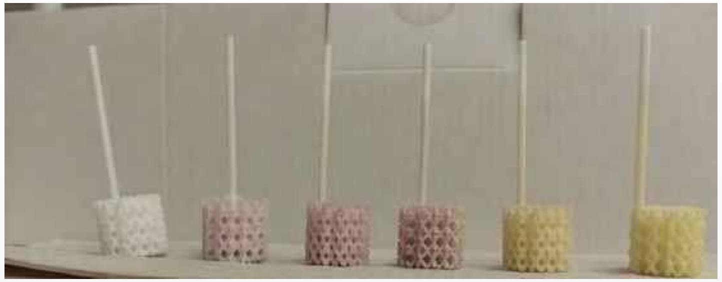
Our premilinary experiments:
Gold recovery by 3D-printed nylon adsorbents

Gold concentration in the initial solution

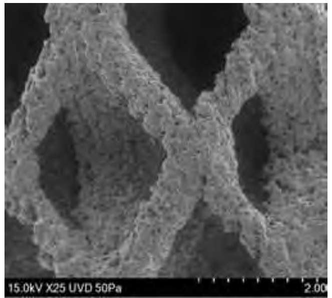
0 mg/l 10 mg/l 50 mg/l 100 mg/l 150 mg/l 200 mg/l



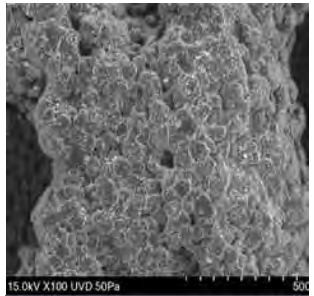
Directly after adsorption
The colored ones show adsorbed gold from the solution



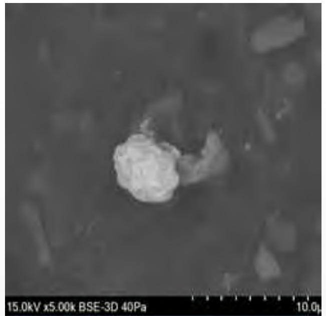
After 24 hours gold nanoparticles formed on the surface change the colour reddish



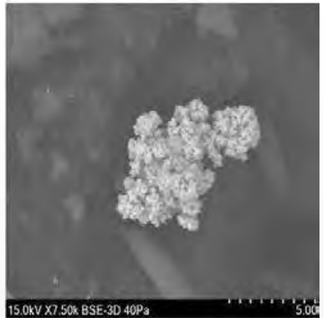
Magnification X 2 mm



Magnification X 500 µm



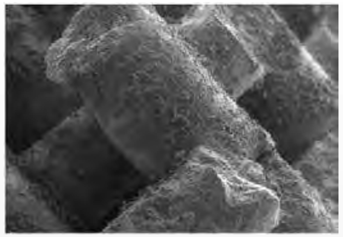
Magnification X 10 µm



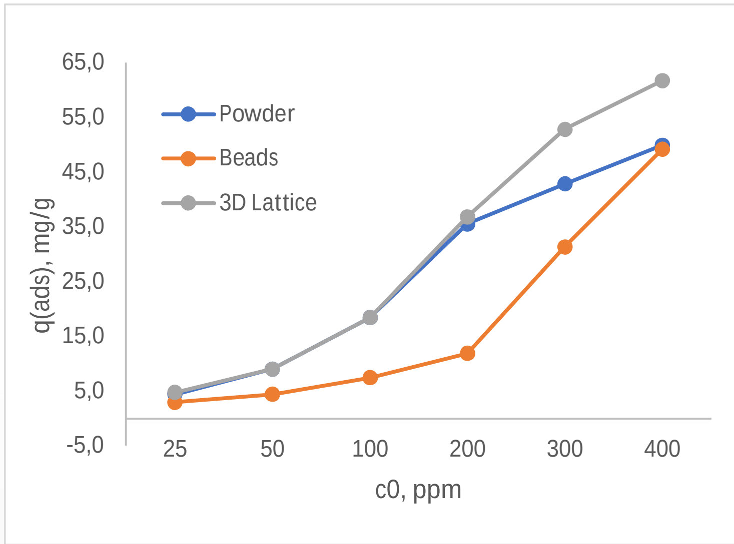
Magnification X 5 µm

Our premilinary experiments:
3D-printed geopolymers for organics removal

Direct ink-jet writing
(University of Padova)



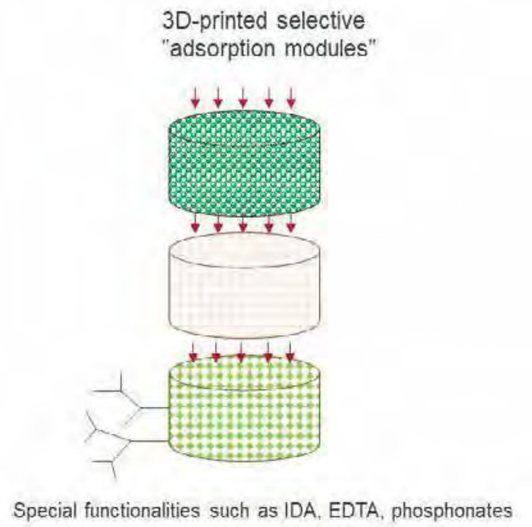
Adsorption of Orange II

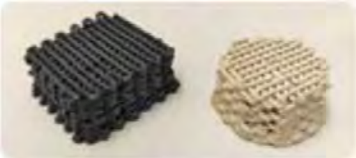


Sea4Value project

LUT task: Production of selective 3D-printed adsorbents

- Adsorption/ion-exchange is effective and selective way to recover trace amounts of metals
- Especially, selective ion-exchange resins are widely applied
- In Sea4Value project:
    - Inks and printing powders will be prepared by mixing matrix materials (polymers) with selective ion-exchange resins
    - Printing will be conducted by SLS or DIW using optimized models
    - 3D-printed modules will be tested for selective recovery and concentration of Sc, In, V, B, and Mo
    - Adsorption/desorption cycles will be optimized

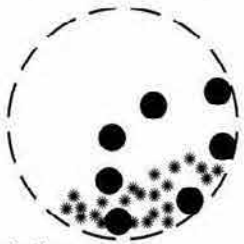




Production of 3D-printed adsorbents

Element	Resin
In	Lewatit TP207
Sc	Chelex 100
Mo	Resin D314
V	Valox resin 312
B	Dowex 2x8

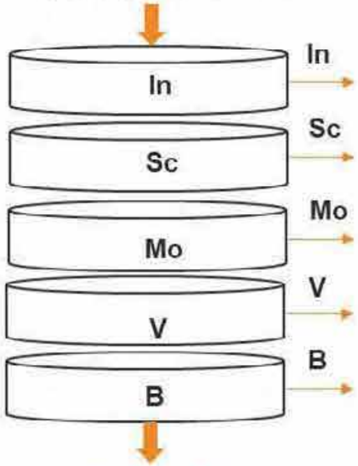
Ball mill
Particle size aprx. 50 micron



Mix PA12 powder with resin powder 10 wt%

AM of adsorbents by 3D-printer

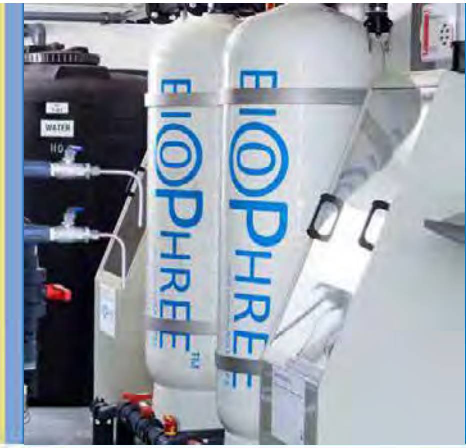
Brine solution
In, Sc, Mo, V, B, Li, Rb, Ga

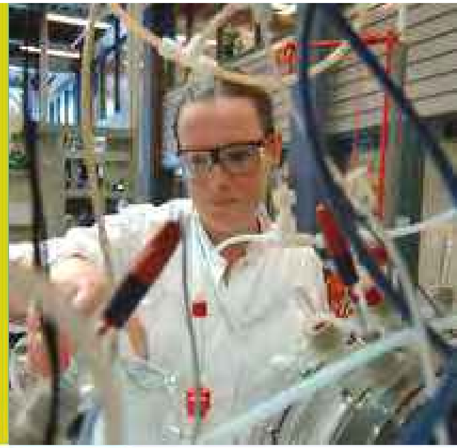


Li, Rb, Ga

Thank you!

Contact: eveliina.repo@lut.fi





BioPhree: Reversible phosphate adsorption for P-removal to ultra-low levels and P-recovery. Demonstrations and perspectives

Wokke Wijdeveld, Wetsus

ULTIMATE Adsorption webinar, 31 March 2021

combining scientific excellence with commercial relevance

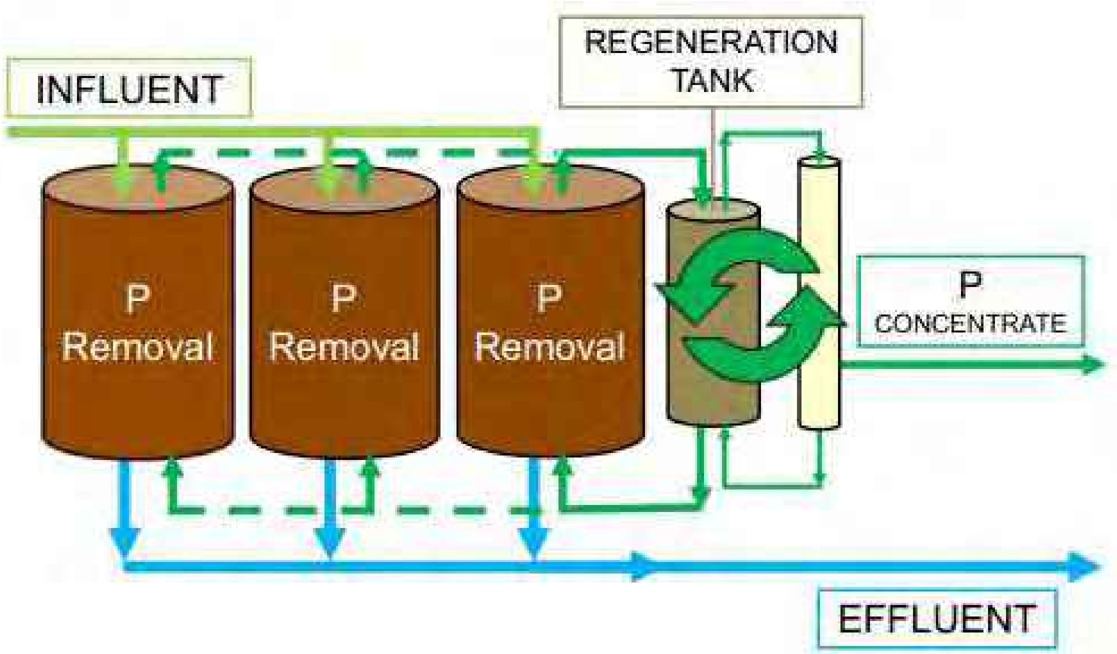
Adsorption to reach <10 ppb P

Eutrophication

Zero-Liquid Discharge

wetsus

BioPhree concept



Iron oxide based adsorbents

- Many others exist:
  - Hematite
  - Magnetite
  - Maghemite
  - Lepidocrocite
  - .....

- Hybrid ion exchange resin (IEX)
- Often Ferrihydrite based
- High capacity, but unstable

- Porous granules
- Usually Goethite based
- Stable, but slow kinetics

wetsus

THE GEORGE BARLEY WATER PRIZE

$10M Prize

Stage 1: Proposal
Stage 2: Demonstration at lab-scale
Stage 3: Demonstration at pilot-scale
‘GRAND CHALLENGE’: Full-scale

Lake Simcoe, Canada
Okeechobee, Florida

water mining

value for society

Demonstration for phosphorus, salts, water and energy recovery from urban wastewater

Case Study: Larnaca, Cyprus

Case Study: La Llagosta, Spain

wetsus

WWTP Larnaca, Cyprus (2021-2022)

- Process:
  - Oxidation ditch
  - FeCl dosing
  - MBR + UF
  - Tertiary disinfection (chlorination)
- Size:
  - 100,000 p.e
  - 10,000 m^3 wastewater /day
- Special
  - Treated water stored in lagoon
  - 100% used for irrigation of crops
  - Concerns over salinity
  - Pilot to treat 24 m^3/d

Location: https://goo.gl/maps/ycUe4HZHMid5C1MK8

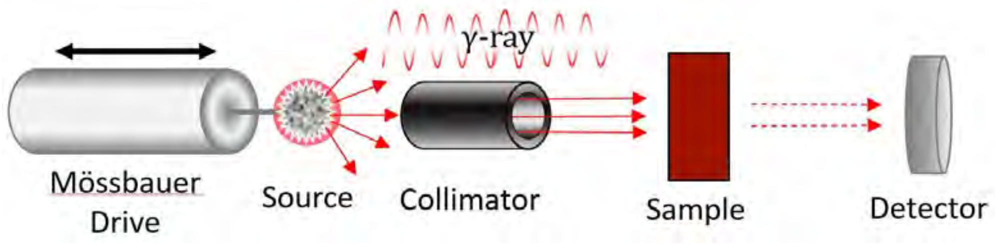
WWTP La Llagosta, Spain (2022-2023)

- Process:
  - Aeration
  - Nitrification/denitrification with Banderpho (under construction)
- Size:
  - 360,000 p.e
  - 47,000 m³ wastewater /day
- Special
  - AnMBR demonstrated in Water-Mining
  - Followed by ViviCryst and BioPhree
  - Pilot will treat 10 m^3/d

Location: https://goo.gl/maps/jGfwBYmtScDGXPDJA

wetsus

Our greatest tool- Mössbauer spectroscopy

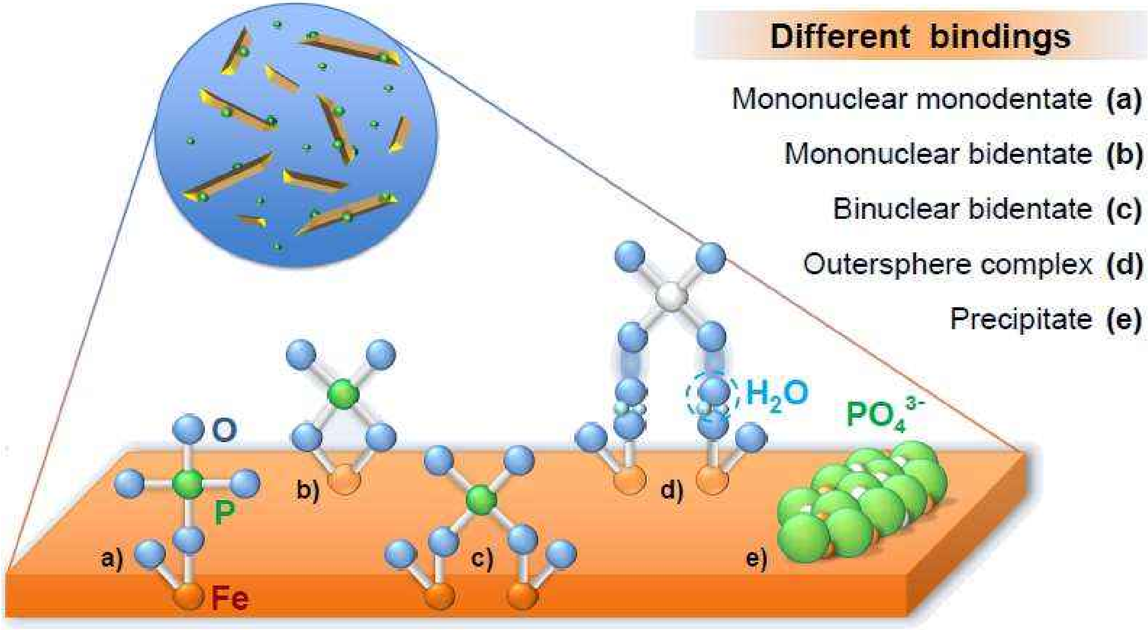


Fresh IEX			Used IEX		
21%	Fe^{3+}	Goethite	31%	Fe^{3+}	Goethite
7%	Fe^{3+}	Hematite	8%	Fe^{3+}	Hematite
72%	Fe^{3+}	Ferrihydrite	61%	Fe^{3+}	Ferrihydrite

wetsus

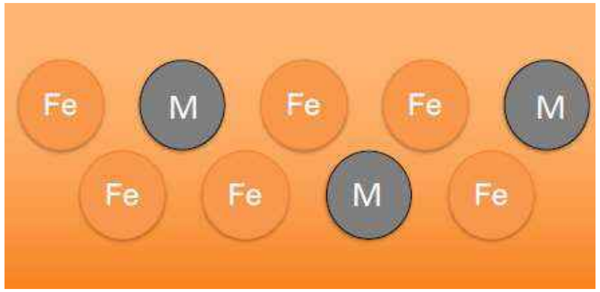
Nano-particles approach

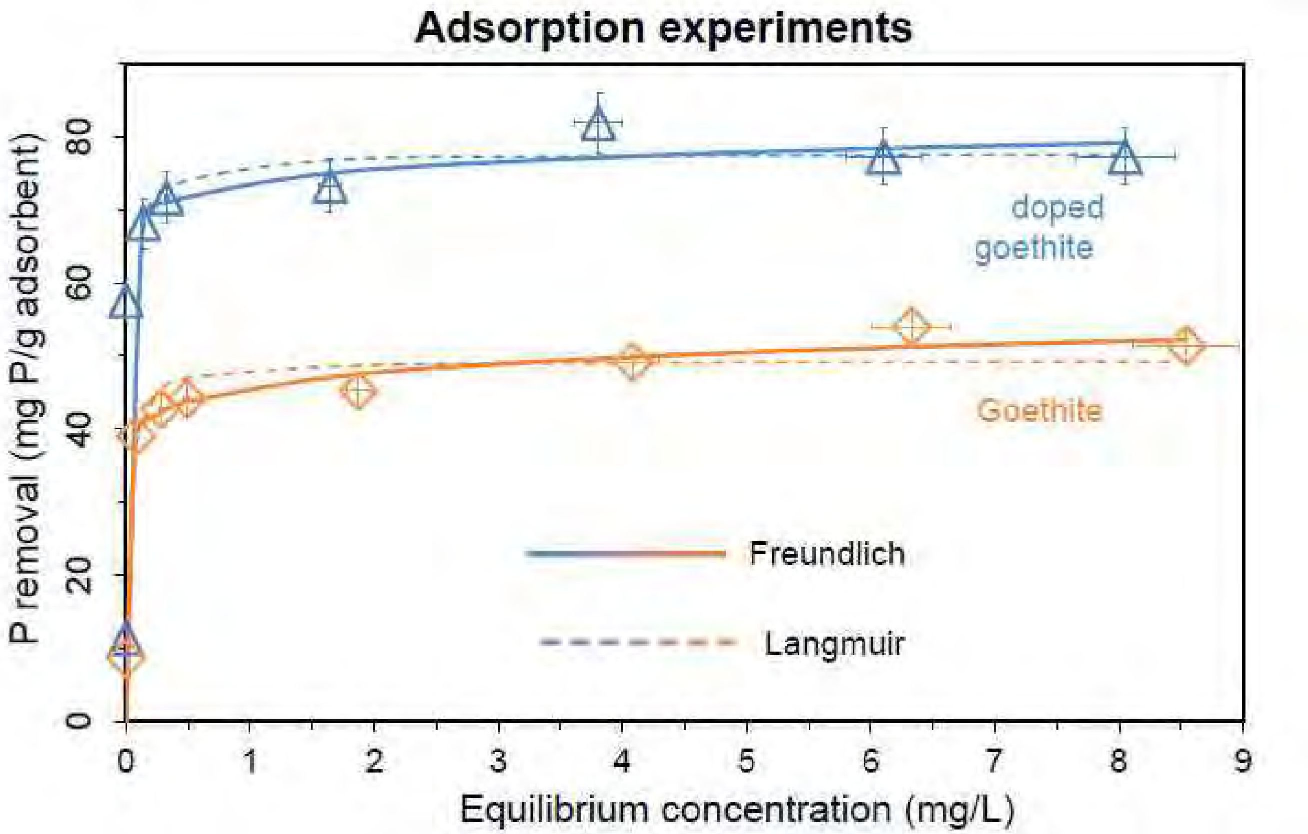
- Pure interaction between iron oxide & P
- Effect of competing ions
- Good signal for Mössbauer study



PhD study Carlo Belloni

Doping of iron oxides





PhD study Carlo Belloni

Perspectives

Reusing adsorbent decreases chemical cost and makes this a very feasible technology for P removal and recovery (See: Kumar,2019)

Water Research X 4 (2019) 100029

Contents lists available at ScienceDirect

Water Research X

journal homepage: https://www.journals.elsevier.com/water-research-x

ELSEVIER

Review

Adsorption as a technology to achieve ultra-low concentrations of phosphate: Research gaps and economic analysis

Prashanth Suresh Kumar [a, b, *], Leon Korving [a], Mark C.M. van Loosdrecht [b], Geert-Jan Witkamp [b, c]

Compare to:

- Precipitation
- Sand filtration
- Constructed wetlands

wetsus

Thank you for your attention

More information:

- www.wetsus.nl
- www.watermining.eu

- wokke.wijdeveld@wetsus.nl

Renewable granular active carbon for removal of organic micropollutants in urban wastewater

Luca Loreggian

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°776541

31/03/2021

Renewable granular active carbon for removal of organic micropollutants in urban wastewater

n|w Fachhochschule Nordwestschweiz

ABWASSERVERBAND
ALTENRHEIN

GAC pilot experiment

GOALS:

1. to produce renewable GAC with similar performances as commercially available GAC
2. to test renewable GACs for the elimination of organic micropollutants (OMPs) in urban wastewater at pilot scale experiment

APPROACH:

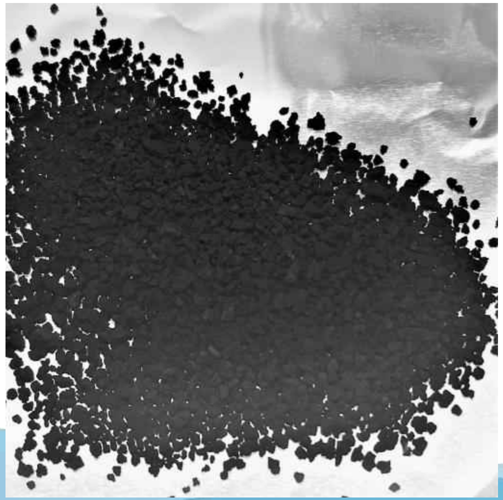
1. Laboratory and pilot experiments to investigate the effect of pyrolysis and activation on GAC performances
2. Definition of the conditions for pyrolysis and activation of 2 renewable resource for GAC production
3. Production of renewables GAC
4. Operation of GAC filter (Pilot plant at AVA Altenrhein) for 8-12 months

Production of renewable GACs

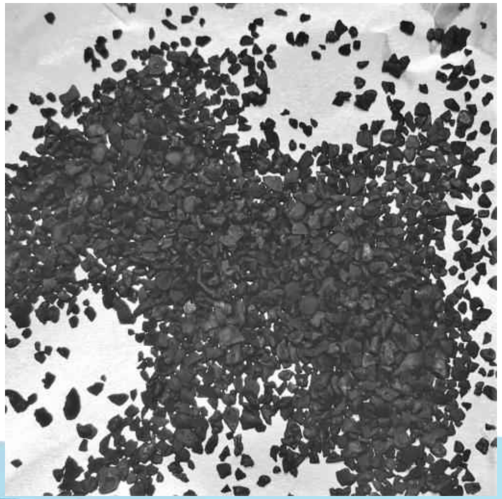
Phase	Objective
Pilot trials (Pyreka, Agroscope)	To generate samples under different conditions: • 2 renewable resources (CP, SS) • Temperature of pyrolisis and activation (700, 800, 900°C) • Activation gas (CO_2, H_2O) • Residence time (10, 20, 30’) **21 samples in total**
Characterization of samples	To define physical properties and performances: • Yield of production • Particle size distribution • Density • Hardness • Specific surface, and porous size distribution • Adsorption (saK254, OMPs)

The GACs

Sample name	Cond.	SAK adsorption [%]	total area [m^2/g]	total porous volume [m^3/g]	PB hardness [%]	tap density [kg/m^3]	Production yield [%]
SS GAC	CO_2_800°C	9	46	0.176	**87**	592	50
CP GAC	H_2O_900°C	**17**	678	0.398	63.3	260	13
401V	-	23	Unk.	Unk.	>90	490	Unk.

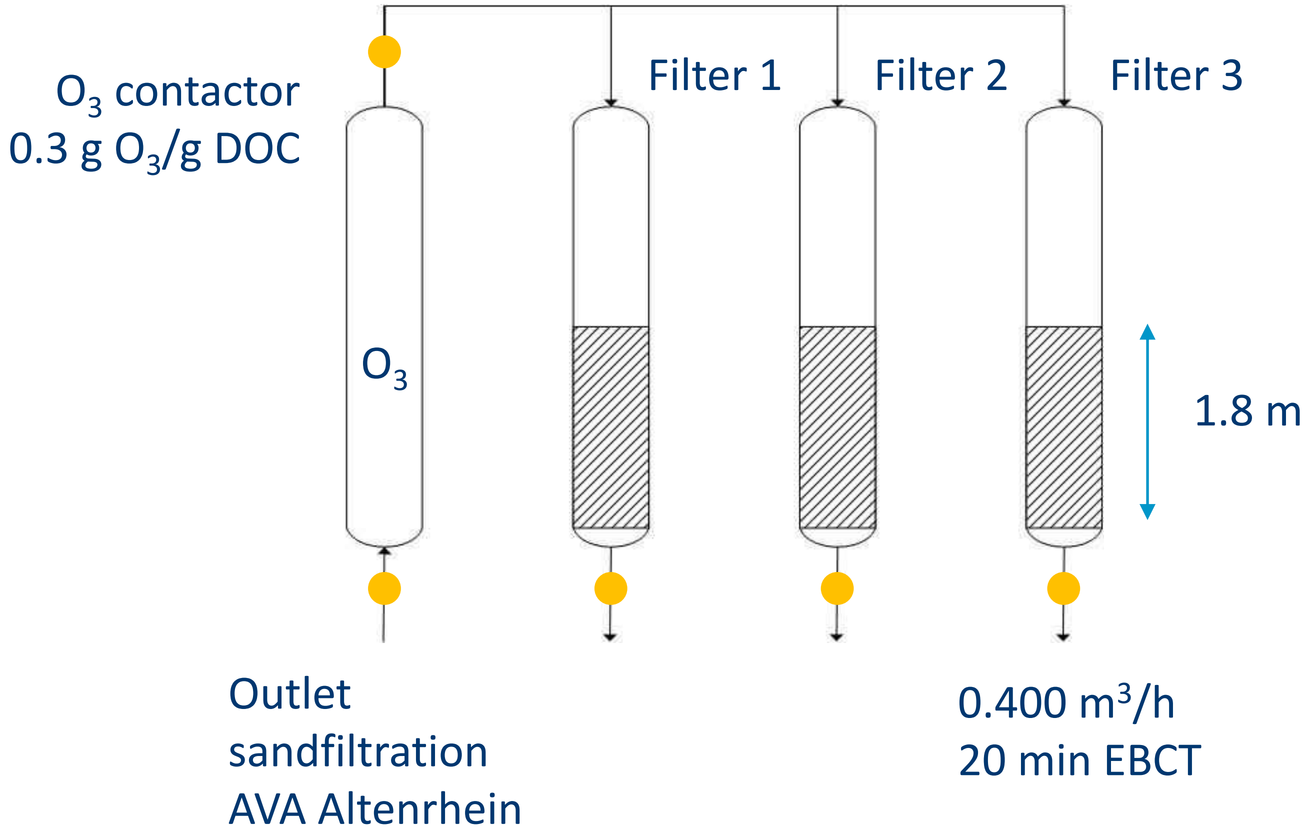


SS_GAC



CP_GAC

The pilot plant



Filter 1	Chemviron 401V (401V)
Filter 2	Cherry pit GAC NextGen (CP Nextgen)
Filter 3	Sewage sludge GAC NextGen (SS Nextgen)
●	Sampling point

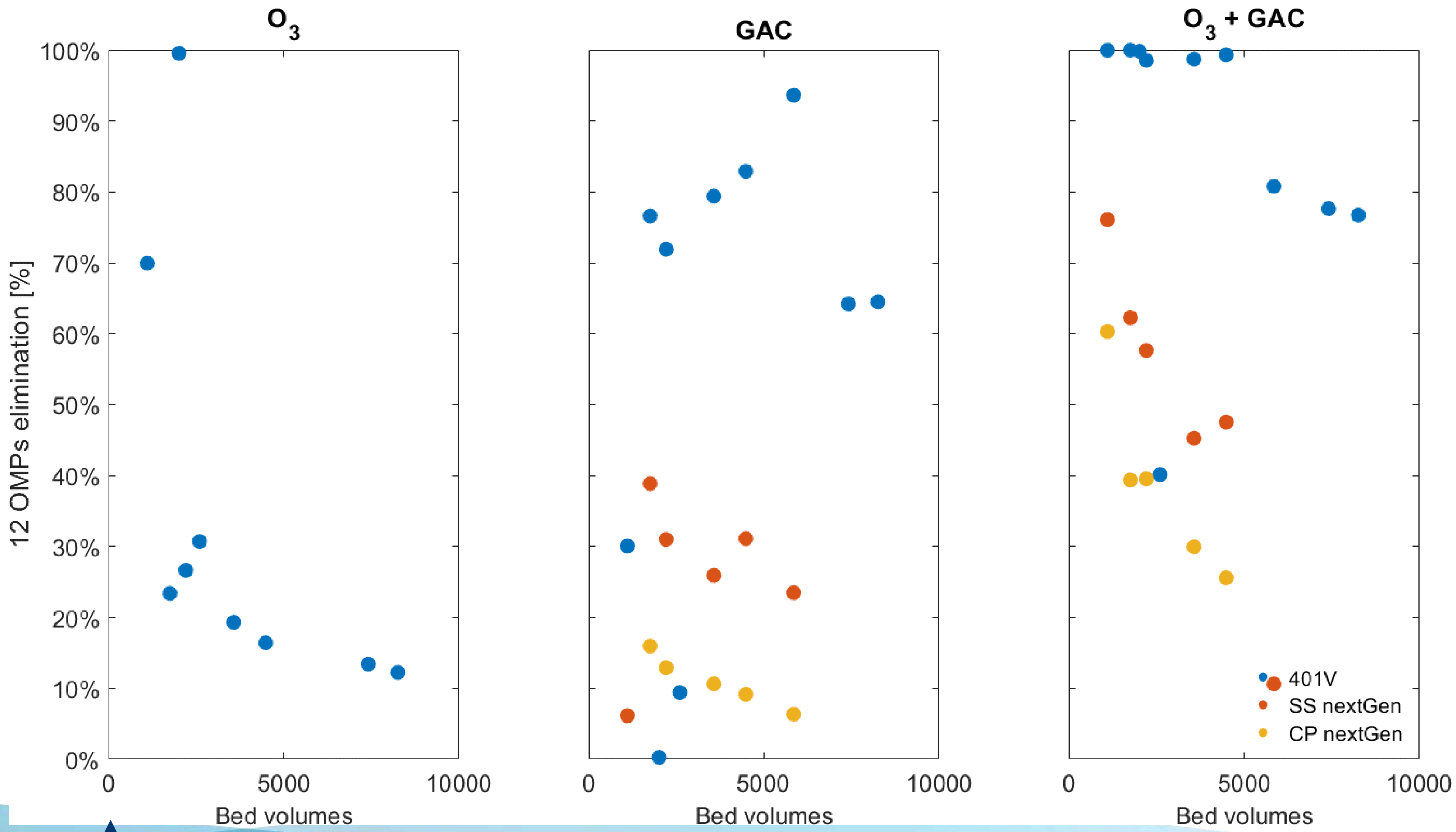
GAC pilot plant

Geometry of the filters		
Diameter of the column	m	0.3
Height of GAK_the fixed bed contactor	m	1.8
Volume of the fixed bed contactor	m^3	0.127
mass of SS_GAC	kg	67
mass of CP_GAC	kg	33
mass of 401V	kg	62

Analytics
SPE - LC MS for organic micropollutants OMP elimination
Sak254 and DOC as proxy for OMPs

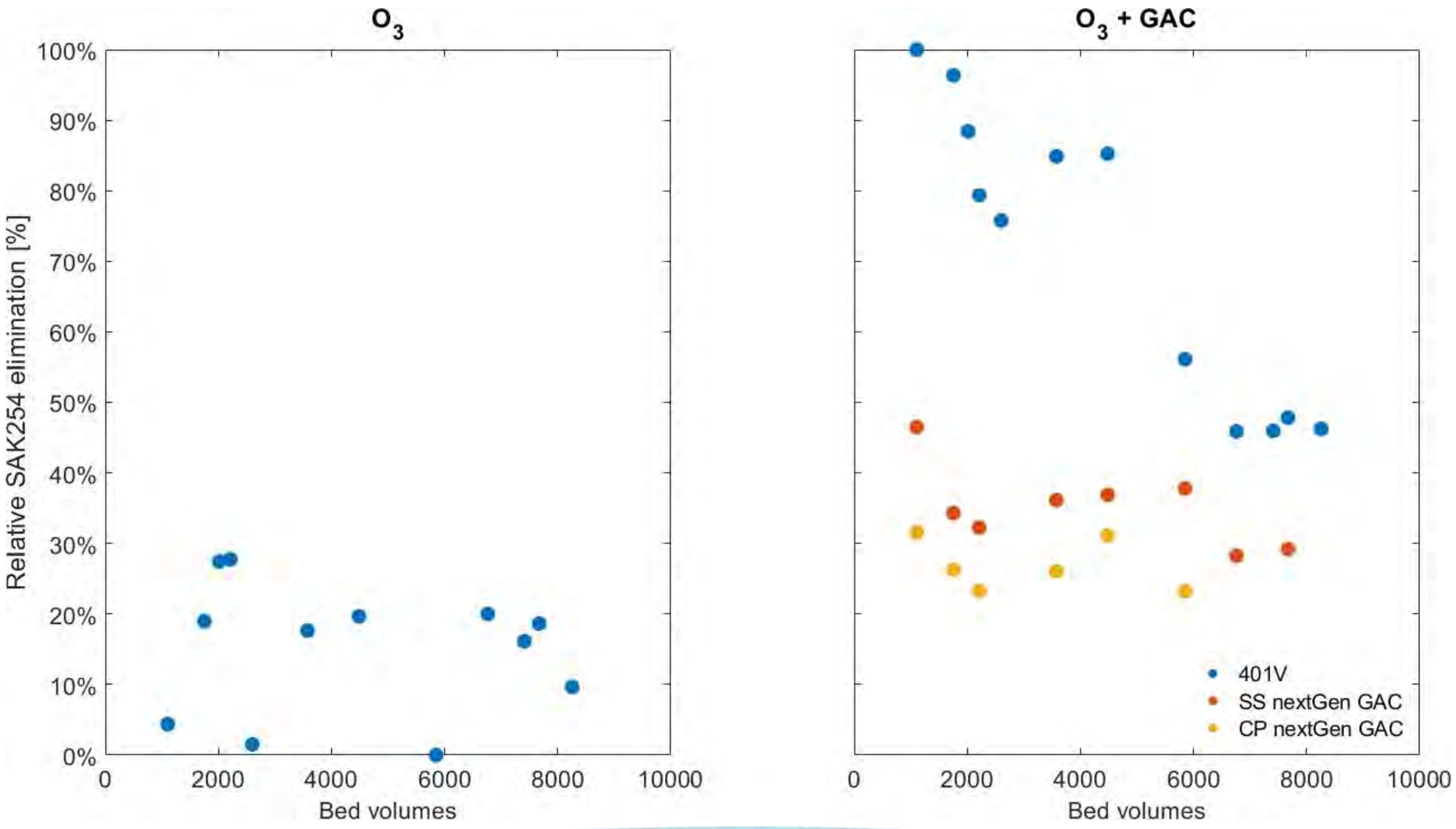
- Automated backwashing system
- Automated sampling at the outlet

Pilot study - 12 OMPs elimination

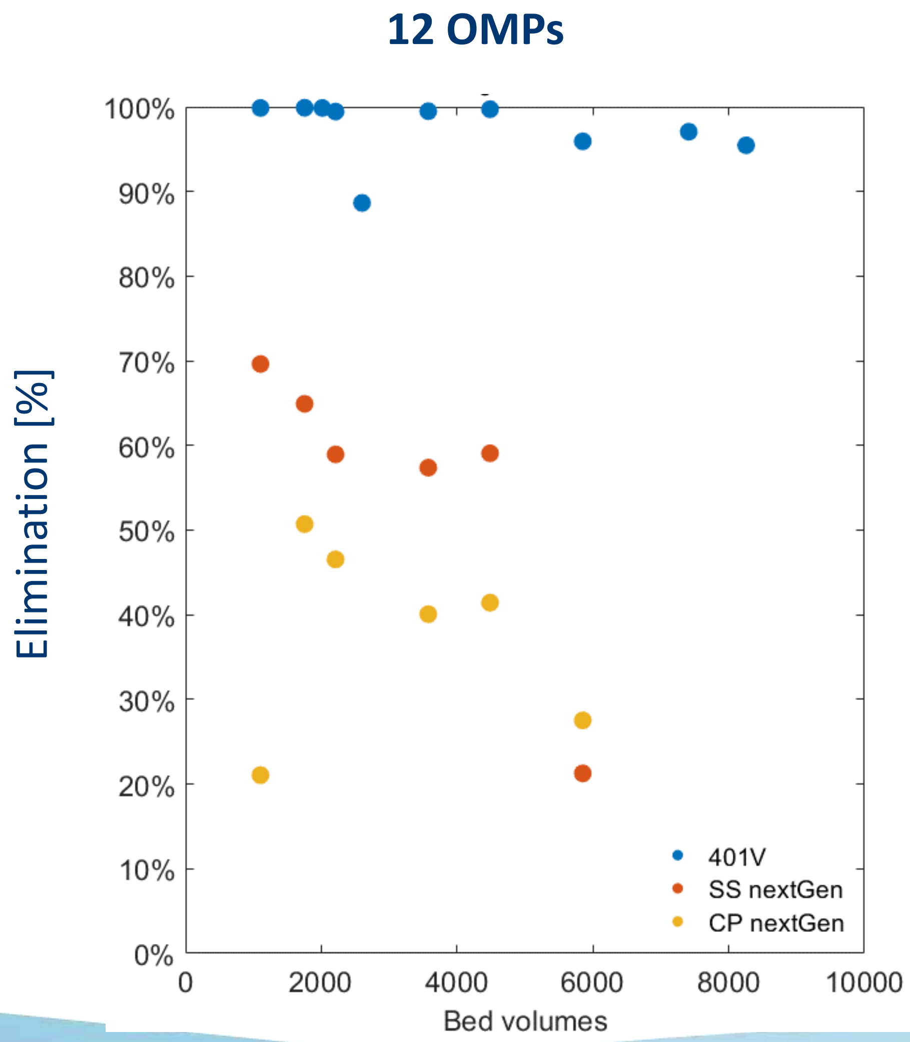


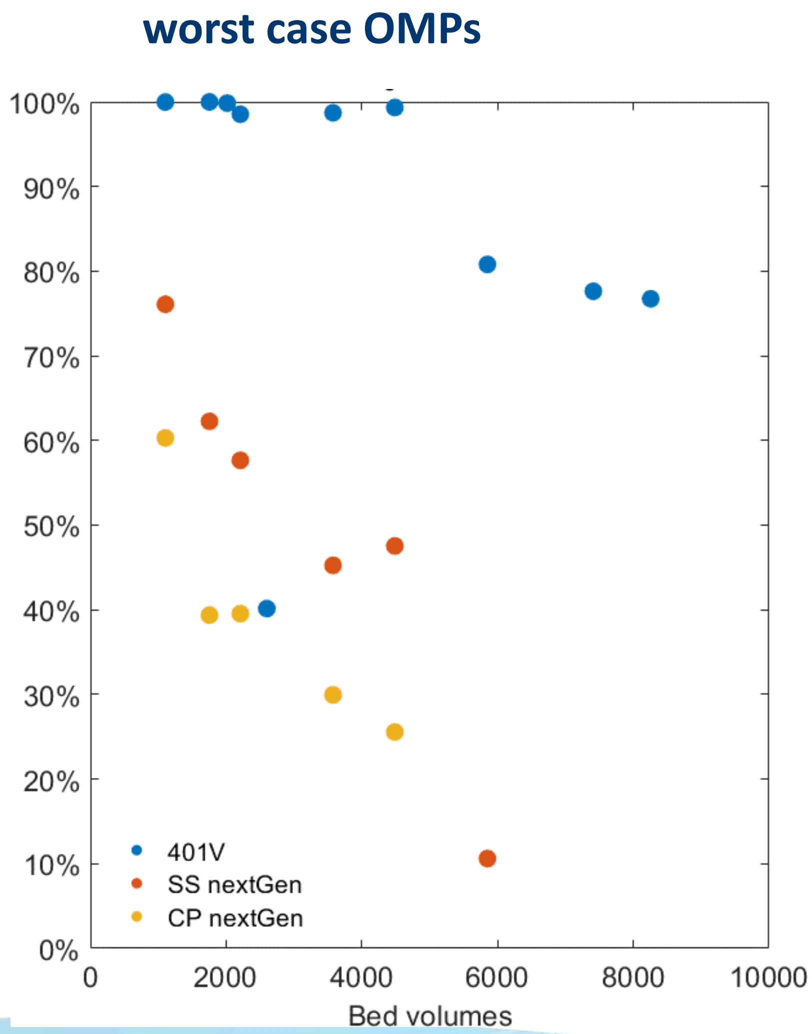
Nov 2020

Pilot study - Relative sak254 elimination



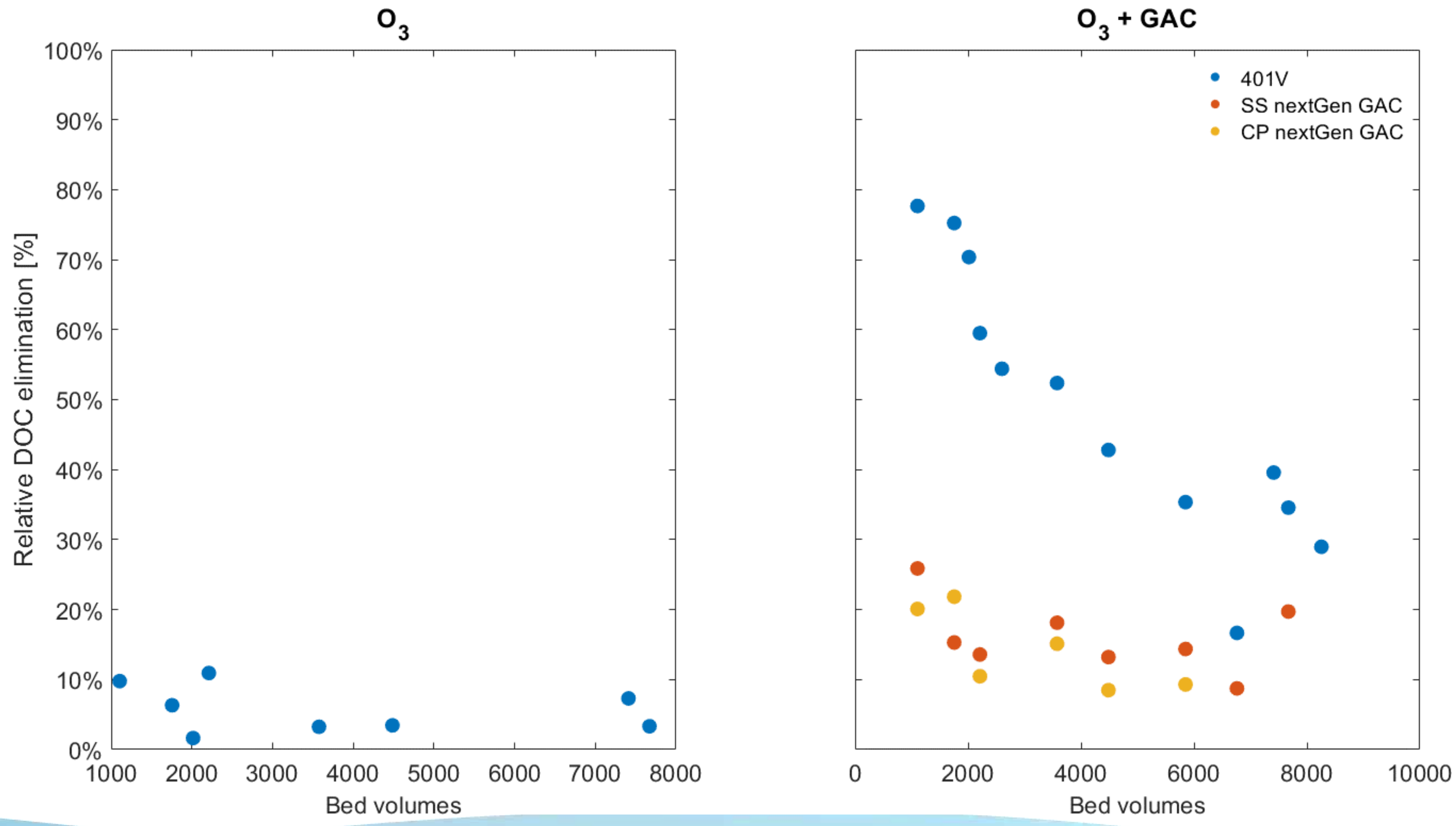
Pilot study - the «worst case» OMPs elimination



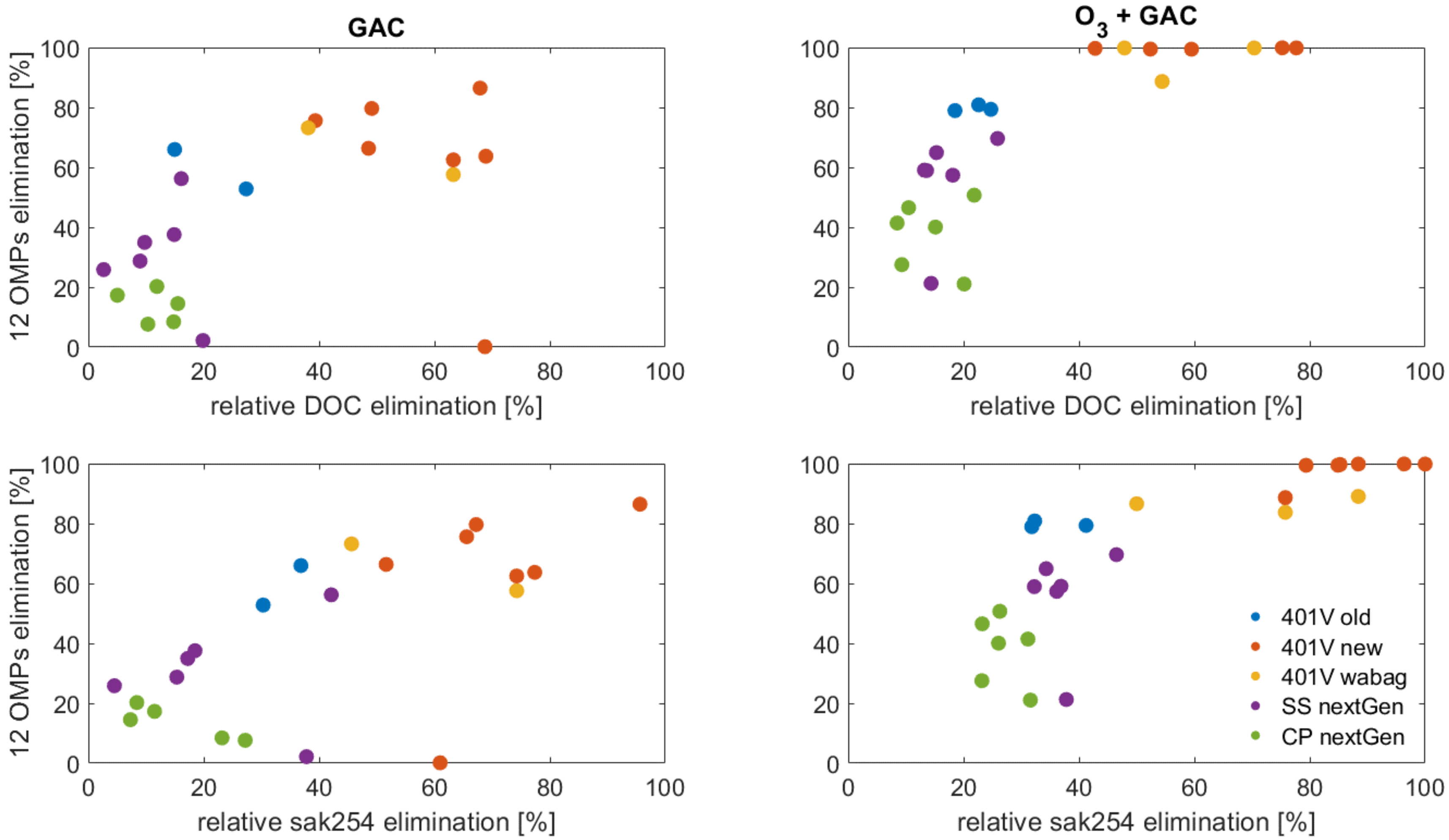


1. Venlafaxin
2. Candesartan
3. Irbesartan

Pilot study - Relative DOC elimination



Pilot study - DOC/OMP & sak/OMP correlation



Conclusions

- We identified 2 GAC from renewables sources to be tested at pilot scale
- After 5 months of operation, the first results indicate successfull elimination of OMPs via GAC filter
- Standard operating conditions do not ensure sufficient elimination as demanded in swiss ordinance (i.e. 80% elimination). Operating conditions of the filters should be optimized (EBCT and O_3 dosage)

- Sak254 and DOC are useful but not accurate proxy for OMP elimination. Direct measurements of OMP is always preferable.

Thank you for your attention!

n|w Fachhochschule Nordwestschweiz

M. Thomann

A. Nättorp

D. Gysin

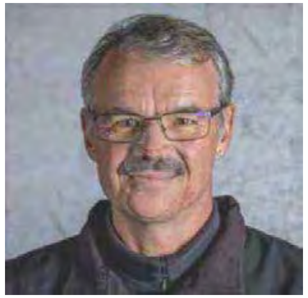
T. Bisang

M. Huspeka

ABWASSERVERBAND ALTENRHEIN

C. Egli

R. Peng



H. Graf

WABAG

W. Goldinger

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Annex 3: Presentations – Biogas technologies

The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

Online seminar on innovative biogas technologies

A. Kleyböcker, S. Casa Garriga, F. Fantone, C. Bruni

October, 30th 2020

Ultimate (June 2020 – May 2024):
Industry water-utility symbiosis for a smarter water society

- Promotion, establishment and extension of **Water Smart Industrial Symbioses**
- Development and demonstration of **innovative technologies** for symbioses
- **Assessment** of the technologies and development of **digital „support tools“**
- Development of **new business models** towards marketability

9 Symbioses between:

Industrial sectors
- Agro-food
- Beverage
- (Petro)chemical
- Biotech

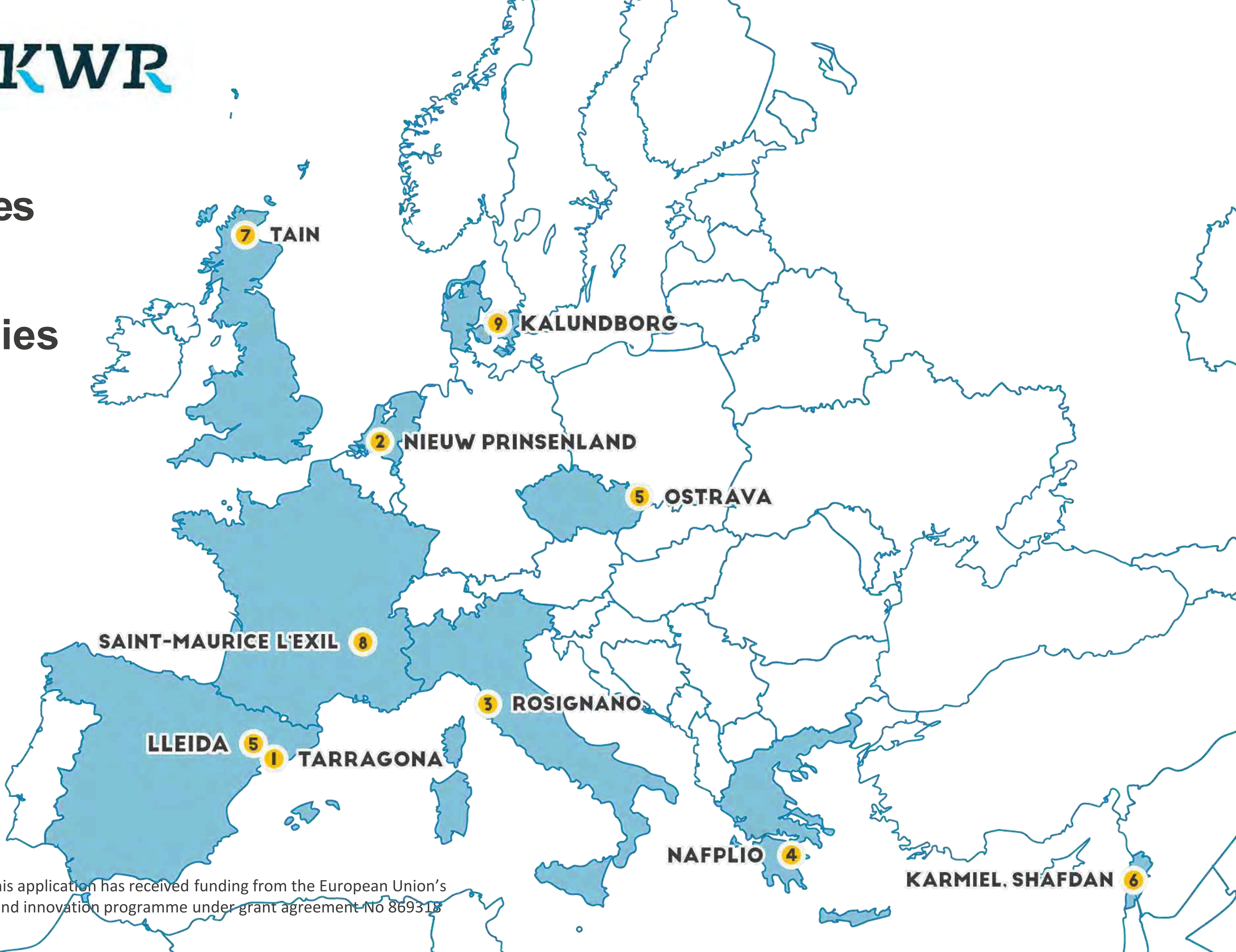
Service providers
- Municipal utility
- Multi-industry utility
- Specialized SME
- Water services provider

Coordinator: KWR

9 Case Studies

27 Partners

37 Technologies



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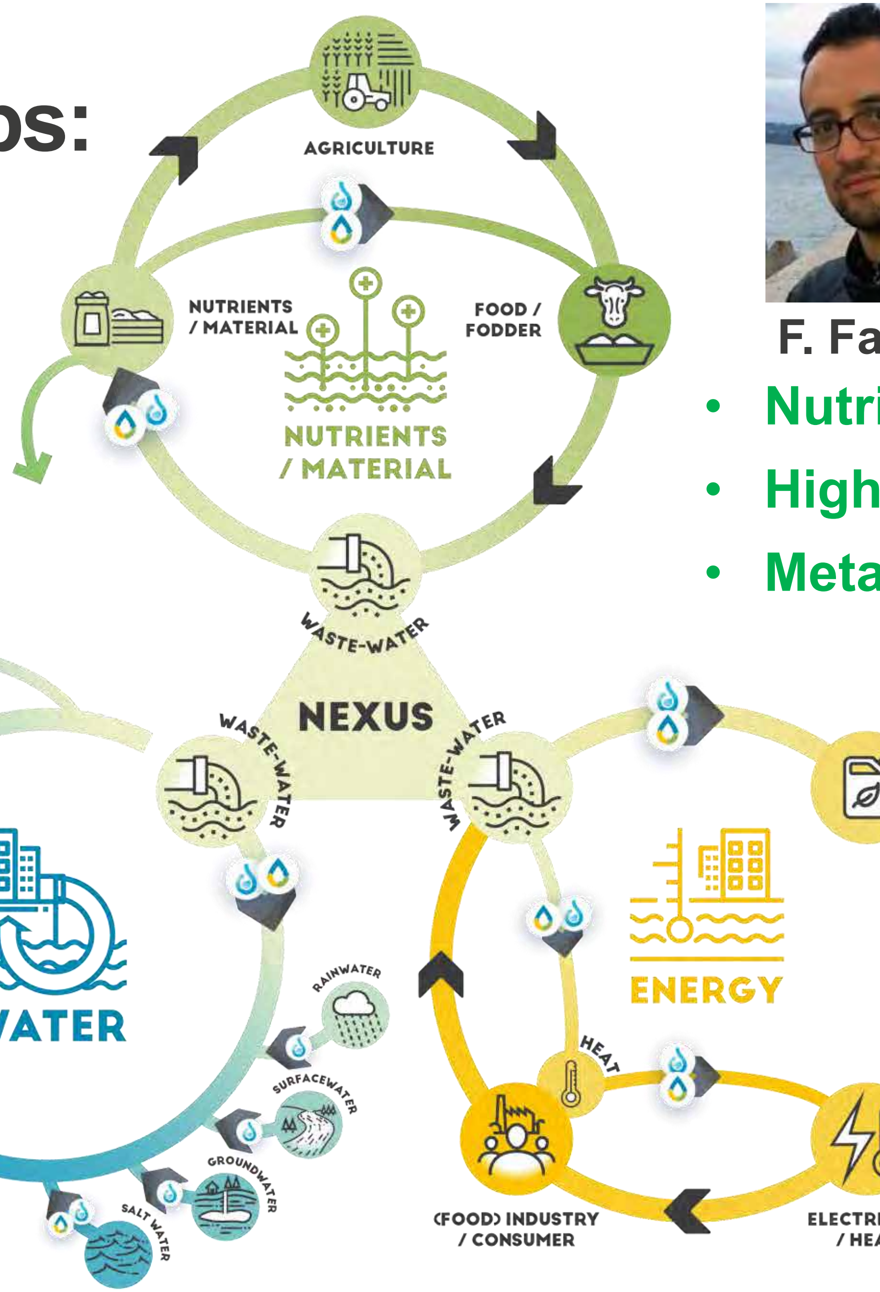
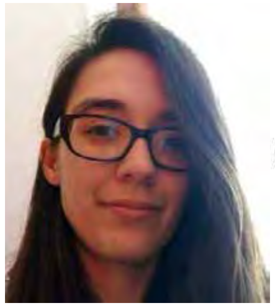
3 Cross-cutting Technology Groups: 9 Topics





F. Fatone C. Bruni

UNIVERSITÀ POLITECNICA DELLE MARCHE

- Nutrient recovery
- High added value products
- Metal recovery

eurecat
Centre Tecnològic de Catalunya

S. Casas

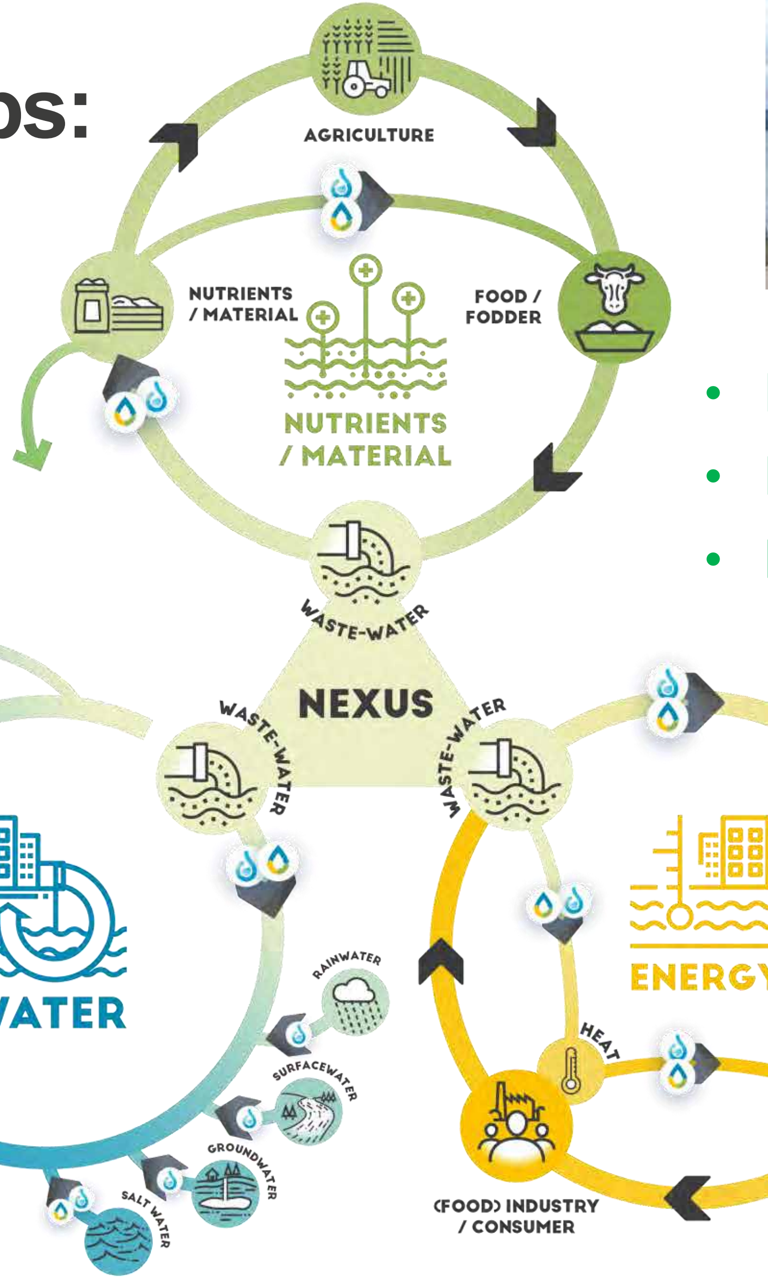
- Membrane technologies
- Adsorption technologies
- Advanced oxidation processes

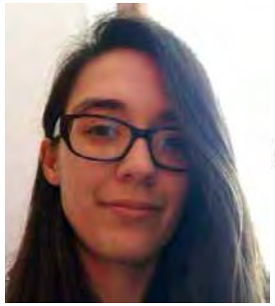
KOMPETENZZENTRUM Wasser Berlin

A. Kleyböcker

- Biogas technologies
- Heat recovery
- Digitalization

3 Cross-cutting Technology Groups: 9 Topics





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eurecat
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9 Case Studies

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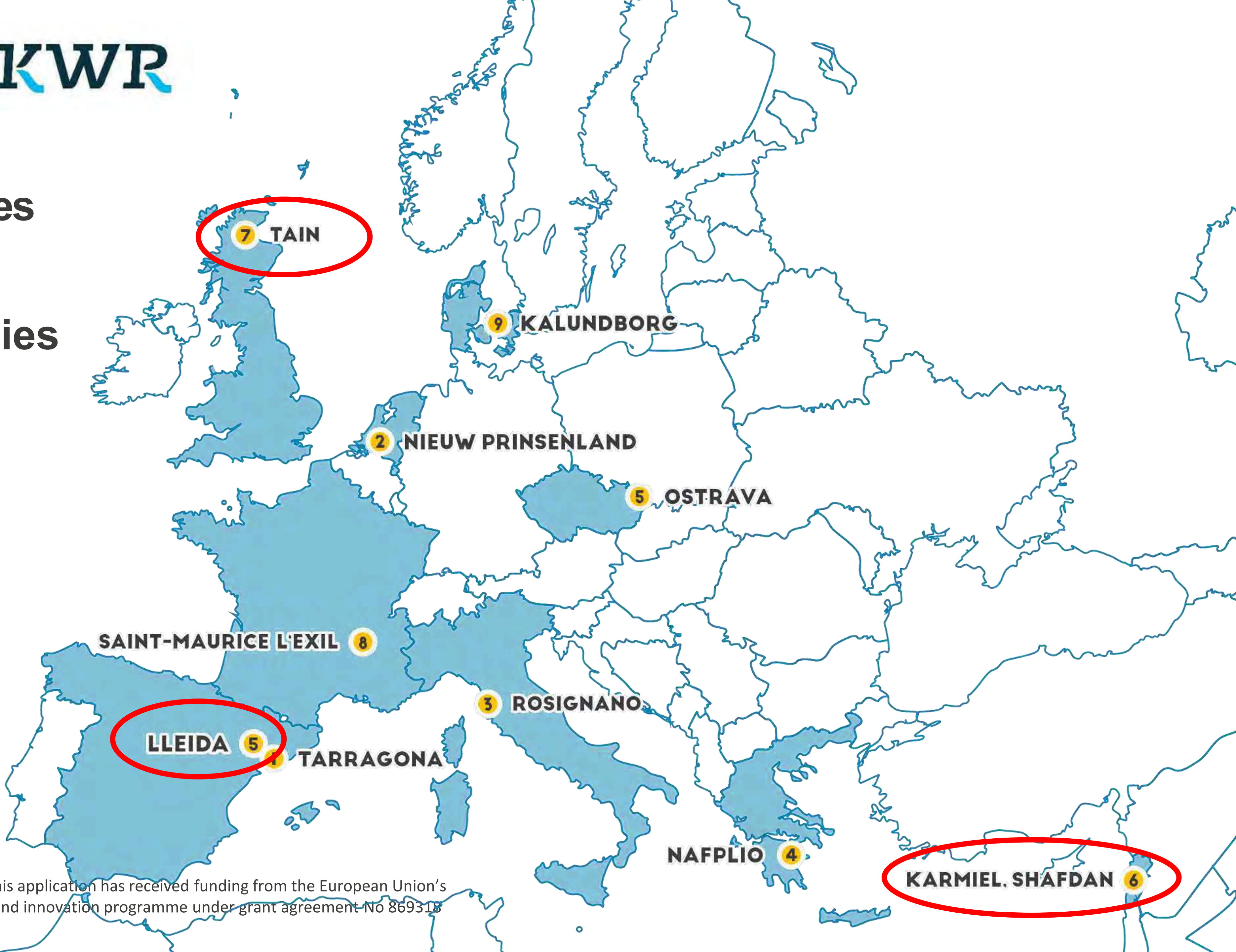


The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

Online seminar on innovative biogas technologies

10:15	**Biogas production in CS7 Tain**: Biogas production in an anaerobic membrane bioreactor (AnMBR) from distillery effluent *Marc Pidou (Cranfield University)*
10:30	**Biogas production in CS5 Lleida**: AnMBR versus bioelectrochemical fluidized bed reactor (BEFB) *Antonio Giménez Lorang (FCC Aqualia)*
10:45	**Biogas production in CS6 Shafdan & Karmiel**: Immobilized high rate anaerobic system (AAT) & biogas process stabilizing measures (PAC) *Isam Sabbah (The Galilee Society)*
11:00	**NextGen**: Anaerobic treatment of weak effluents at low temperatures *Ana Soares (Cranfield University)*
11:30	**SmartPlant**: Biogas recovery in primary treatment with a polyfoam biofilter (AAT) *Isam Sabbah (The Galilee Society)*
12:00	**End**

ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

CS 5 Lleida/Ostrava

A. Giménez-Lorang

aqualia

Biogas production in CS5 Lleida: AnMBR versus BEFB, 30.10.2020

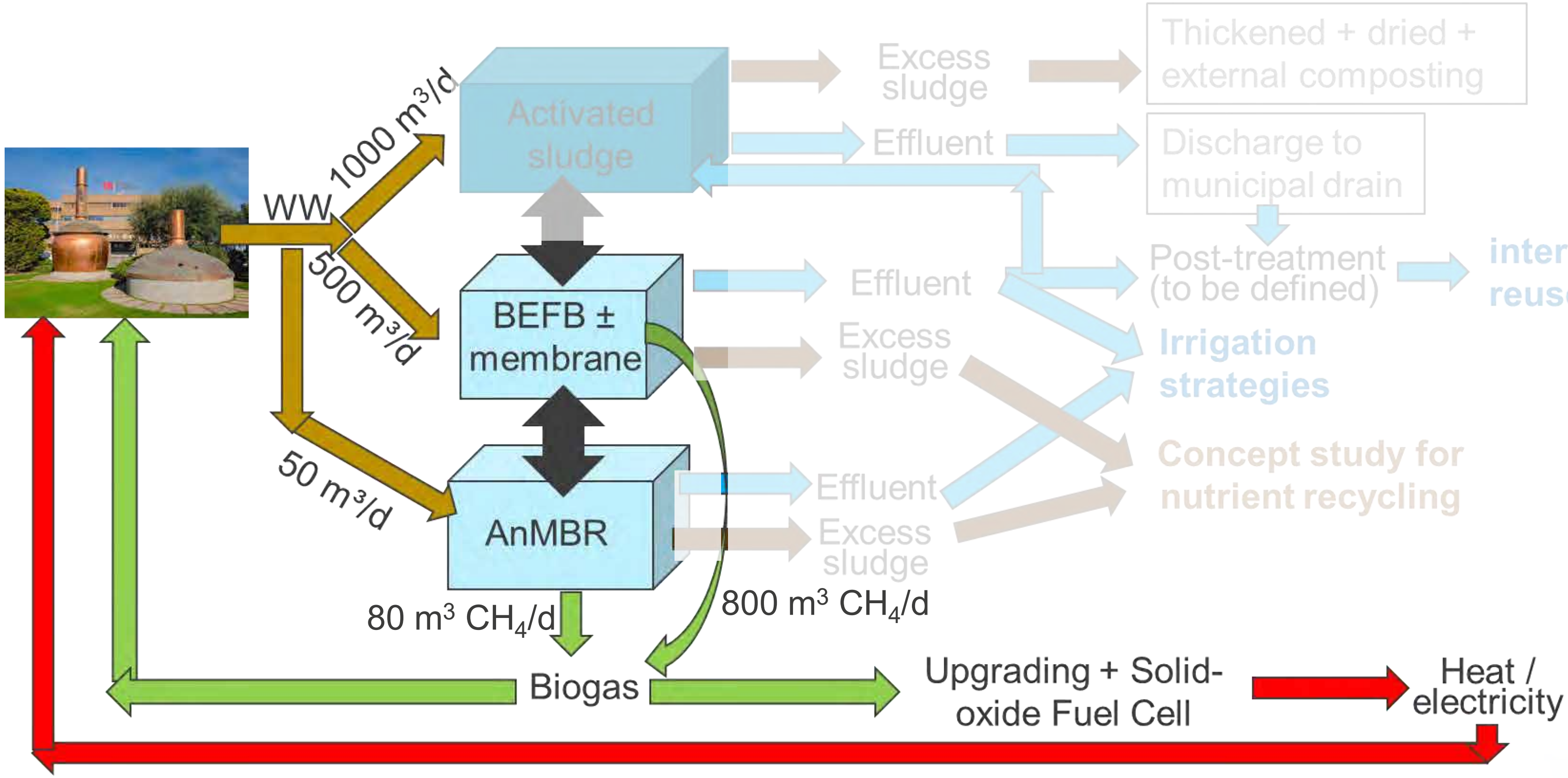
ENERGY - Task 1.3.2

Anaerobic treatment of brewery wastewater and electricity production via solid-oxide fuel cell

OBJECTIVES:

Biogas production → biogas upgrading to biomethane → heat

Electricity production via solid-oxide fuel cell operated with biogas or methane



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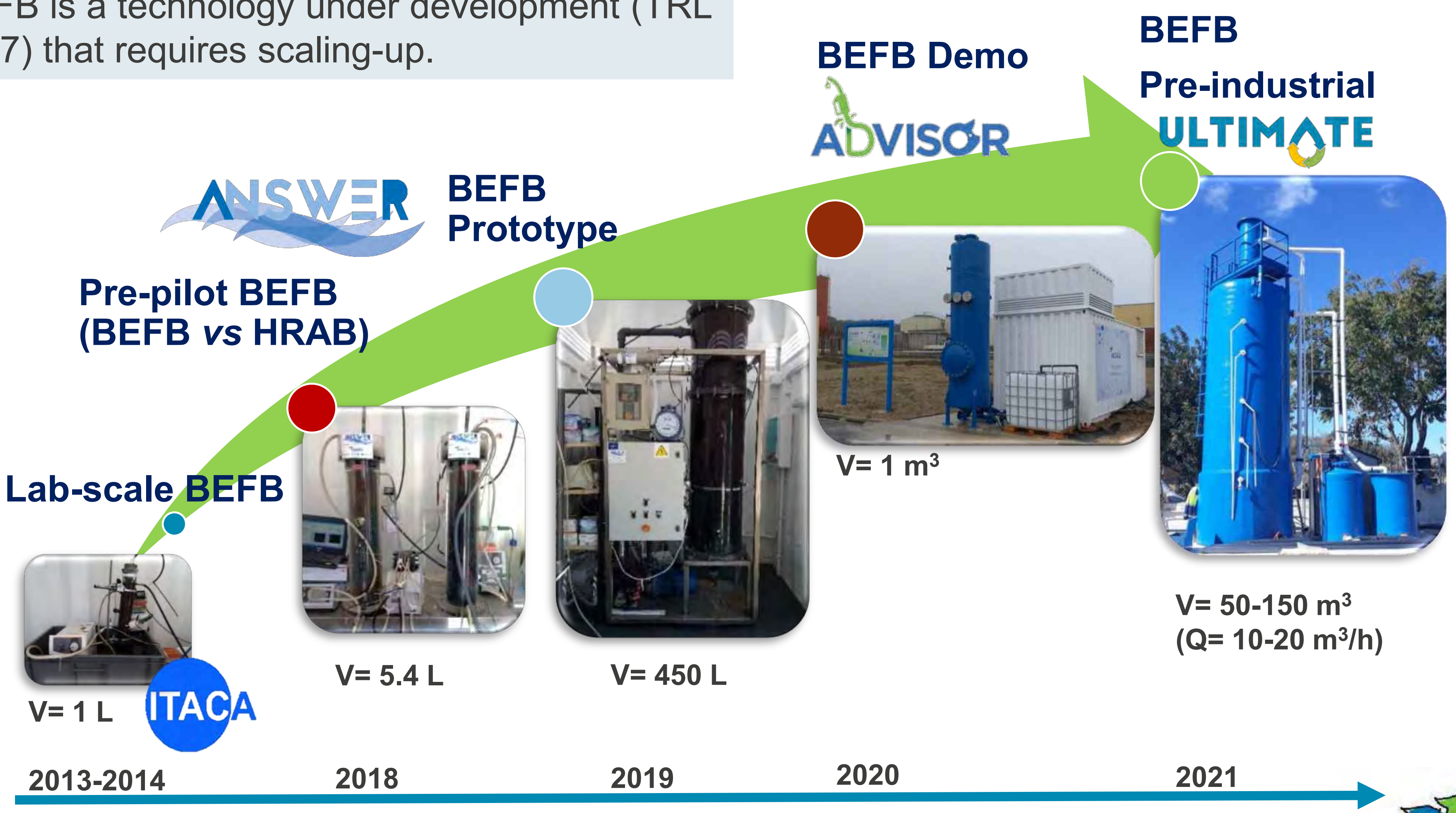
BEFB = BioElectrochemical Fluidized Bed

BEFB is a technology under development (TRL 5→7) that requires scaling-up.



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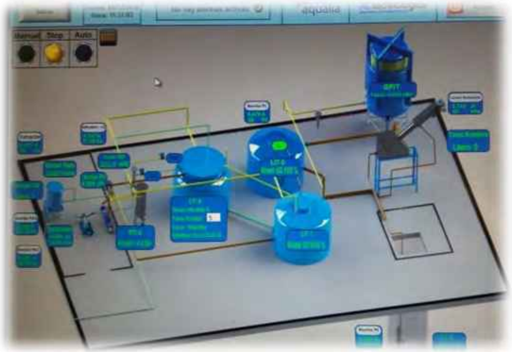
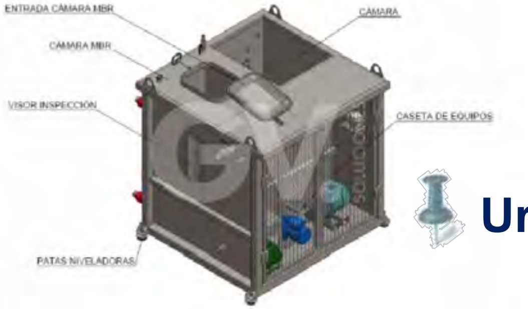
aqualia

AnMBR = Anaerobic Membrane Bioreactor





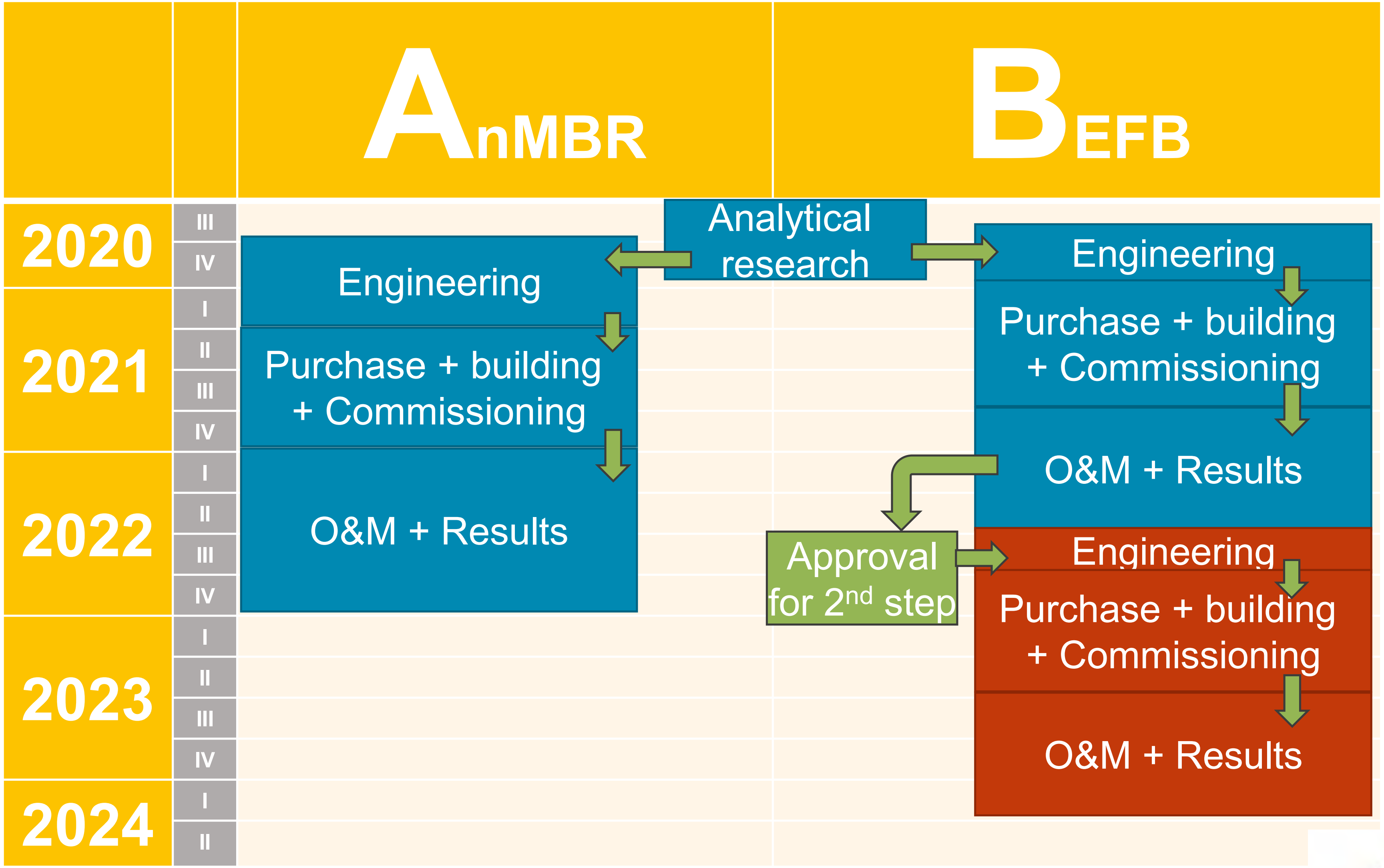
Urban | Black water | Industry | OFMSW

SAnMBR control system:
co-patented with U.Valencia / Polytechnic U. Valencia EP16382140.8

The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

aqualia

Schedule



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AnMBR vs. BEFB

	AnMBR	BEFB
Suspended matter tolerance	+	-
Quality of treated water / performance	++	+
Energy consumption	(-)	+
Methane productivity	¿=?	¿=?
Biogas heat value	¿?	¿?
Toxic / inhibitory compounds tolerance / resilience	-	+
Organic overload tolerance / resilience	-	+
Low temperature tolerance / resilience	-	+
Nutrient removal	-	+

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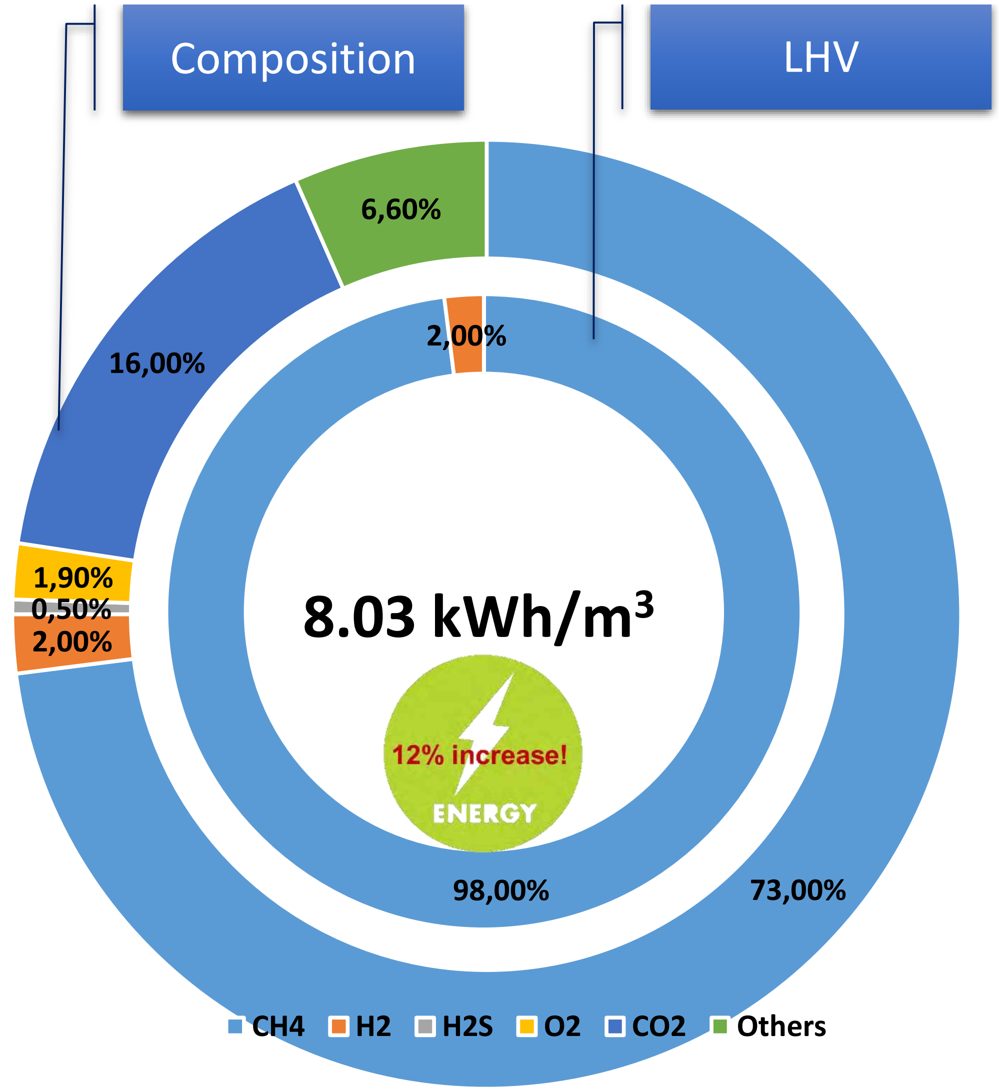
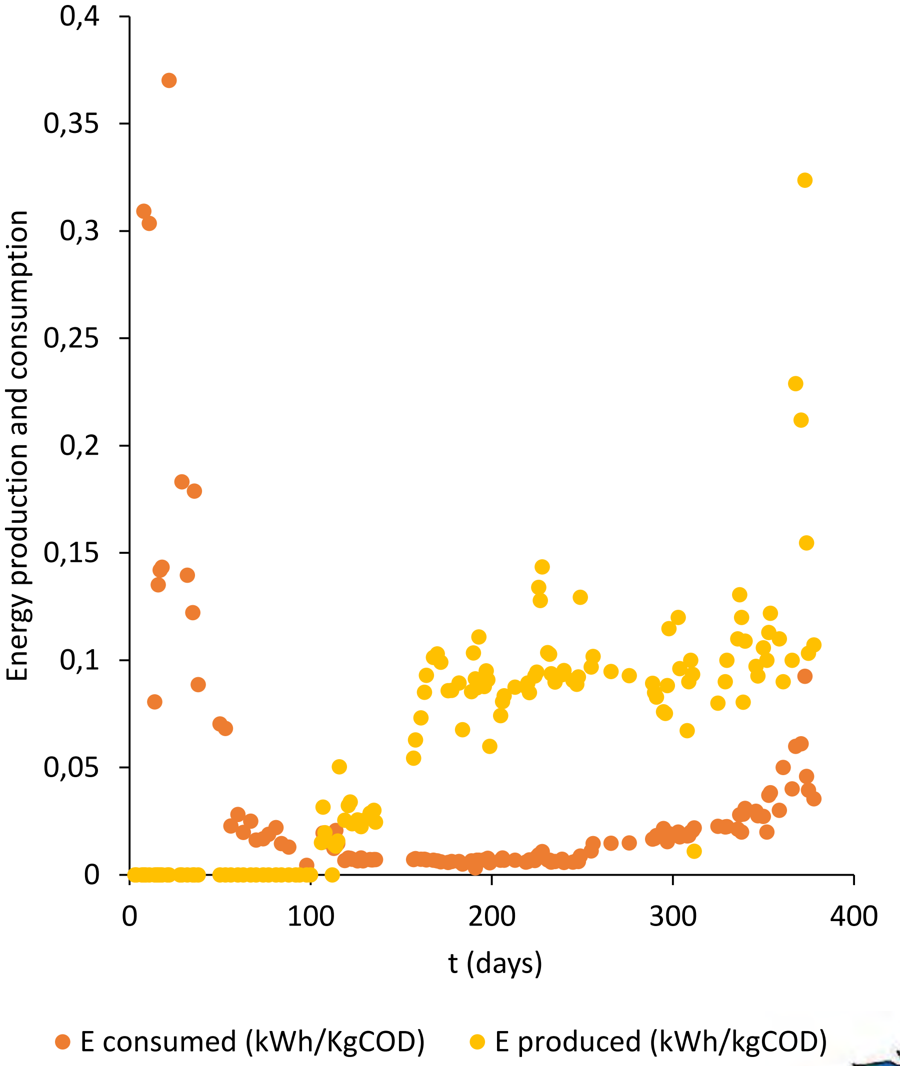
aqualia

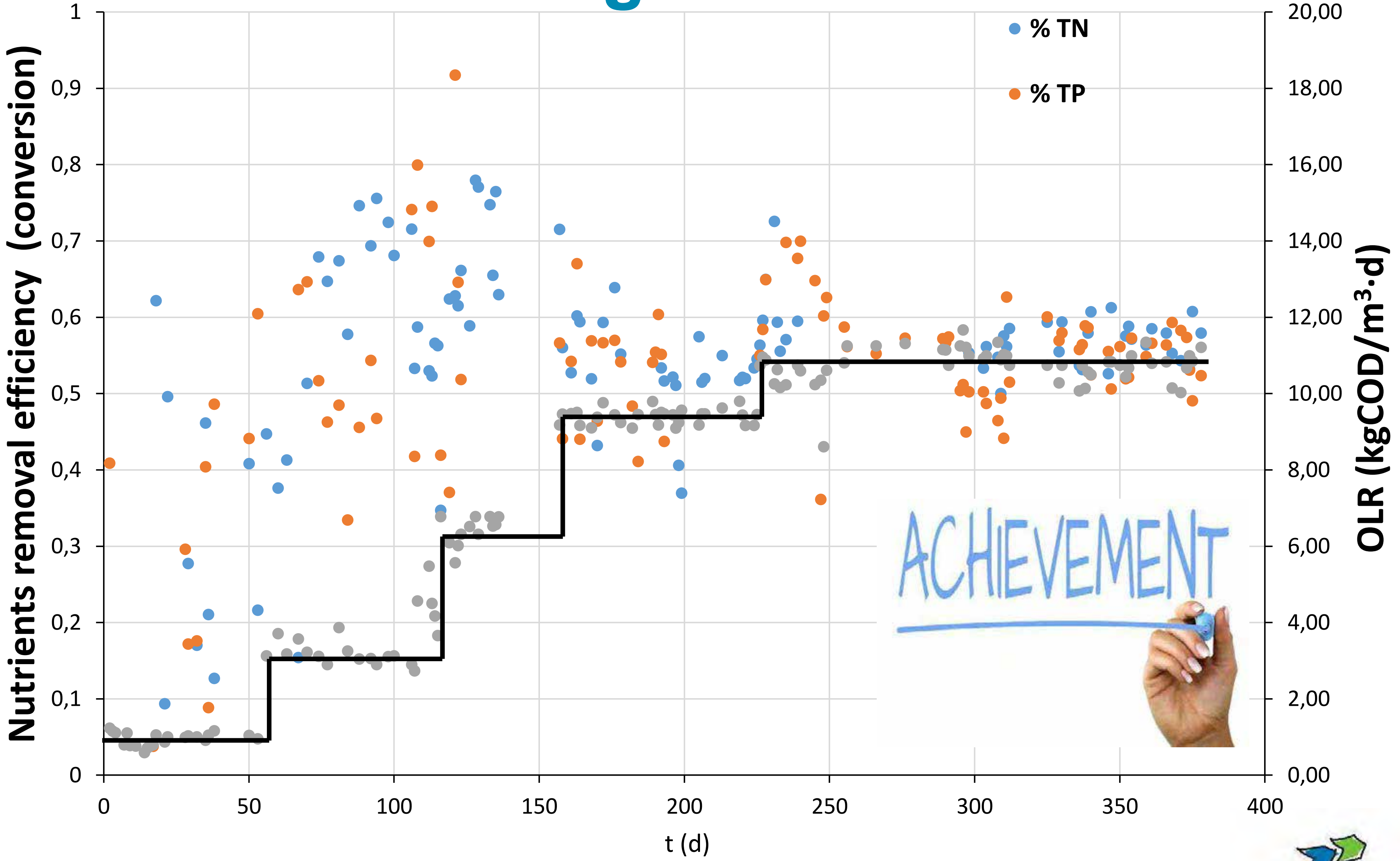
BEFB biogas quality – self-sufficient process





The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

Nutrient removal through an anaerobic treatment



The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

Fuel Cells

- Conversion of chemical energy of fuel (hydrogen, natural gas, methanol, other hydrocarbon) into electric and heat energy.
- Classification according to electrolyte, fuel or operation temperature.
- To gain competitiveness: Sector trying to decrease material production cost, energetic production cost (<40$/kW) and increasing durability.

Type	Advantages	Disadvantages
SOFC ***Solid oxide fuel cell***	• High efficiency, suitable for CHP • Fuel flexibility, tolerance to fuel impurities • No need for precious metal catalysts	• Long startup time • High temperature corrosion and break down of fuel cell elements

SOLID POWER

BlueGen BG-15

Electrical efficiency**	Up to 57%
Overall efficiency**	Up to 88%
Seasonal space heating energy efficiency class	A+++
Annual fuel consumption***	22.000 kWh per year
Fuel types	Natural gas according EN 437 Bio methane LNG
Fuel inlet pressure	Max pressure: 25 mbar Min pressure: 15 mbar
Water consumption	up to 32 l/day
Electrical power supply	Max: 0.2 kW

Schedule:

6/21: 1st trial in urban WWTP (Lleida)

+

9/2022: 2nd trial in industrial WWTP Mahou San Miguel (Lleida)

The project leading to this application ha
Horizon 2020 research and innovation programme under grant agreement No 869318

ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

CS 5 Lleida/Ostrava

A. Giménez-Lorang

aqualia

ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

CS7 – Tain (Glenmorangie distillery)

Cranfield University

Aquabio

Meeting: October, 30th 2020

CS7


7 TAIN
9 KALUNDBORG
2 NIEUW PRINSENLAND
5 OSTRAVA
SAINT-MAURICE L'EXIL 8
3 ROSIGNANO
LLEIDA 5
1 TARRAGONA
NAFPLIO 4
KARMIEL, SHAFDAN 6


GLENMORANGIE


GLENMORANGIE
THE ORIGINAL

Sustainability strategy

- Wastewater treatment for discharge in the Dornoch Firth
- Biogas production for energy recovery as heat
- Nutrient rich sludge used a soil enhancer in local Barley fields

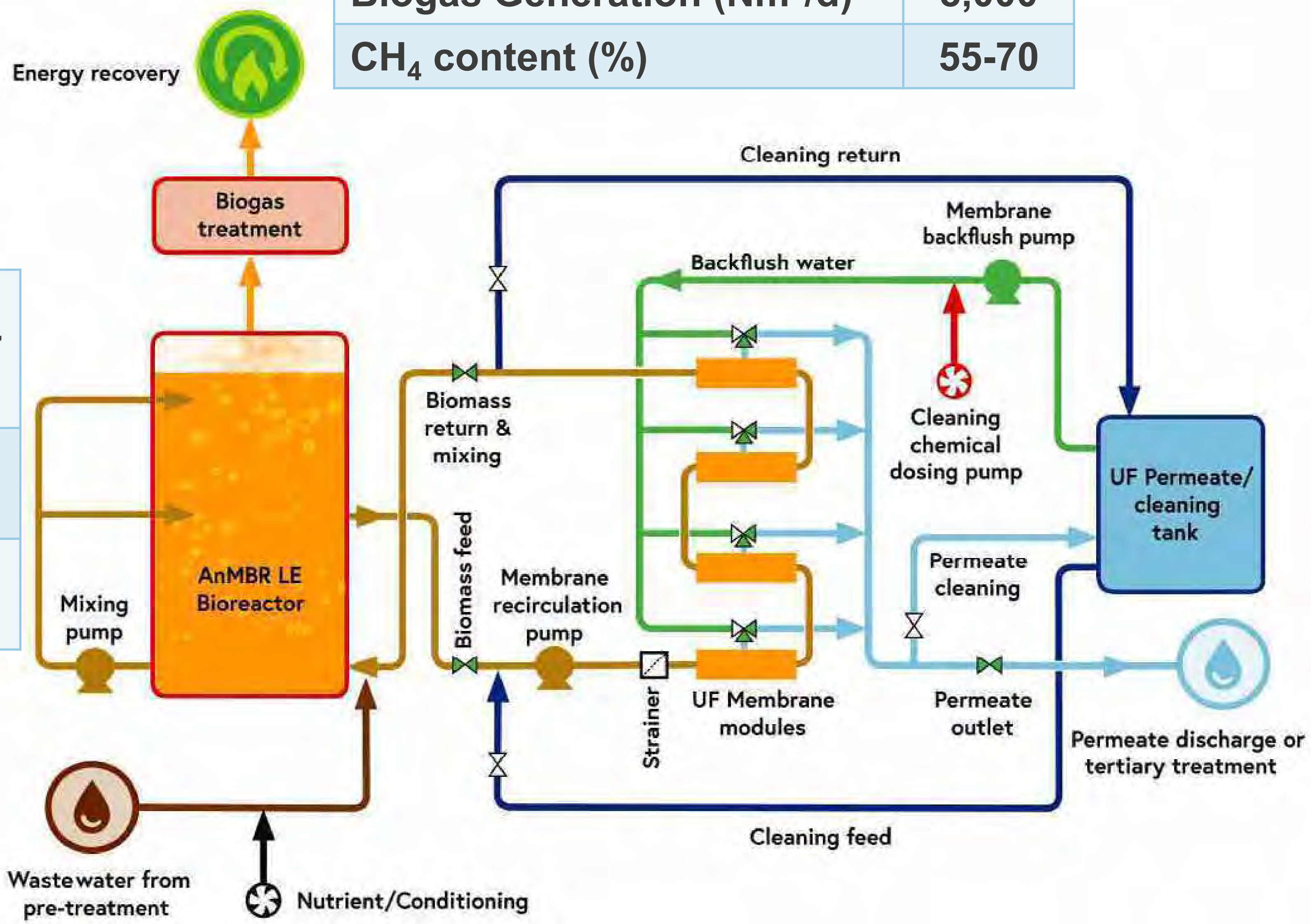
- Dornoch Environmental Enhancement Project: restore Native European oysters and enhance biodiversity in the Dornoch Firth

AnMBR LE^{TM}

Aquabio

Biogas Generation (Nm^3/d)	8,000
CH_4 content (%)	55-70

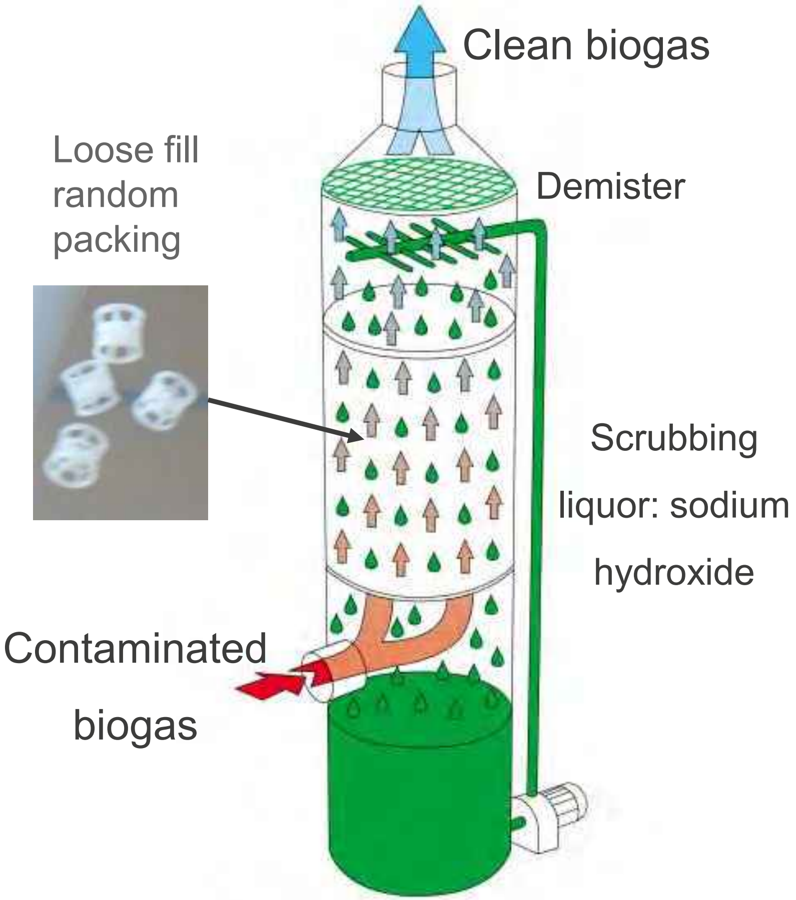
Peak/average AnMBR Feed flow rate (m^3/d)	467/377
Design COD load (kg/d)	14,527
Average total COD removal	> 95%



The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

Biogas scrubber and boiler

Packed tower scrubber for H_2S removal



https://www.forbesgroup.co.uk/environmental-technologies/packed-tower/

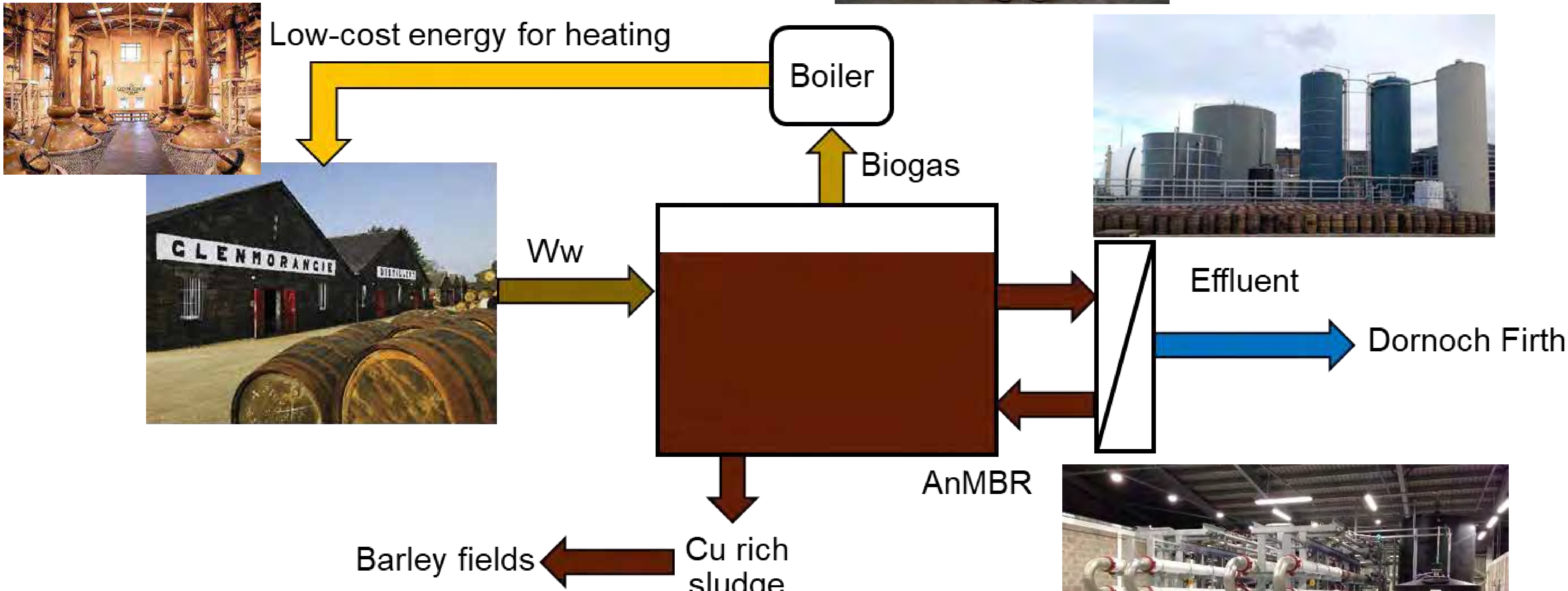
Biogas fired steam boiler

Maximum continuous rating (kg/hr)	**2067**
Design temperature (ºC)	**188**
Working pressure	**8 barg**

The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

Current system

Reduces the dependence in fossil fuel of the distillery by 15%



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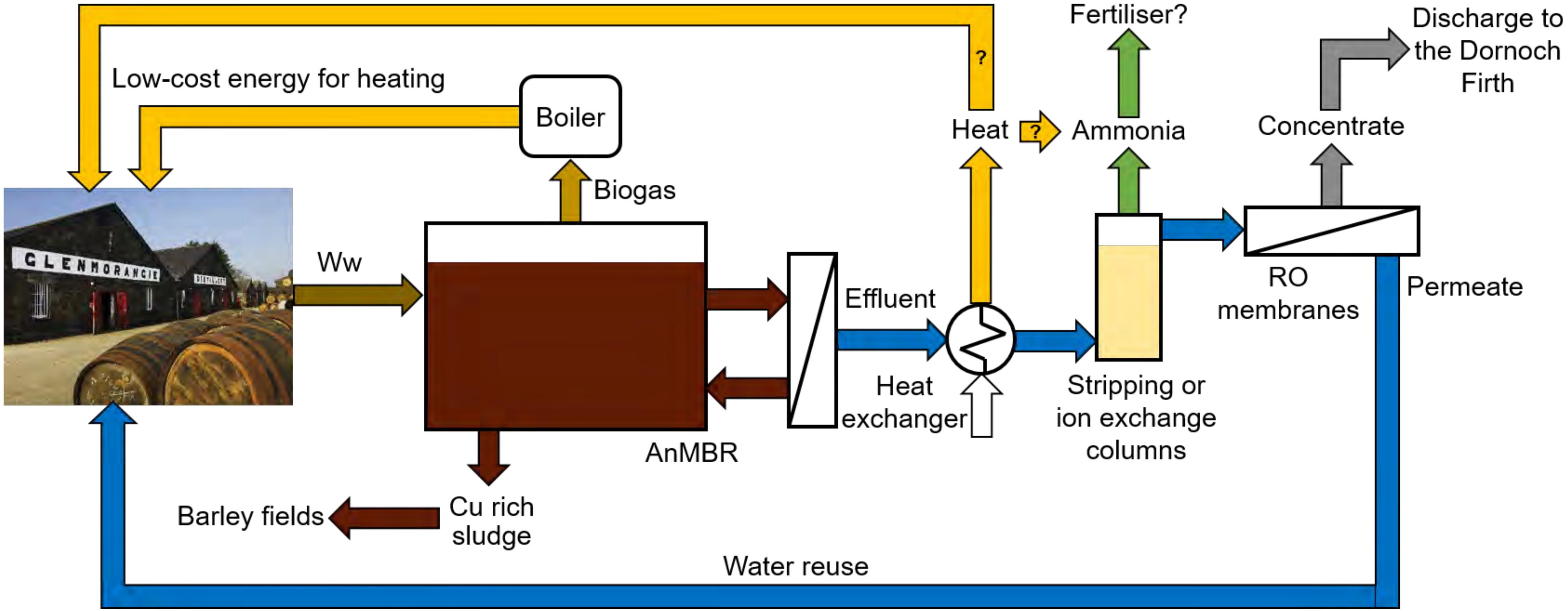
As part of Ultimate…



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ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

Thank you!

WATER SMART INDUSTRIAL SYMBIOSIS

Biogas production in CS6 Shafdan & Karmiel:

Immobilized high rate anaerobic system (AAT) & biogas process stabilizing measures

I. Sabbah, K. Baransi-Karkaby, N. Massalha, G. Horn, A. Aharoni, H. Raanan Kiperwas, D. Iossifidis, E. Bizani, C. Christophoridis, M. Touloupi

CS meeting on “Biogas Technologies”: October, 30th 2020

Symbiosis in Karmiel and Shafdan:

Municipal / Agro-industrial WWTP

MEKOROT
Israel National Water Co.

SME and technology providers

AgRobics

Greener than Green TECHNOLOGIES

جمعية الجليل
אגודת הגליל
The Galilee Society

Current situation

Karmiel		Shafdan	
30 K m^3/d →	Karmiel WWTP	400 K m^3/d →	Shafdan WWTP
Municipal / Agro-industrial WW and (demo scale AAT)	- Pre-treatment - Primary clarifier - Activated sludge - Sand filtration	Municipal / Agro-industrial WW	- Pre-treatment - Primary clarfier - Activated sludge - Tertiary treatment via SAT

The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

ENERGY - Task 1.3.3

Biogas production from anaerobic pre-treatment of municipal and/or industrial wastewater in **Karmiel**

Partners:

MEKOROT Israel National Water Co.

AgRobics

جمعية الجليل
אגודת הגליל
The Galilee Society

Greener than Green TECHNOLOGIES

OBJECTIVE:

Reducing the high organic load peaks in WWTP main stream, caused by mixing with olive mill and slaughterhouse wastewater, using iimmobilized high rate anaerobic system (AAT).

30 K m^3/d

Karmiel WWTP

Municipal / Agro-industrial WW (**120 m^3/d**)

Scenario 2

OMW (0.5-2 m^3/d)

OMW tank / pre-treatment

Packed resin bed

Mixing tank

AAT

Recovery of polyphenols task 1.4.5

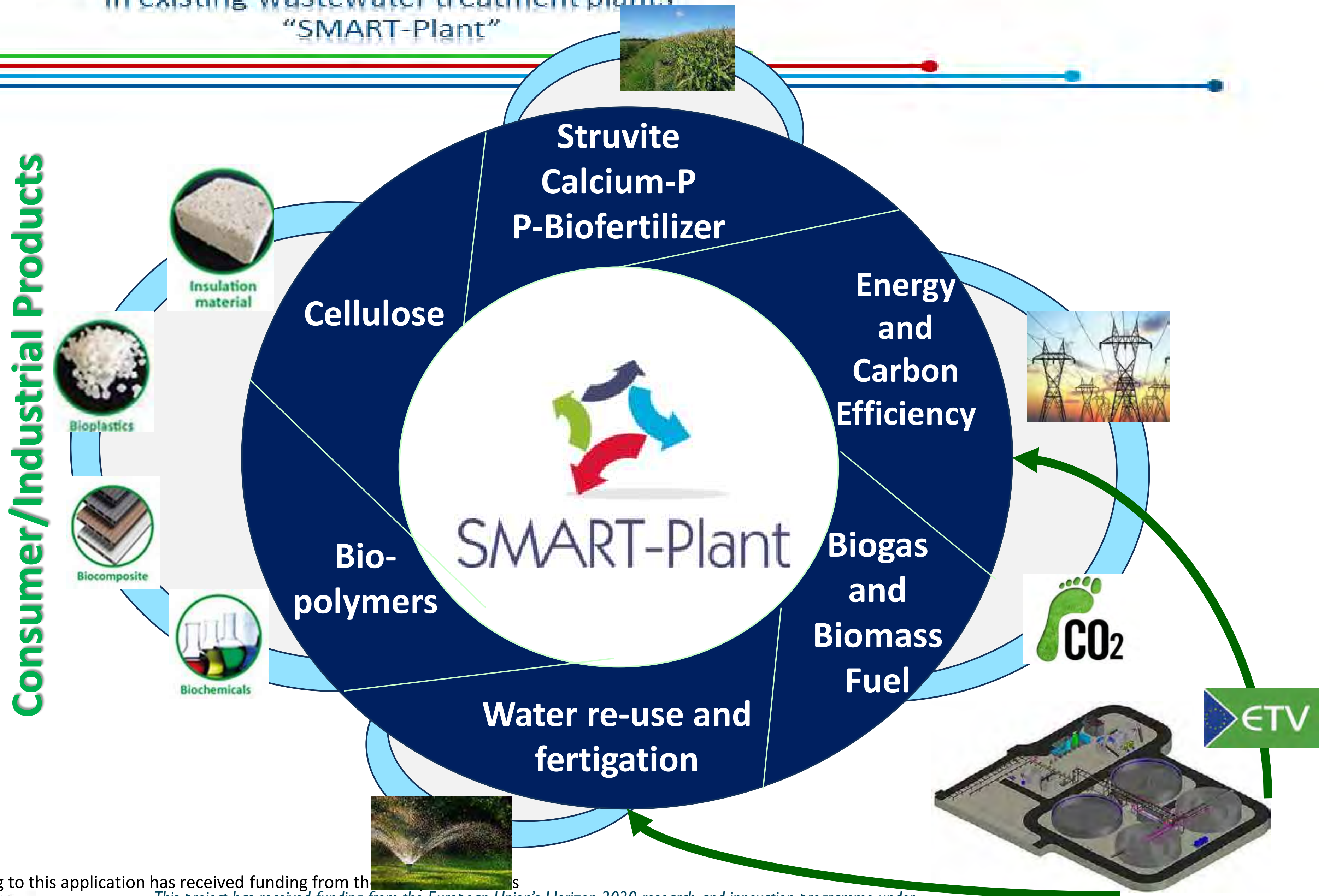
Biogas recovery: **(8-15) m^3/d**

Tests under different ratios of discharge

The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

Methane Yield: 0.12-0.15 m^3 CH_4/kg oDM

Scale-up of low-carbon footprint MAterial Recovery Techniques in existing wastewater treatment PLANTs



The project leading to this application has received funding from th[e] [European Union's] Horizon 2020 research and innovation programme under grant agreement No 869318

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 690323

ETV

Aim

Reduced **loads of COD and TSS** on the biological treatment system → Energy-efficient water reuse; **Biogas** production.

European Commission

Horizon 2020
European Union funding
for Research & Innovation

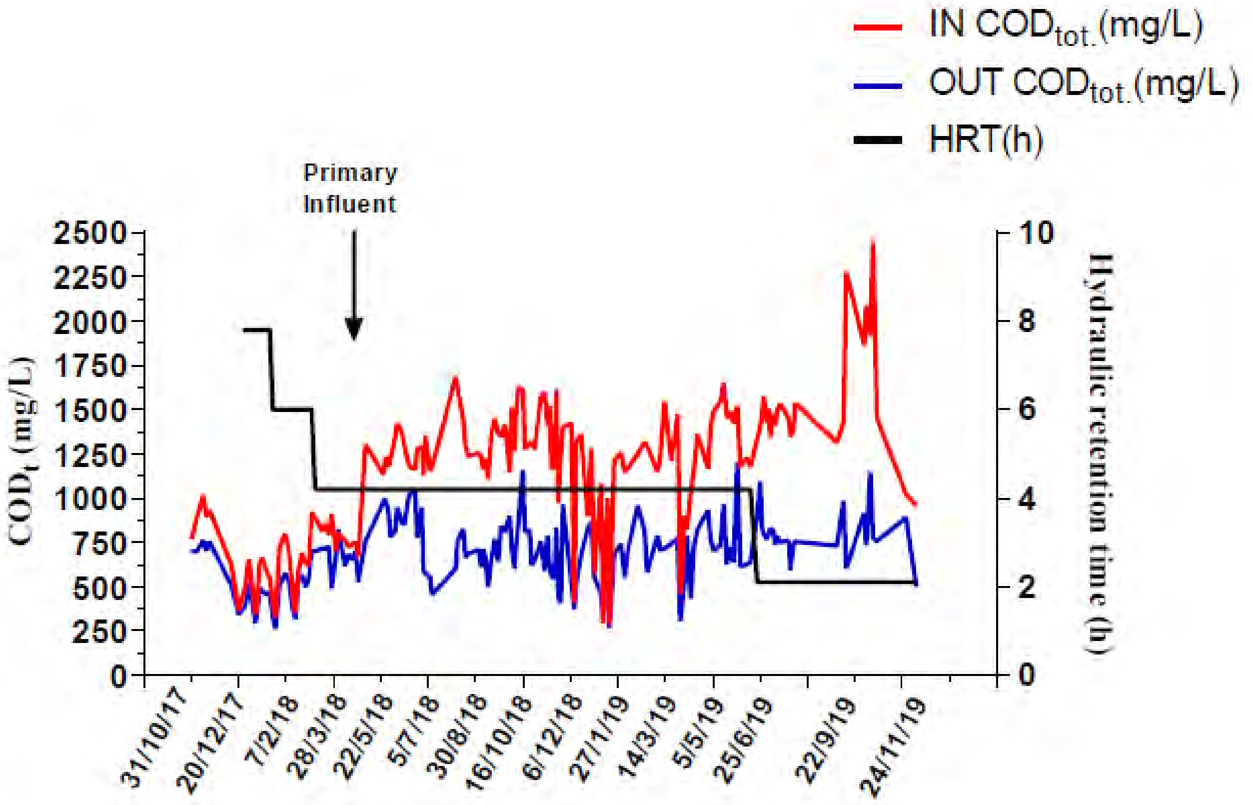
The project leading to this application has received funding from the European Union's

Operation

- 240 m³/d waste water flow
- 55-60% COD removal
- 50% TSS removal
- HRT= 2-4 hours

Recovery Efficiency

- 5-10 m³ biogas/day
- 72% CH4%

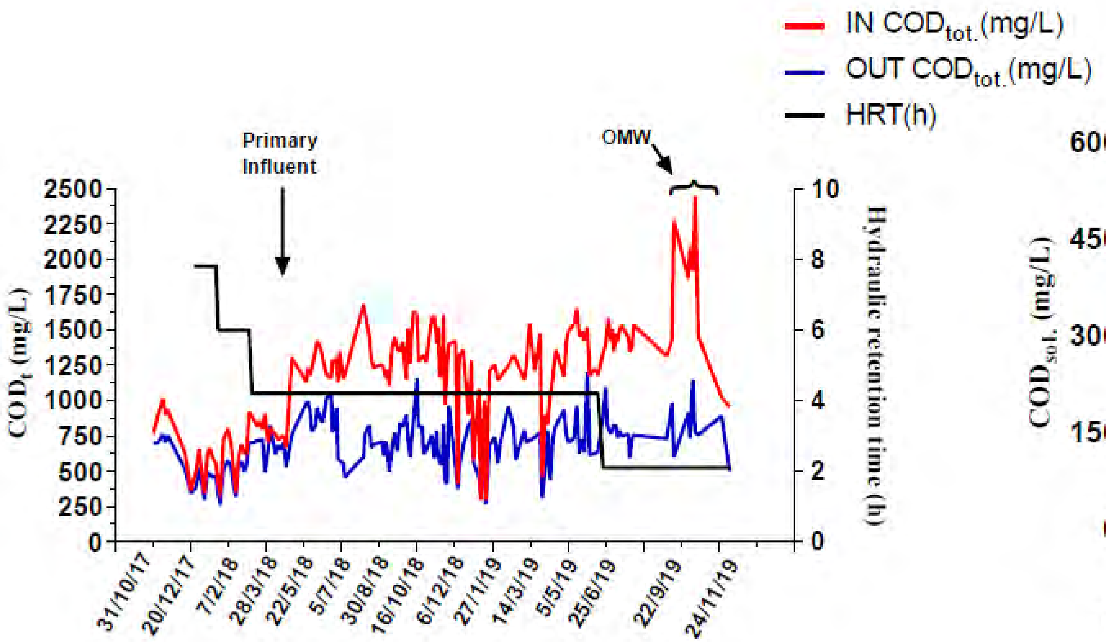


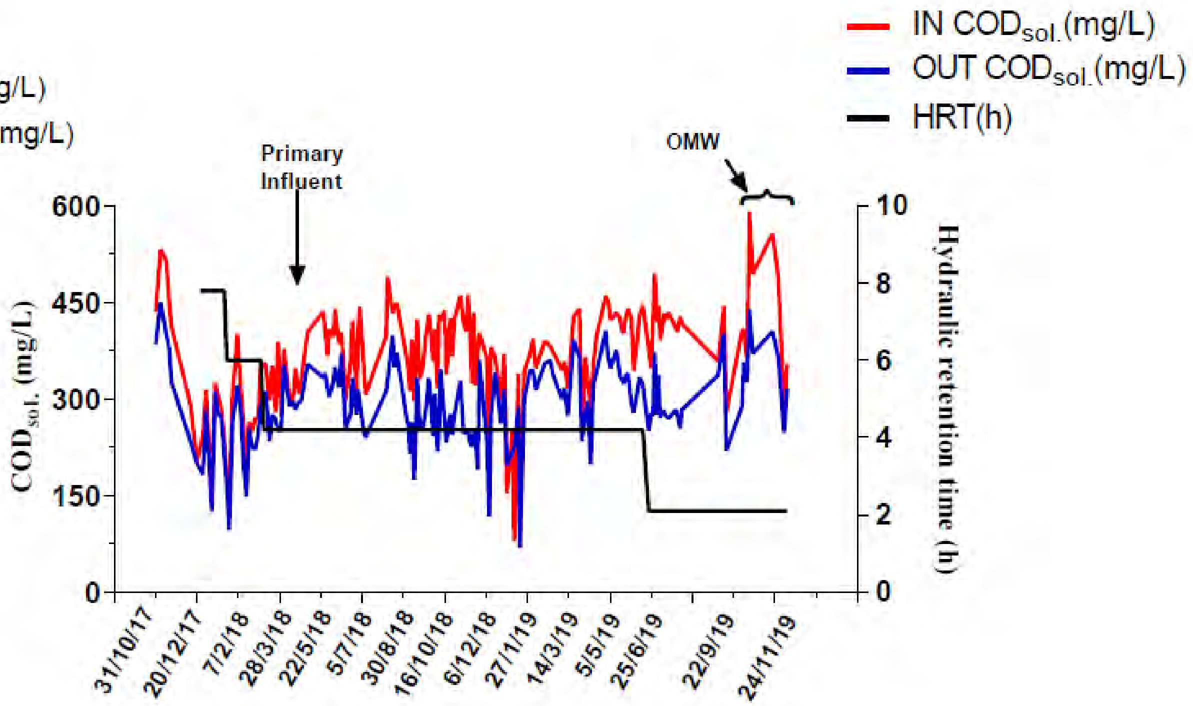
The project leading to this application has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 869318

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 690323

6

Shaving the peaks





The project leading to this application has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 869318

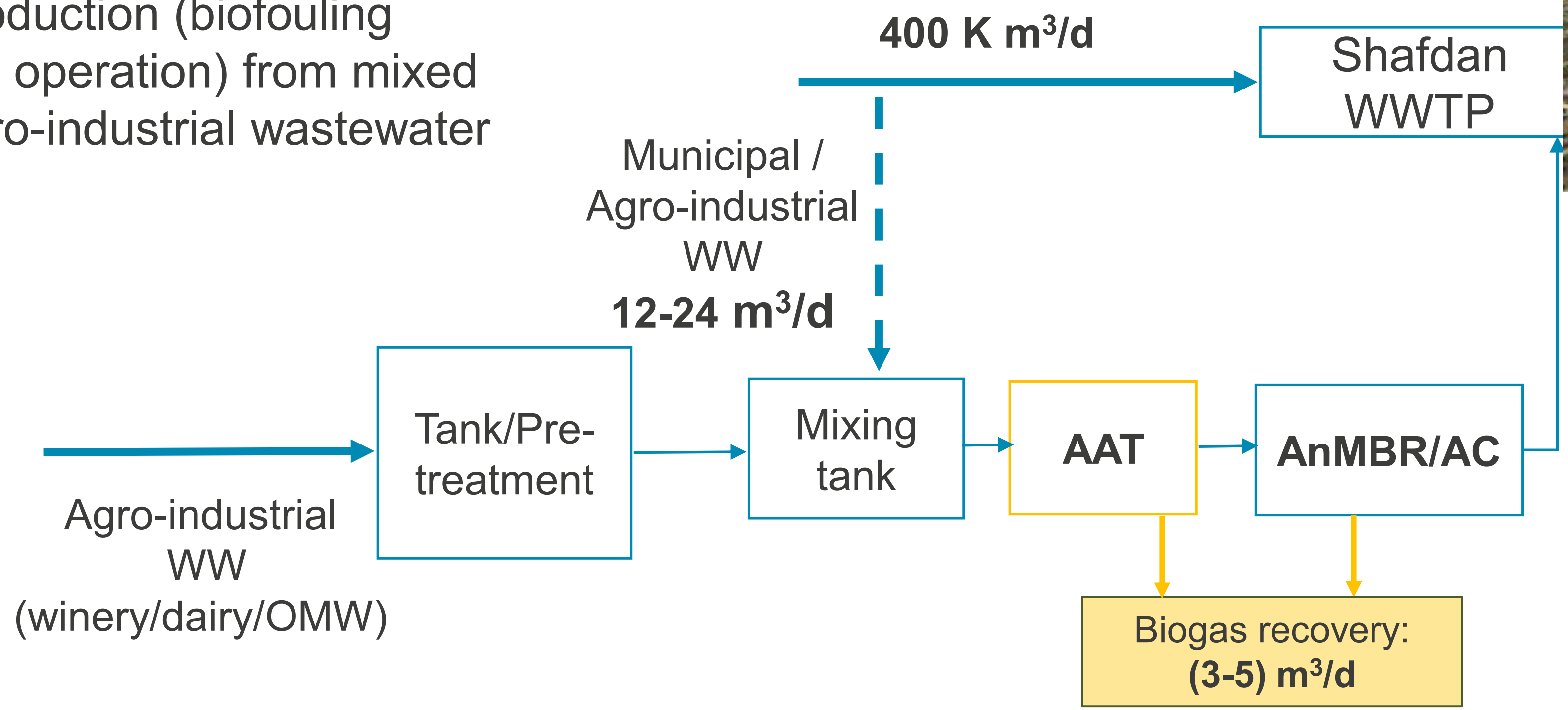
ENERGY - Task 1.3.4

Combining anaerobic biofilm treatment with membrane filtration and activated carbon in **Shafdan**

Partners:

OBJECTIVE:

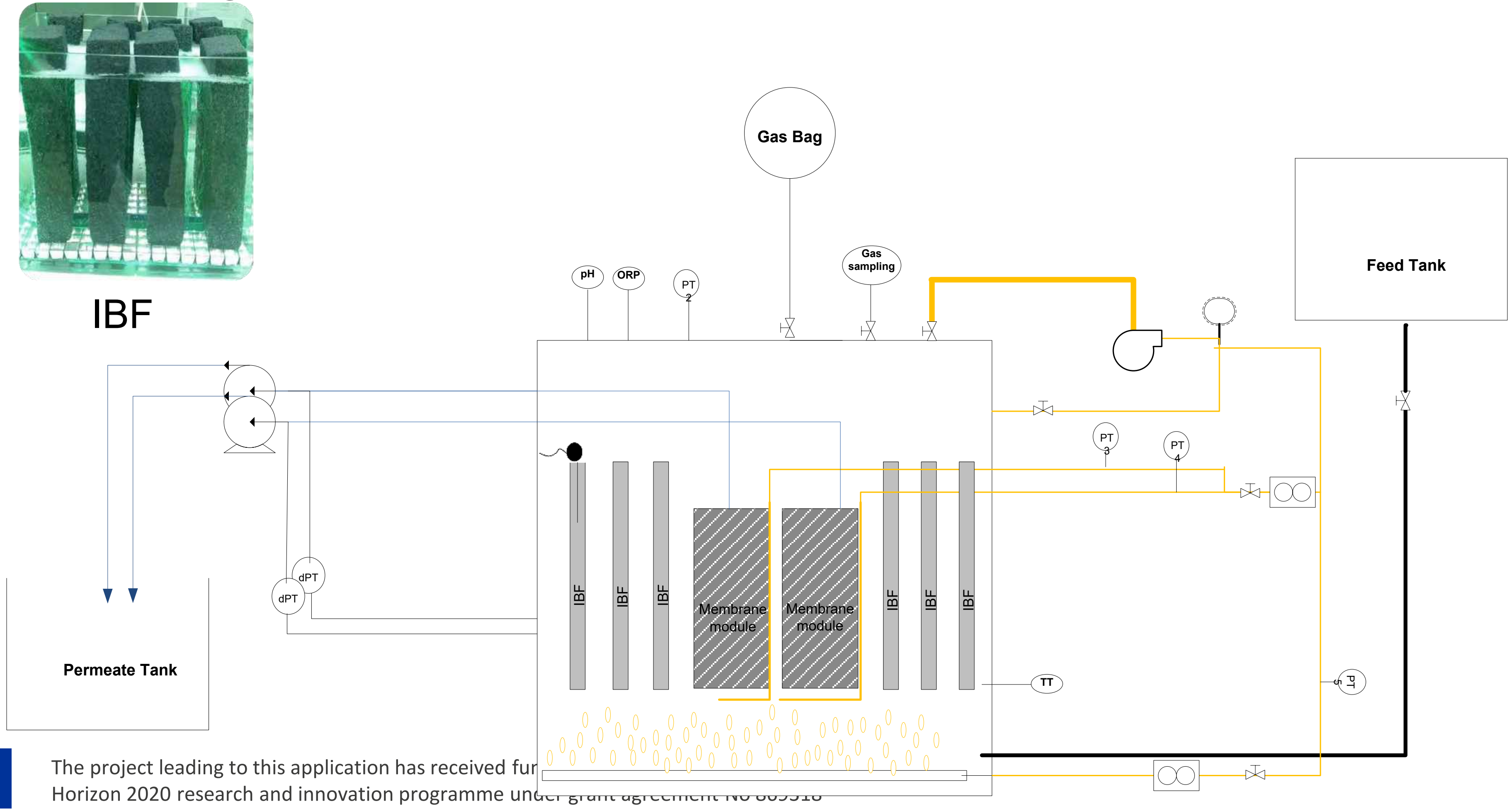
Testing the **efficiency of AnMBR based on AAT combined with Activated carbon** for higher biogas production (biofouling reduction/optimal operation) from mixed domestic and agro-industrial wastewater



Methane Yield: 0.18-0.22 m^3 CH_4/kg oDM

The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

Innovation: The use of immobilized biomass in PAC fixed foam instead of granular biomass offers a promising approach for fouling reduction which is unexplored yet within AnMBR technologies.



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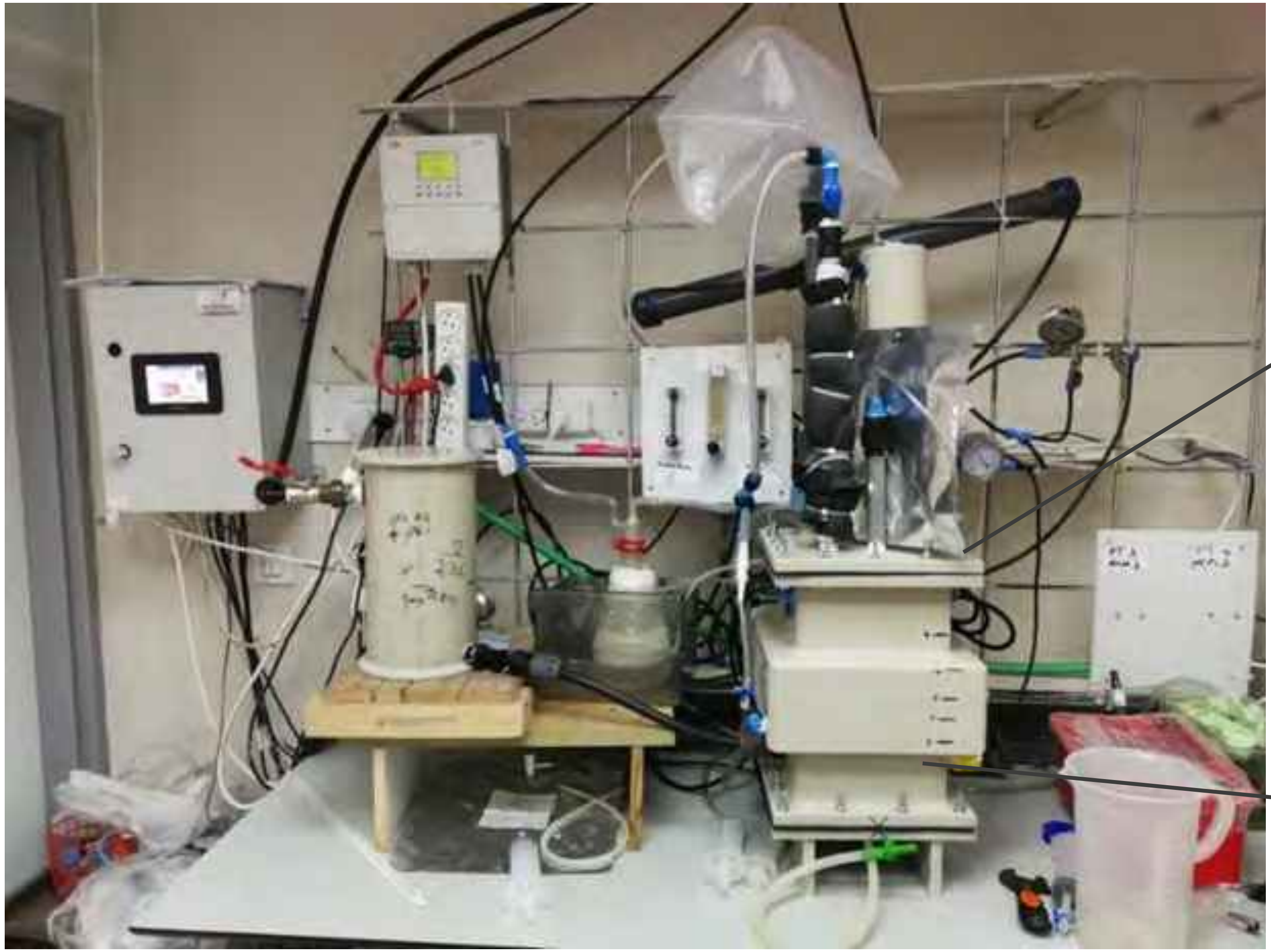
Horizon 2020 research and innovation programme un



The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

MATERIAL - Task 1.4.5
Recovery of high-value products from olive mill wastewater in Karmiel

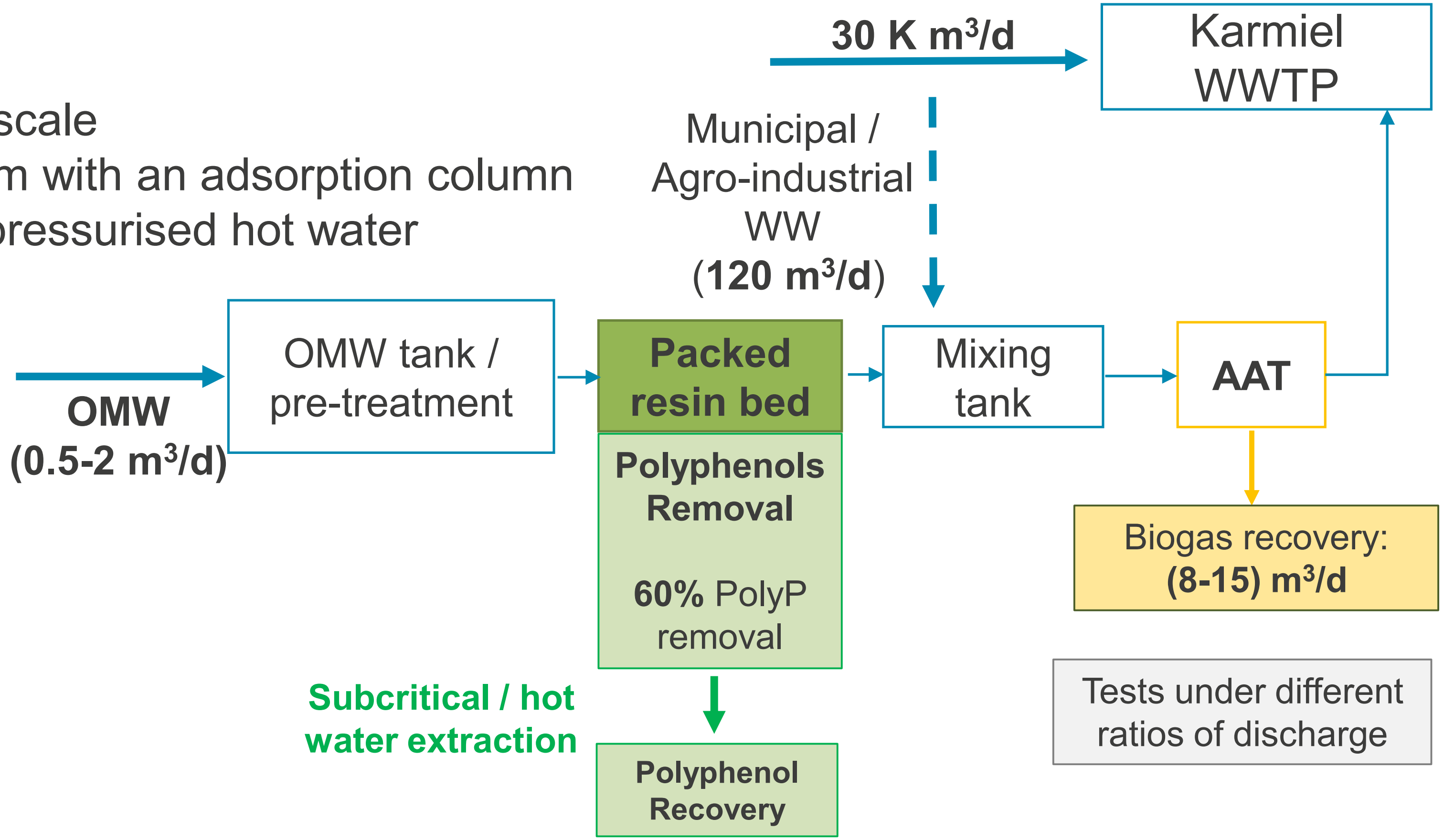
Partners:

OBJECTIVES:

Recovery of polyphenols from olive mill wastewater

Content of study:

- Pre-trials in lab-scale
- Pilot plant system with an adsorption column
- Extraction with pressurised hot water



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Thank you

ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

Prof. Isam Sabbah (GSR and AGB)

Dr. Katie Baransi Karkaby

Sari Musa

Claire Tawafshi

Ms. Nura Awwad
M.Sc. Student

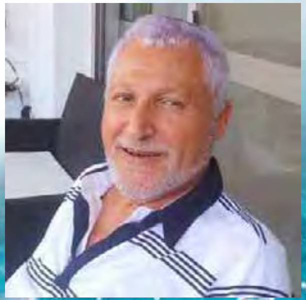
Mr. Stav Shimshoni
M.Sc. Student

Gilad Horn (AGB)- CEO

Dr. Nedal Massalha (AGB & GSR) -CTO and researcher

Mahdi Hassanin

Hadas Raanan Kiperwas
Mekorot



Avi Aharoni
Mekorot

CS meeting on "Biogas Technologies": October, 30^{th} 2020

Scale-up of low-carbon footprint material recovery techniques in existing wastewater treatment plants "SMART-Plant"

SMART-Plant

The Galilee Society

AgRobics

MEKOROT
ISRAEL NATIONAL WATER CO.

SmartPlant: Biogas recovery in primary treatment with a polyfoam biofilter Advanced Anaerobic Treatment (AAT)

Evaluation and simulation at a pilot-scale system

Isam Sabbah

جمعية الجليل
אגודת הגליל
The Galilee Society

Webinar on "Biogas Technologies": October, 30th 2020

SMART-Plant

European Commission
Horizon 2020
European Union funding for Research & Innovation

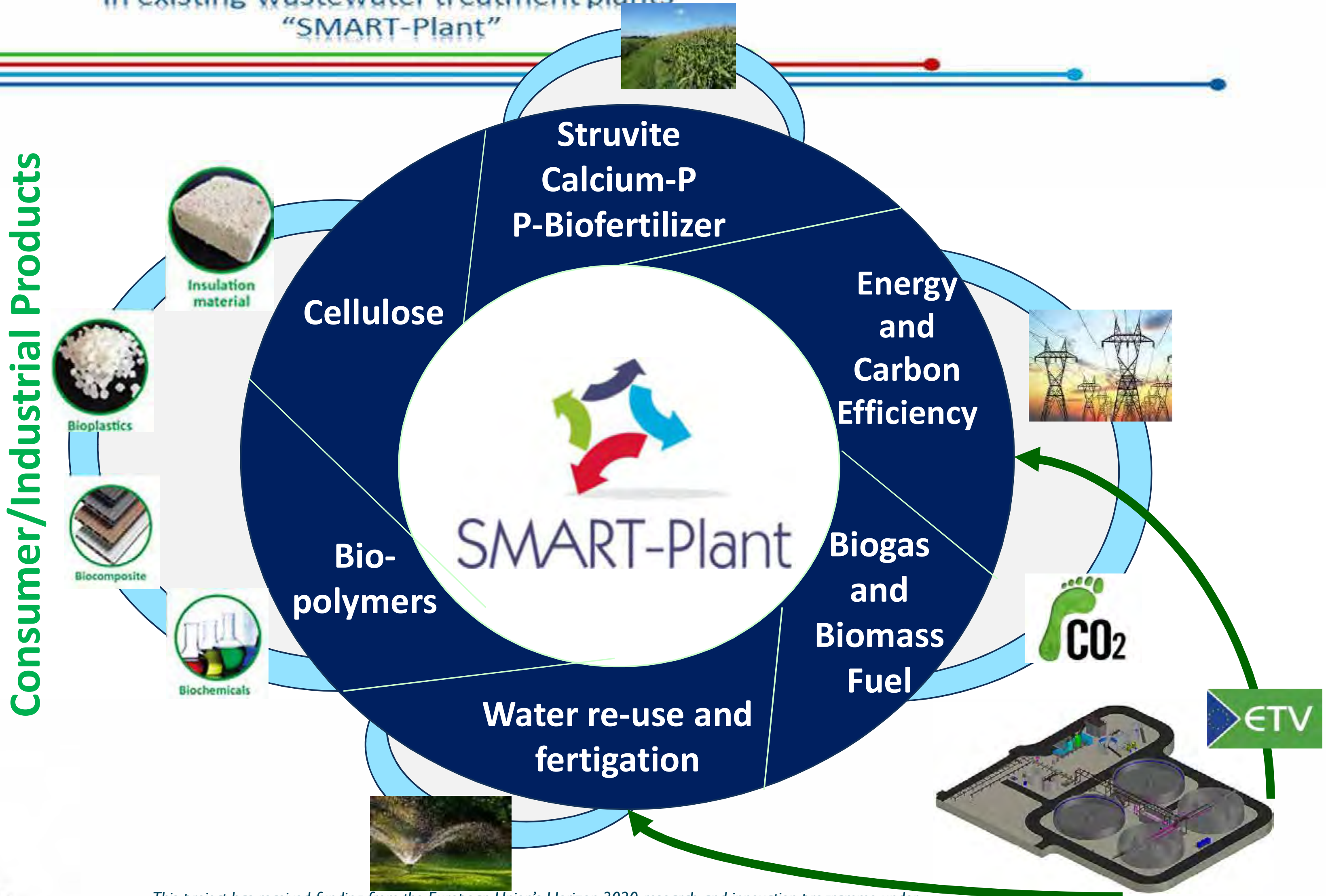
Introduction

OBJECTIVE:

Pilot scale evaluation of the start-up and operation of the Advanced Anaerobic Treatment (AAT) reactor receiving real municipal wastewater and the recovery of biogas as sub-product.

- ***Applied*** *before secondary biological treatment units to reduce organic loads and consequently operational costs (e.g.* O_2 *supply); shaving peaks of illegal agro-industrial discharge streams;*
- ***Completely different approach*** *to traditional UASB reactors due to the "bio-stabilized", polymer-based matrix impregnated with anaerobic microorganisms;*
- ***More stable operation*** *because the matrix provides physical protection for the microorganisms and therefore resulting in no biomass washout;*
- ***Recovery of*** CH_4 *as a bioproduct with a high potential for energy generation;*
- ***The aim*** *is the implementation of this robust, affordable, and environmentally sound process guarantees sustainable wastewater treatment adhering to existing and future effluent quality requirements and energy-saving approaches.*

Scale-up of low-carbon footprint MAterial Recovery Techniques in existing wastewater treatment PLANTs



Co-funded by the Horizon 2020 programme of the European Union

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 690323

SMART-Plant

HOME THE PROJECT ENE3 MEMBERS AREA NEWS PARTNERS CONTACT

Demostration Sites

ALL SITES

- Geestmerambacht
- Karmiel
- Manresa
- Cranfield
- Carbonera
- Psyttalia
- Carbonera (b)
- London
- Manresa (b)

http://smart-plant.eu/index.php/map

Co-funded by the Horizon 2020 programme of the European Union

SMART-Plant

SMARTechs integrated in existing WWTPs (transformed in WRRFs)


SMARTech1 - Geestmerambacht WWTP (NL)


SMARTech2a – Karmiel WWTP (IL)


SMARTech2b and Downstream SMARTech B - Manresa WWTP (Spain)


SMARTech3 – WWTP at Cranfield University (UK)


SMARTech 4a and SMARTech 5 Carbonera WWTP (Italy)


SMARTech 4b - Psyttalia WWTP (Greece)

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ACHIEVEMENTS OF SMART-PLANT

	SMARTech n.	Integrated municipal WWTP	Key enabling process(es)	SMART-product(s)
Mainstream	ETV	Geestmerambacht (Netherlands)	**Upstream dynamic fine-screen** and post-processing of cellulosic sludge	**Cellulosic sludge, refined clean cellulose**
Mainstream	ETV	Karmiel (Israel)	Mainstream polyurethane-based **anaerobic biofilter**	**Biogas, Energy-efficient water reuse**
Mainstream	2b	Manresa (Spain)	Mainstream **SCEPPHAR**	**Struvite, PHA**
Mainstream	3	Cranfield (UK)	Mainstream **tertiary hybrid ion exchange**	**Nutrients**
Sidestream	ETV 4a	Carbonera (Italy)	**Sidestream SCENA**	**P-rich sludge, VFA**
Sidestream	4b	Psyttalia (Greece)	**Sidestream Thermal hydrolysis – SCENA**	**P-rich sludge**
Sidestream	5	Carbonera (Italy)	**Sidestream SCEPPHAR**	**PHA, struvite, VFA**

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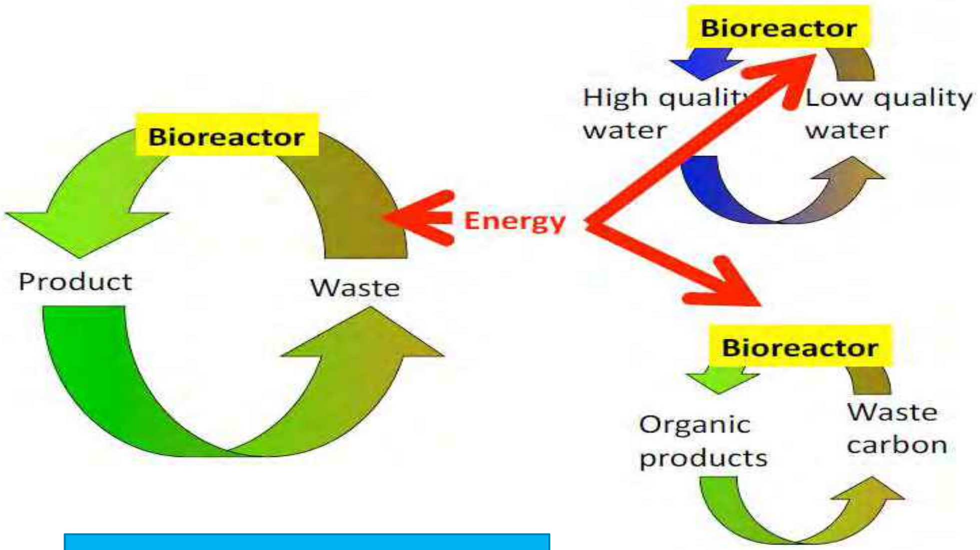
Circular Economy:

The talk is about resources recovery from wastewater by biological technologies, where **Anaerobic** treatment plays the main role within the concept of **circular economy**.

Circular economy is alternative for linear economy: make, use, dispose



From Crage Criddle, 2010

The economic value of the resource

Resource	Per m^3	US \$ per m^3	US \$ per 1000 gal
Organic soil conditioner	0.10 kg	0.026	0.10
Methane	0.14 m^3	0.065	0.25
Nitrogen	0.05 kg	0.065	0.25
Phosphorus	0.01 kg	0.013	0.05
Water	1 m^3	0.325	1.20

From Willy Verstraete (2008)

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History of Anaerobic Reactor

1881: First conventional anaerobic digester was used to liquidify the solid components of sewage

1891: First septic tank to retain solids in sewage

1905: Development of the 'Imhoff' tank in Germany

1930s: Digesters were started to be mixed and heated to improve the digestion of solids in the sewage

1955: Anaerobic contact process was developed to treat soluble organics and dilute wastewaters (**first high-rate system**)

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Anaerobic Waste Treatment Fundamentals

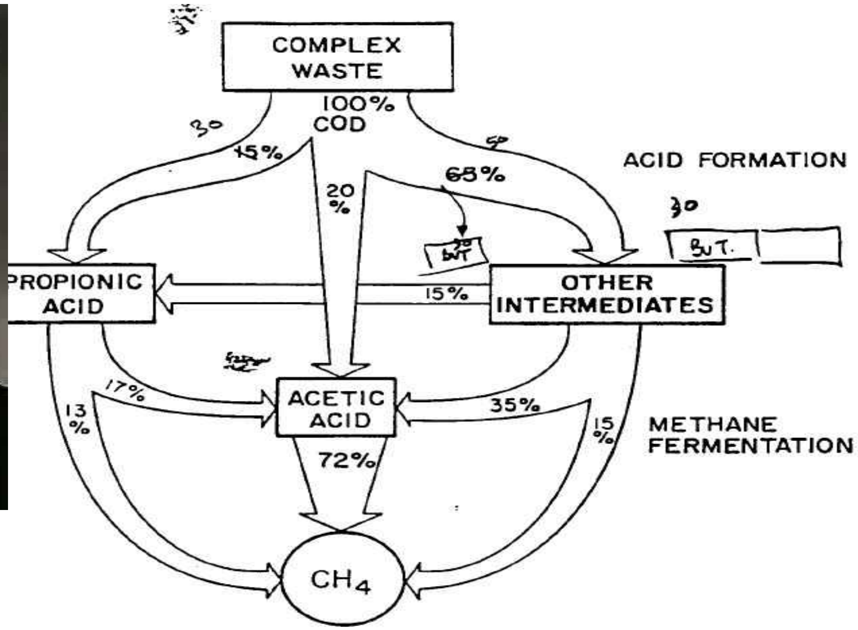
Public Work 1964

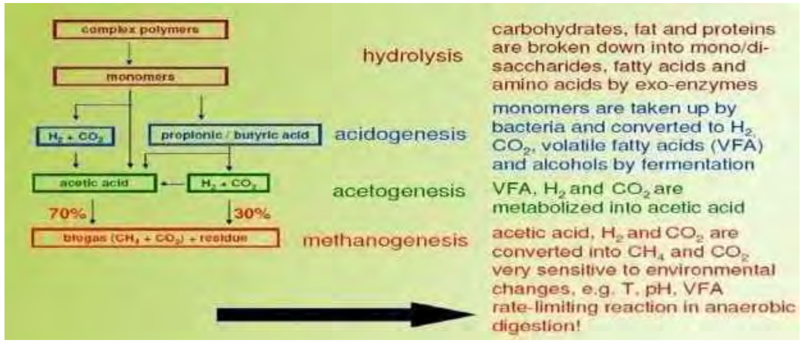
PART ONE | Chemistry and Microbiology

PERRY L. McCARTY
Associate Professor of Sanitary Engineering
Stanford University

portant parameters for design, operation, and control. This first article is concerned with a general description together with the chemistry

portion converted to cells is not actually stabilized, but is simply changed in form. Although these cells can be removed from the waste





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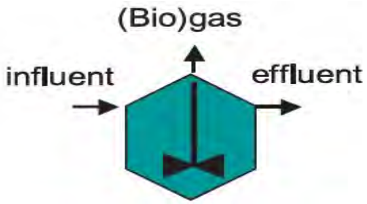
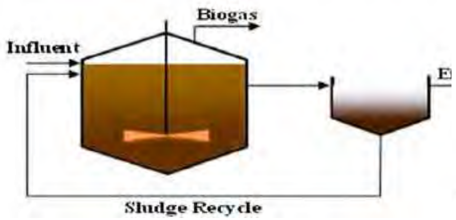
1955 (Schroepfer et al., 1955) | 1960s Young & McCarty 1966) | 1970s & Lettinga | 1980s Lettinga

CSTR



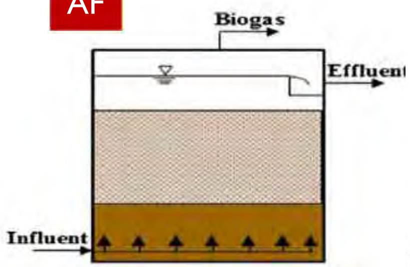
Relative capacity: 1

ACP

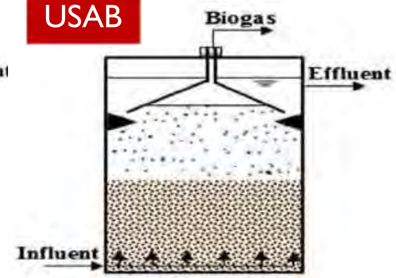


Relative capacity: 5

AF

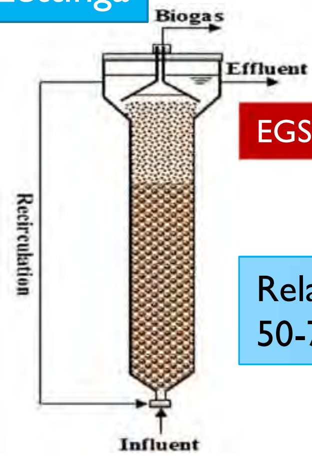


USAB



Relative capacity: 25

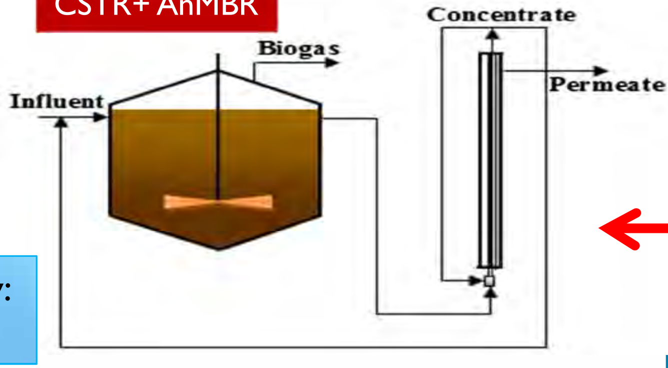
EGSB



Relative capacity: 50-75

High-rate anaerobic systems

CSTR+ AnMBR



Relative capacity: >75

Gatze Lettinga

Based on van Lier, 2015

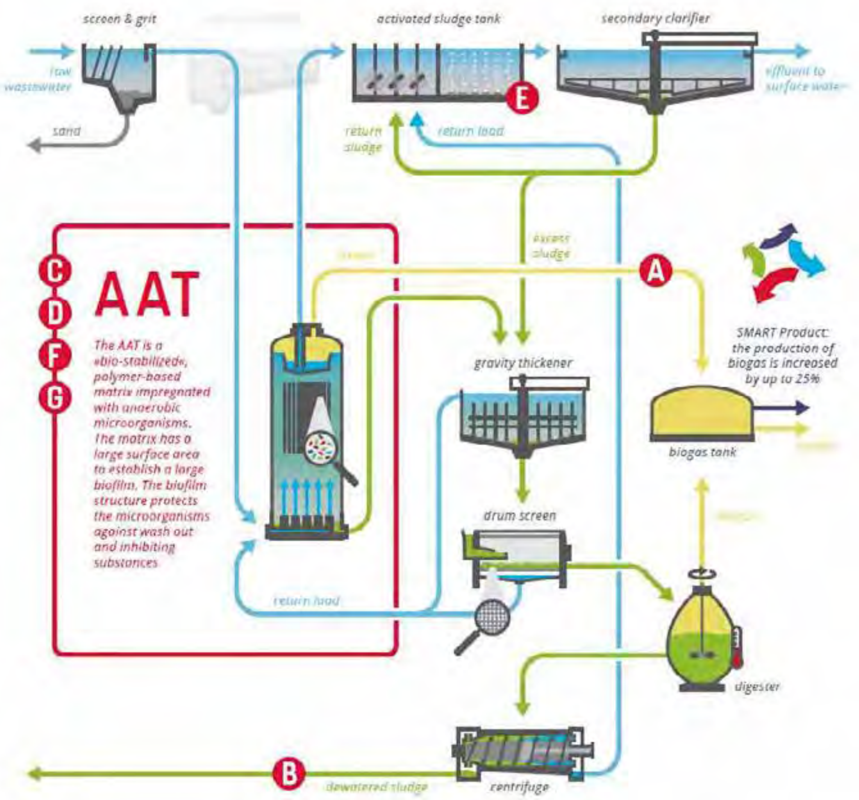
Co-funded by the Horizon 2020 programme of the European Union

WWTP/WRRF

Co-funded by the Horizon 2020 programme of the European Union

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 690323

SMART-Plant Approach



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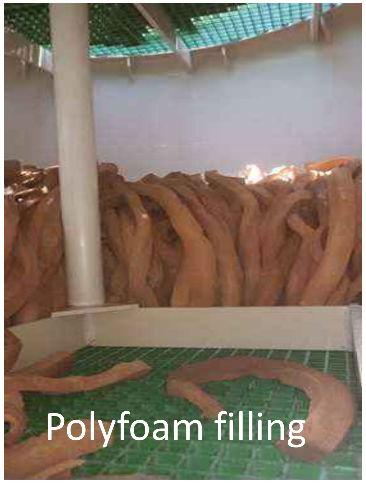
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 690323

SMARTech 2a – _Mainstream polyurethane-based anaerobic biofilter with biogas recovery_

WWTP – Karmiel, Israel



Polyfoam filling

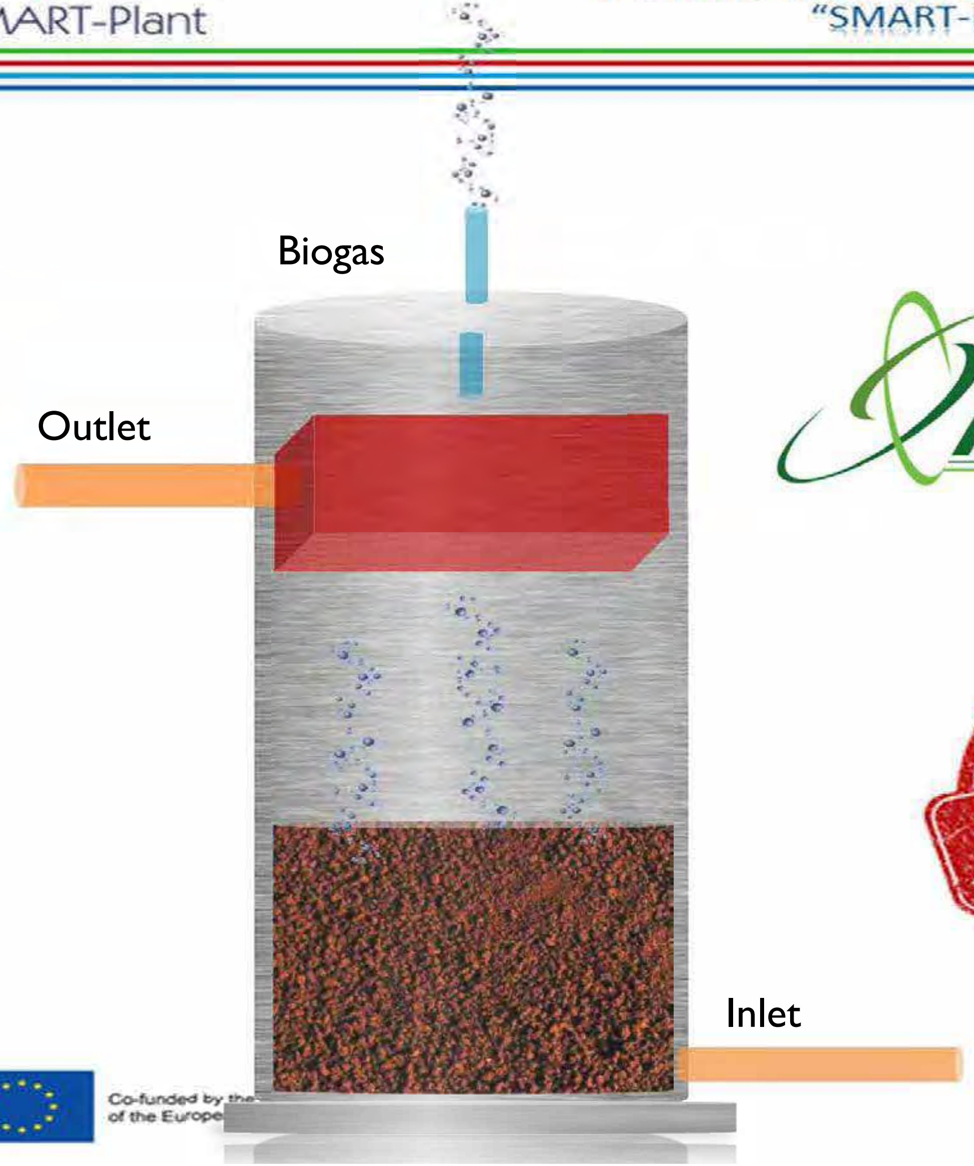
ETV

Aim

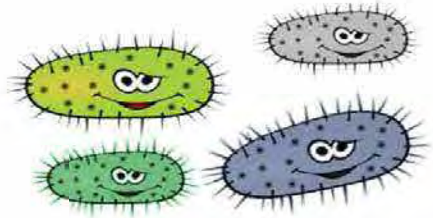
Reduced **loads of COD and TSS** on the biological treatment system → <u>Energy-efficient water reuse;</u> **Biogas** production.

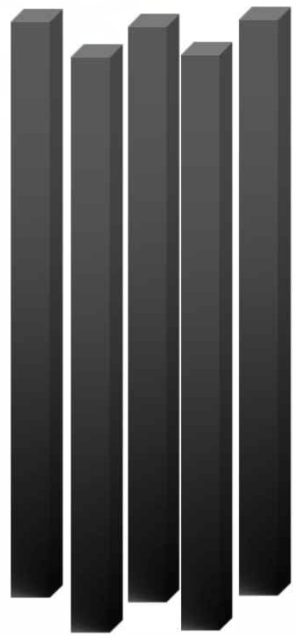
European Commission | Horizon 2020 European Union funding for Research & Innovation

Scale-up of low-carbon footprint material recovery techniques
in existing wastewater treatment plants
"SMART-Plant"



AgRobics





Sabbah et al., 2016, USA Patent # 9452458
Sabbah et al., 2018, Israeli Patent # 221638

Co-funded by the
of the Europe

Operational characteristics – *Mainstream polyurethane-based anaerobic biofilter with biogas recovery* WWTP – Karmiel, Israel

- ***The matrix*** *has large surface area and high capacity that enables the loading of a higher number of microorganisms compared to incumbent wastewater treatment methods;*
- ***The AAT technology*** *increases process stability, decreases energy consumption, lowers operational costs and enhances the efficiency of the anaerobic process for methane production;*
- ***The bio-stabilizers*** *are prepared in special, patented, modular units and inserted into a proprietary modified high rate up-flow anaerobic system (HRUA);*
- ***This hybrid immobilized-HRUA*** *exhibits better performance characteristics and lower cost, without the need for the typical expensive three–phase separator.*

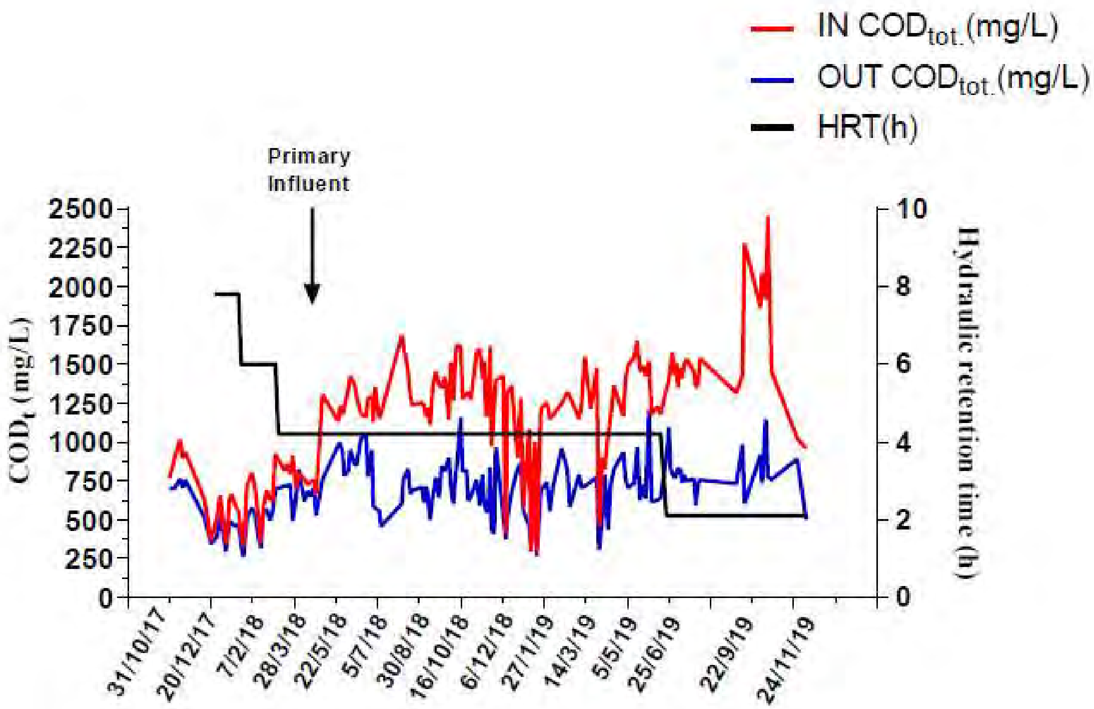
SMART-Plant
European Commission | Horizon 2020 European Union funding for Research & Innovation

Operation

- 240 m³/d waste water flow
- 55-60% COD removal
- 50% TSS removal
- HRT= 2-4 hours

Recovery Efficiency

- 5-10 m^3 biogas/day
- 72% CH_4

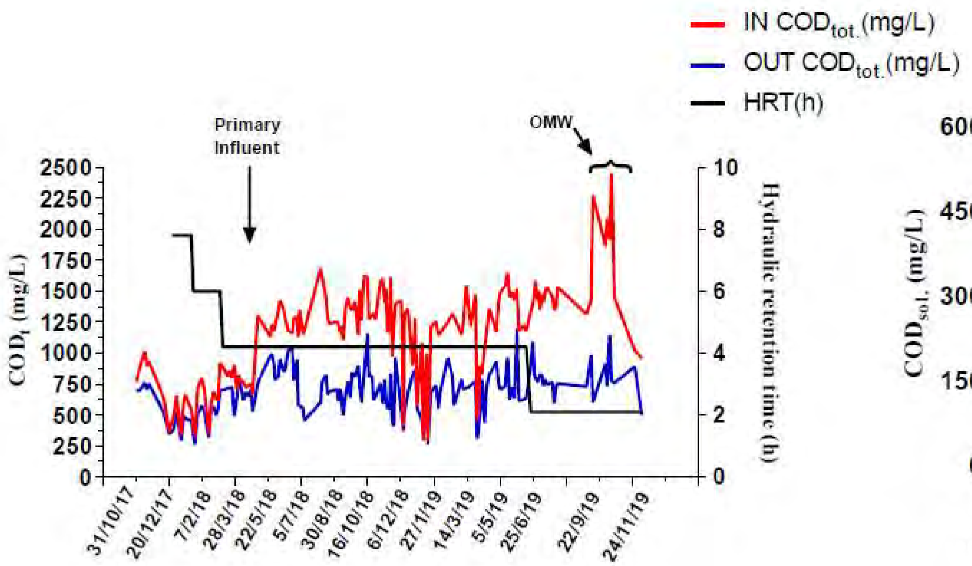


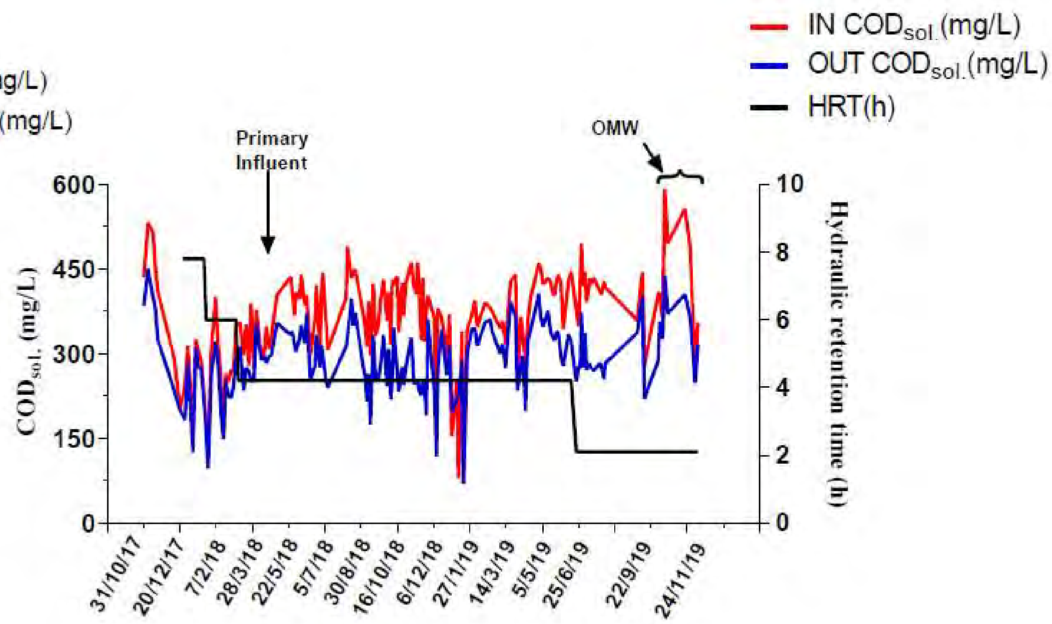
Methane Yield: 0.12-0.15 m^3 CH_4/kg oDM

Co-funded by the Horizon 2020 programme of the European Union

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 690323

Shaving the peaks





Co-funded by the Horizon 2020 programme
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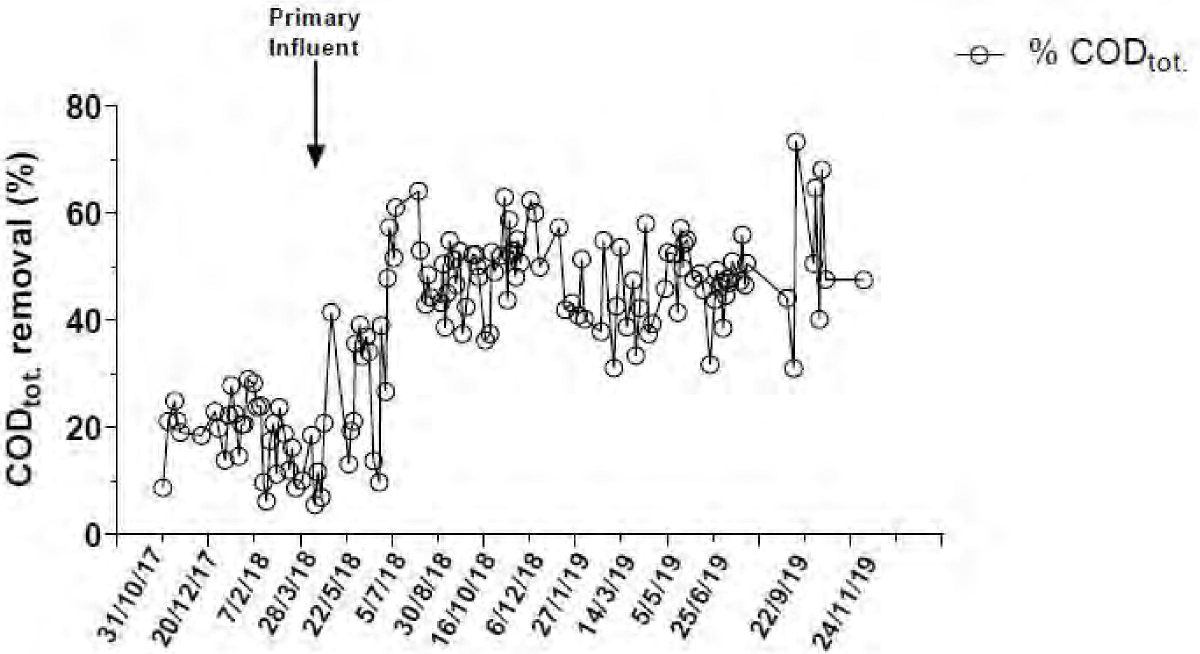
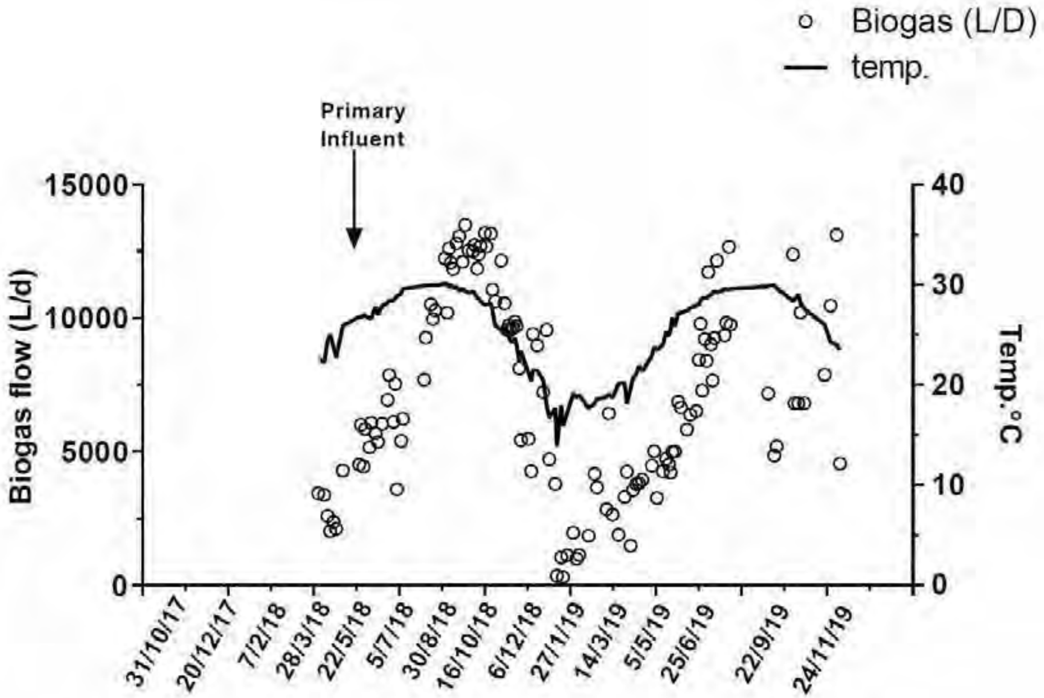
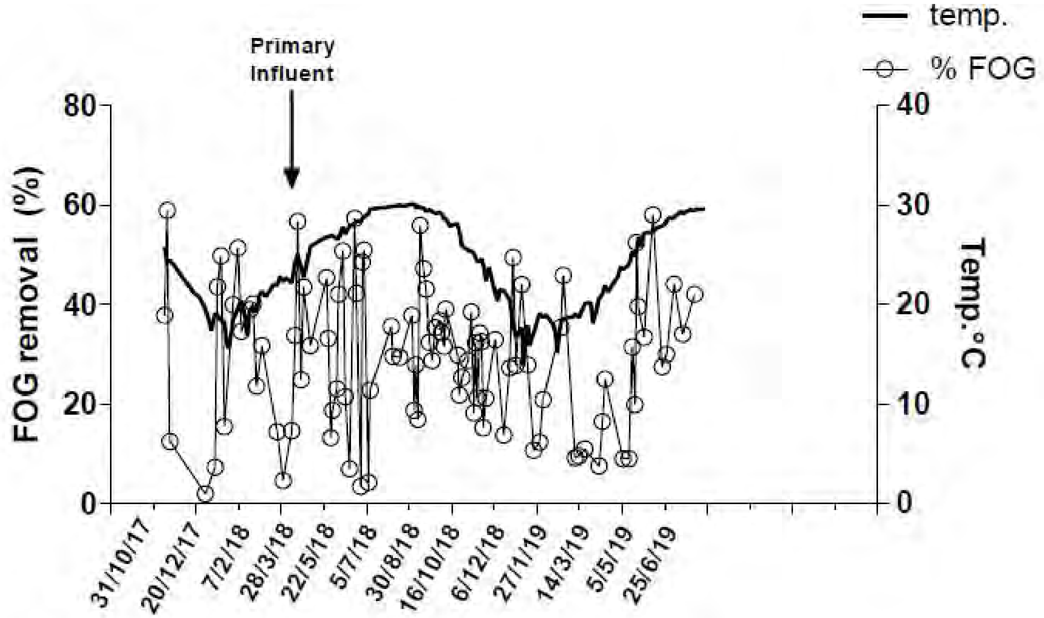


Co-funded by the Horizon 2020 programme
of the European Union

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 690323





Co-funded by the Horizon 2020 programme of the European Union

Material and Methods – *Mainstream polyurethane-based anaerobic biofilter with biogas recovery* WWTP – Karmiel, Israel

Operational data from over 1-year of experimental data (October 2017 – January 2019)

- **Two scenarios were evaluated during the operation period:**

  1. **Scenario 1:** raw sewage flowed first to the primary clarifier (PC) before flowing into the AAT (Q = 48–120 $m^3.d^{-1}$) – startup phase – ***HRT: 0.4 – 0.2 d (9.6-4.8 h)***;
  2. **Scenario 2:** raw sewage flowed directly into the AAT (Q = 120 $m^3.d^{-1}$) – steady-state phase – ***HRT: 0.2d (4.8 h)*** ;

- **The following parameters were analysed : total COD, soluble COD, particulate COD, TSS, and gasflow;**

- **Modelling was done with data from the second scenario.**

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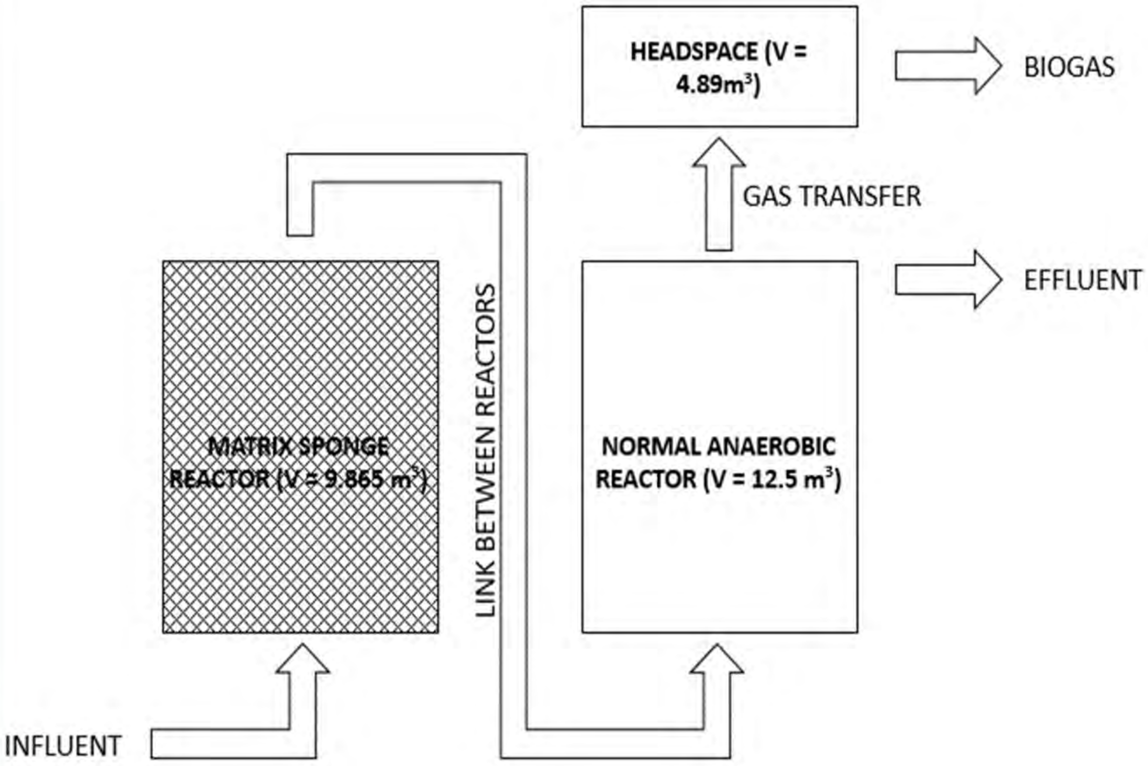
Modelling approach – *Mainstream polyurethane-based anaerobic biofilter with biogas recovery* WWTP – Karmiel, Israel



Considerations:

- **Anaerobic Digestion Model 1 (ADM1);**
- **Two separate completely-mixed reactors in series → plug-flow regime;**
- **Simulation software AQUASIM 2.1v;**
- **Sludge Retention Time (SRT):**
  - **Matrix reactor = ∞ (biomass remains in the reactor);**
  - **Second reactor = 20 d (similar to normal UASB);**
- **Higher concentration of biomass in the matrix reactor;**
- **Fixed percentages used for the influent characterisation into state-variables.**

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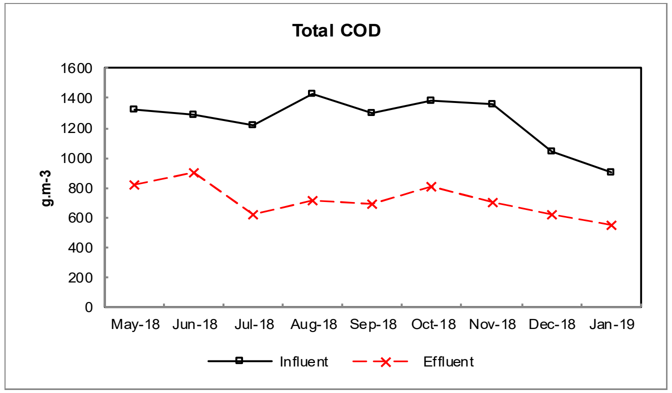
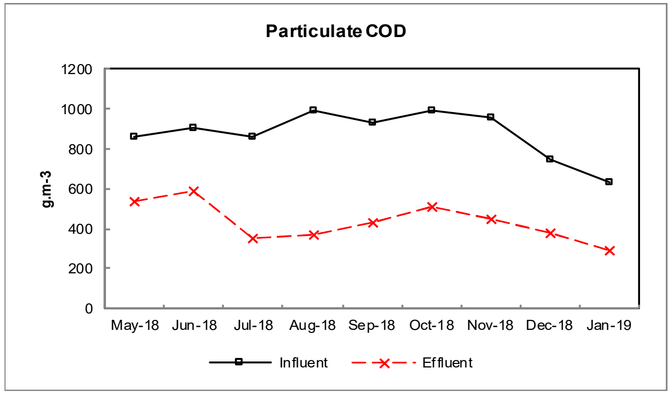
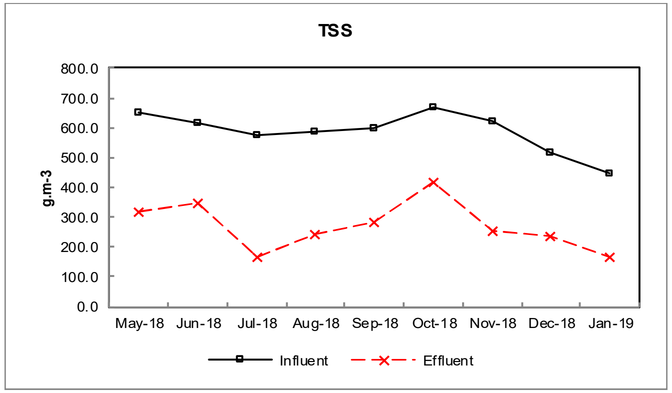
2nd Scenario (steady-state operation without PC) – *Mainstream polyurethane-based anaerobic biofilter with biogas recovery* WWTP – Karmiel, Israel

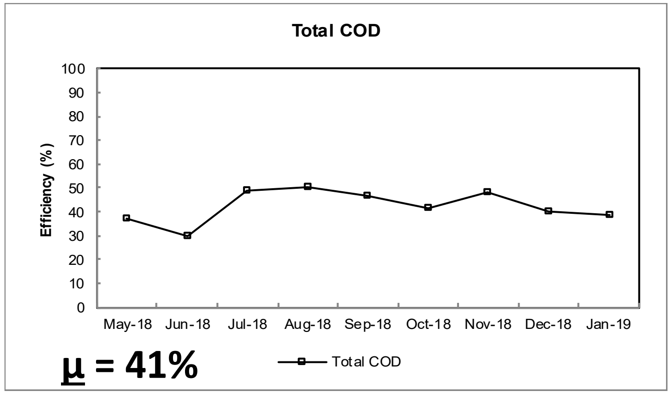
Concentration

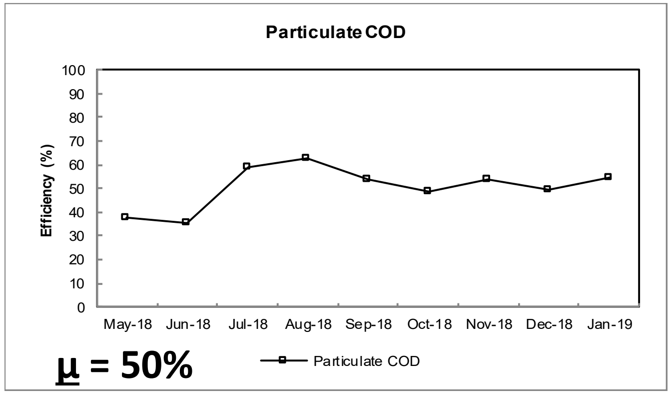


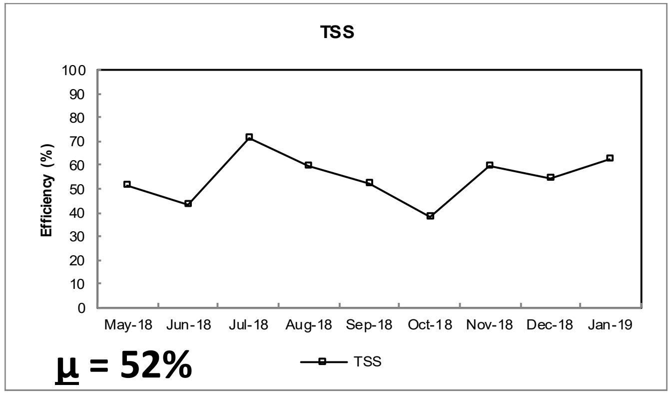




Removal efficieny







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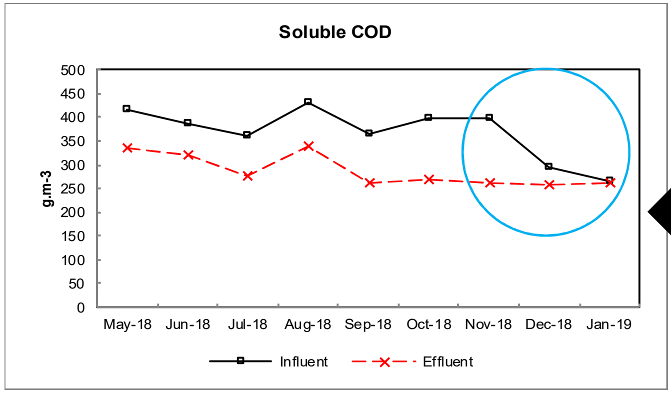
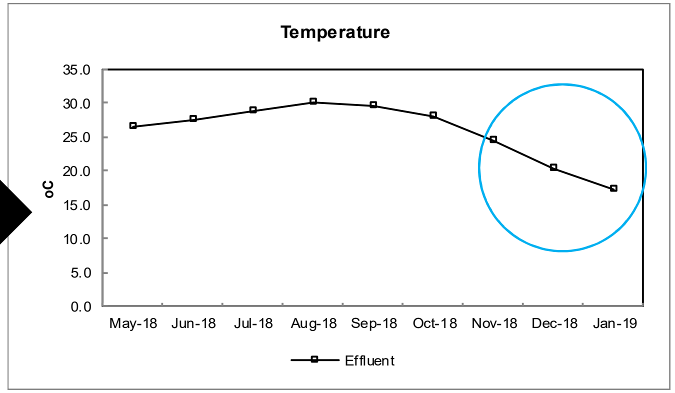
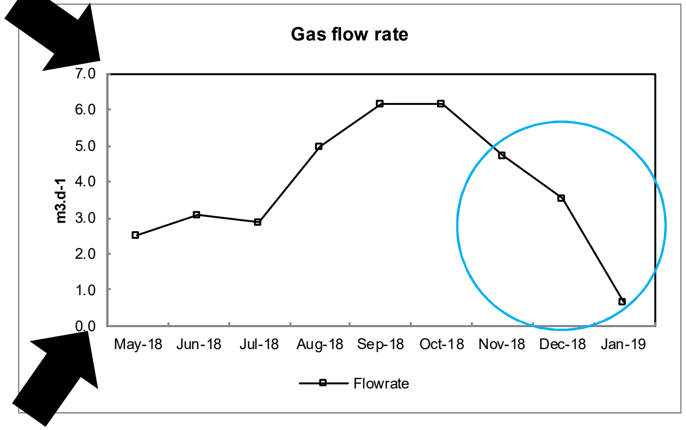
2nd Scenario (steady-state operation without PC) – *Mainstream polyurethane-based anaerobic biofilter with biogas recovery* WWTP – Karmiel, Israel

Concentration

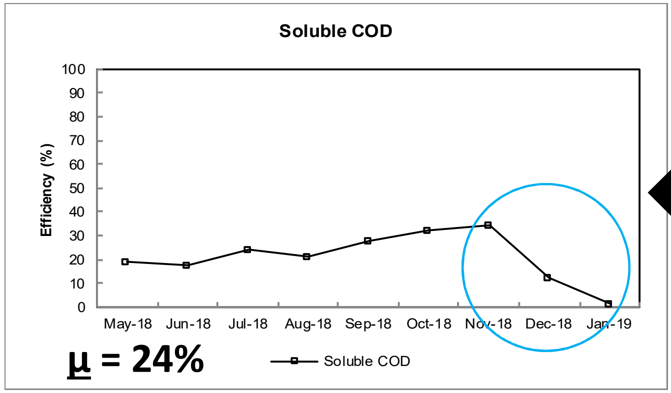


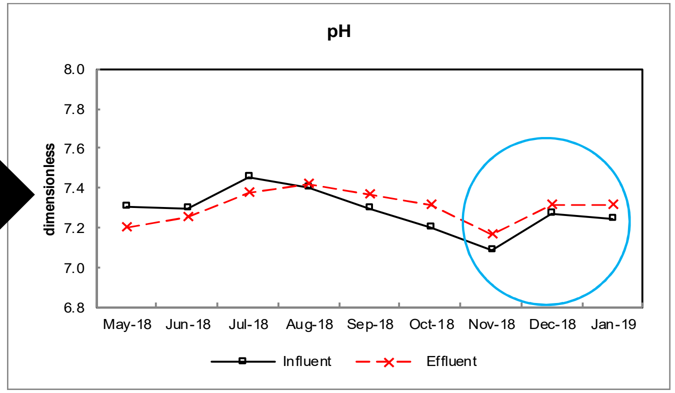


High production during hot months



Removal efficieny





High rainfall + lower temperature → diluted influent → less biogas production (influence on soluble COD) → pH stable

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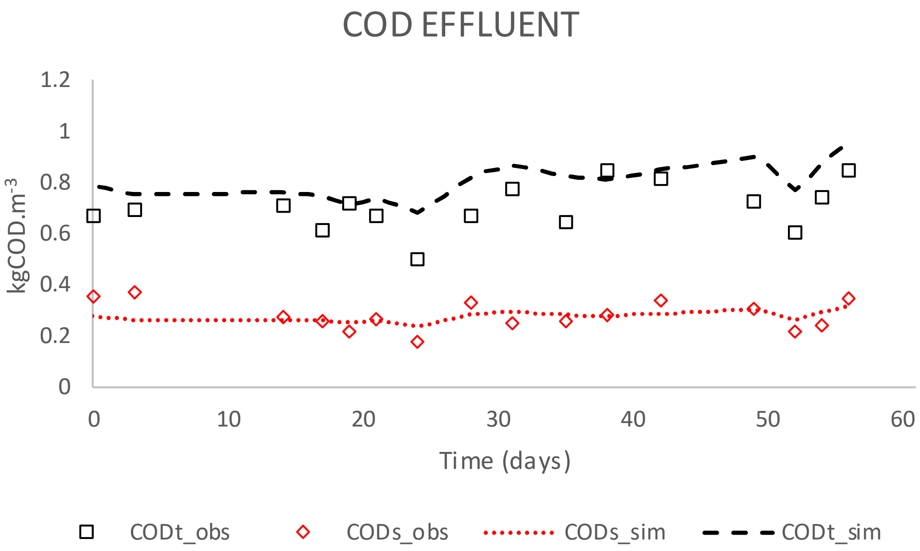
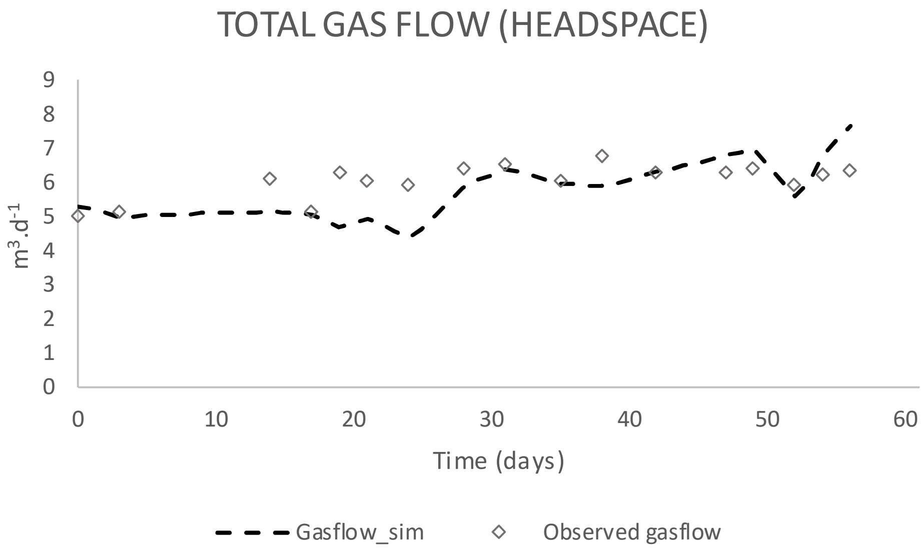
Horizon 2020
European Union funding for Research & Innovation

Model Calibration – *Mainstream polyurethane-based anaerobic biofilter with biogas recovery* WWTP – Karmiel, Israel

Data from 10/8/18 to 11/10/18





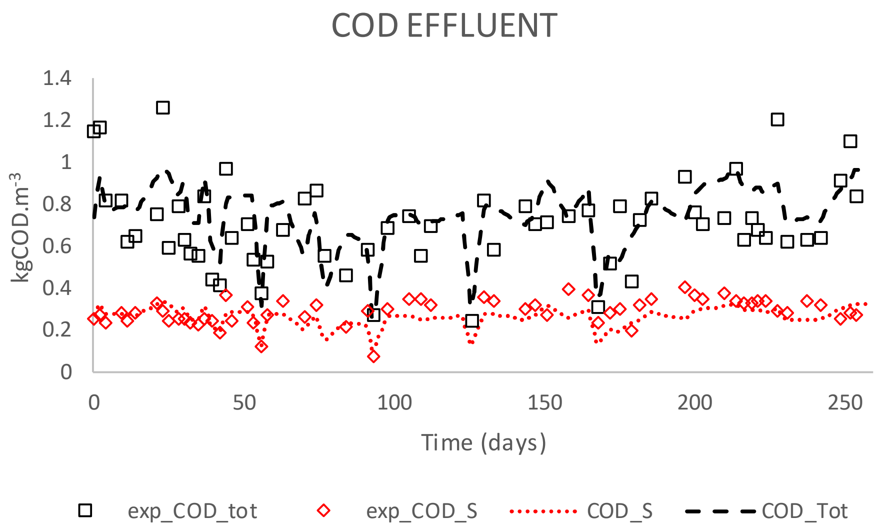
Variable	NRMSD
COD_t	0.178
COD_s	0.176
Gas flow	0.133

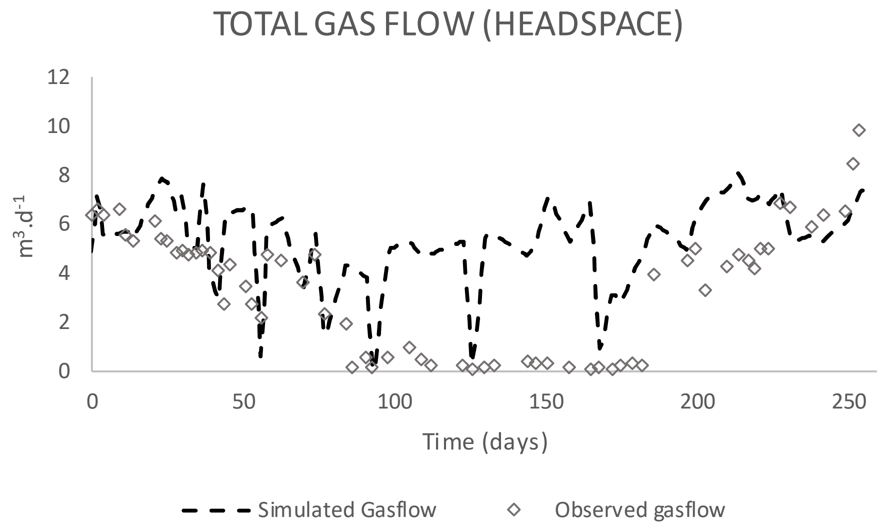
Good fit to the experimental data → relatively low NRMSD

Model Validation – *Mainstream polyurethane-based anaerobic biofilter with biogas recovery*

WWTP – Karmiel, Israel

Data from 14/10/18 to 31/1/19





Model validated with a separate set of data → considering seasonal variation → towards the end data set the model predicted well the amount of CODt and CODs → gasflow was also affected but predicted low flows at the end

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Conclusions – *Mainstream polyurethane-based anaerobic biofilter with biogas recovery* WWTP – Karmiel, Israel

After 390 days of continuous operation of the AAT which included the startup phase and consequently the steady-state phase, the following conclusions can be made:

- ✓ The biomass within the reactor adapated well to the real domestic sewage;
- ✓ After removing the PC, the biomass adapted well to the higher organic load received and continued to increase removal efficiency and biogas production;
- ✓ No bad odours were encountered in the vicinity;
- ✓ Very good removal effciecieny was observed given the low HRT of the reactor and organic load
- ✓ The modelling approach with the ADM1 adapted well to the characteristics of the reactor, therefore usable for future purposes;
- ✓ The purpose of the model is to contribute to designing similar processes in other applications and to allow for also process optimisation. This could be done by varying the flow rates, and lower or higher influent concentrations. It also allows to predict eventual biogas recovery and therefore foresee the amount of a renewable energy that is recovered, as well as the impact on downstream units.

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www.smart-plant.eu

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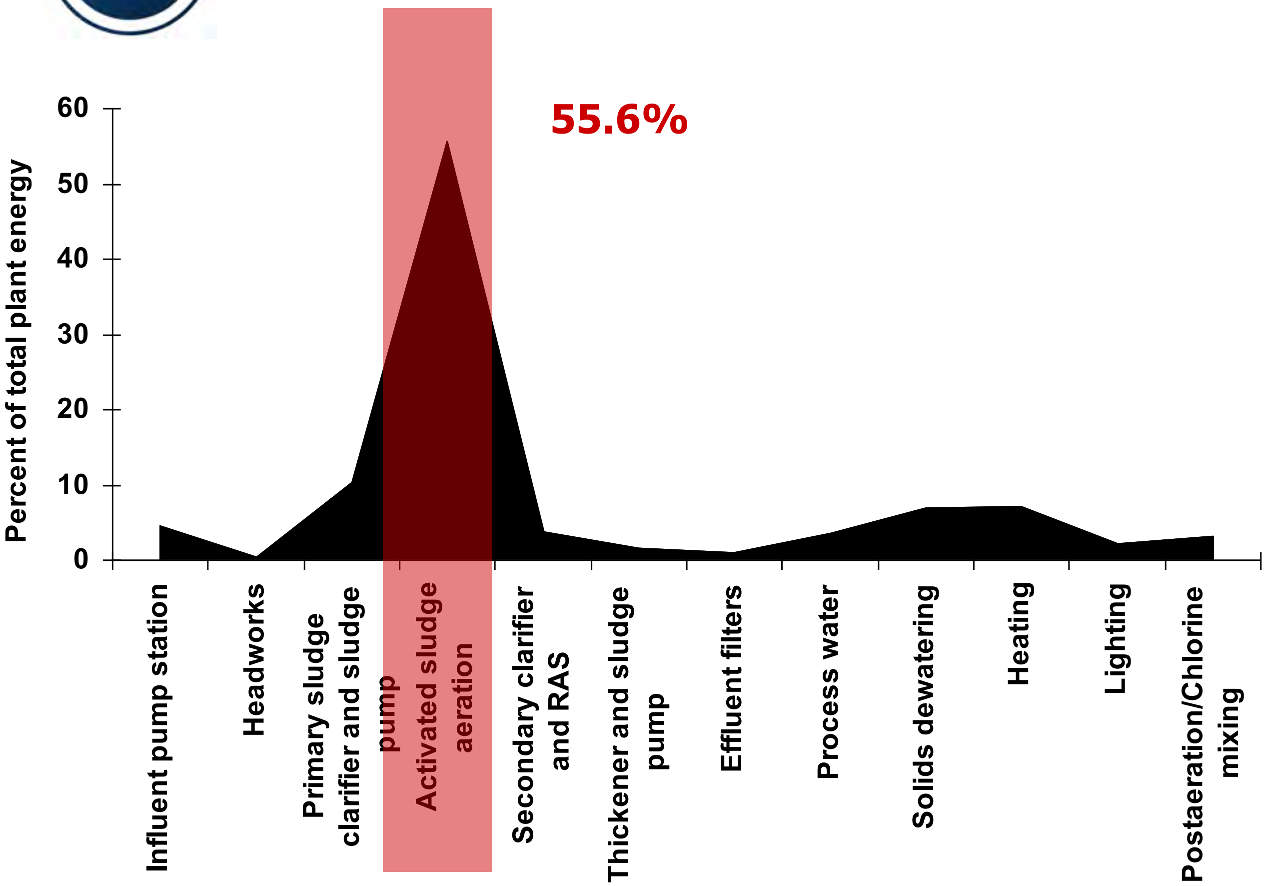
Thank you

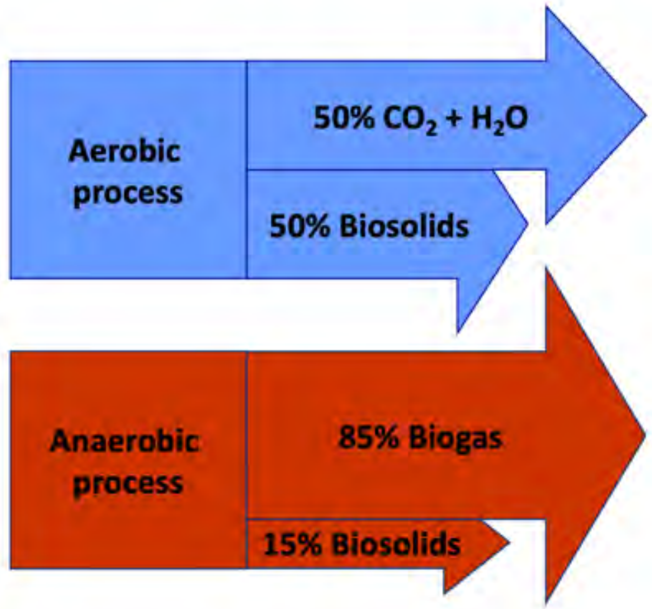
Anaerobic treatment of weak effluents at low temperatures

Professor Ana Soares

Power consumption in wastewater treatment plants



Anaerobic vs. aerobic wastewater treatment



*Tchobanoglous, G., Burton, L.F. and Stensel, H.D. (2003) Metcalf & Eddy, Inc., McGraw-Hill Book Co, International edition.
*Young, D.F. and Koopman, B. (1991) Journal of Environmental Engineering-Asce 117(3), 300-307

Anaerobic digestion vs anaerobic treatment

Anaerobic treatment processes

Sludge:
High BOD + COD
High suspended solids (0.5- 6%)

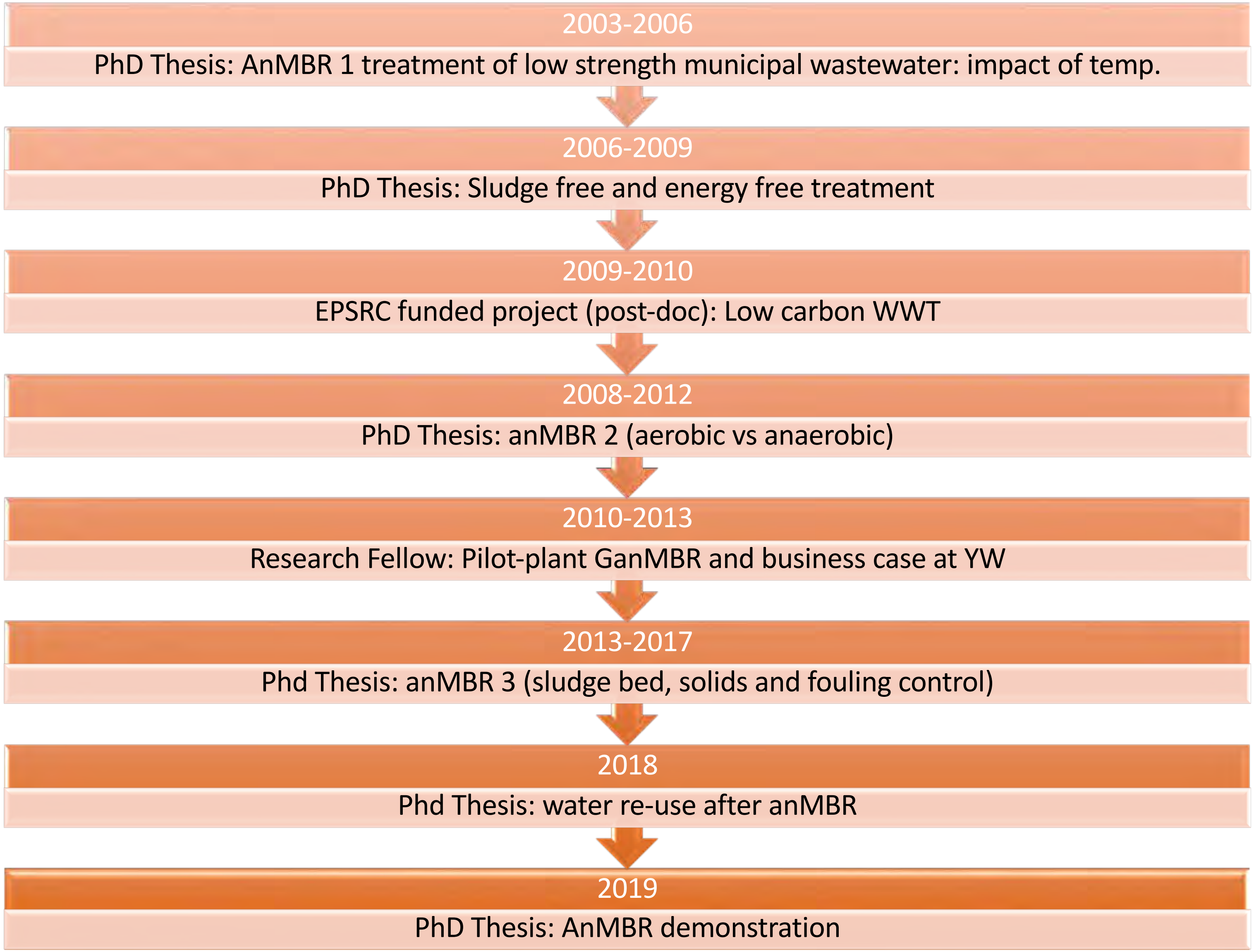
Anaerobic digestion

10-30 day SRT= HRT

Wastewater:
Low BOD + COD
Low suspended solids (0.1-0.6%)

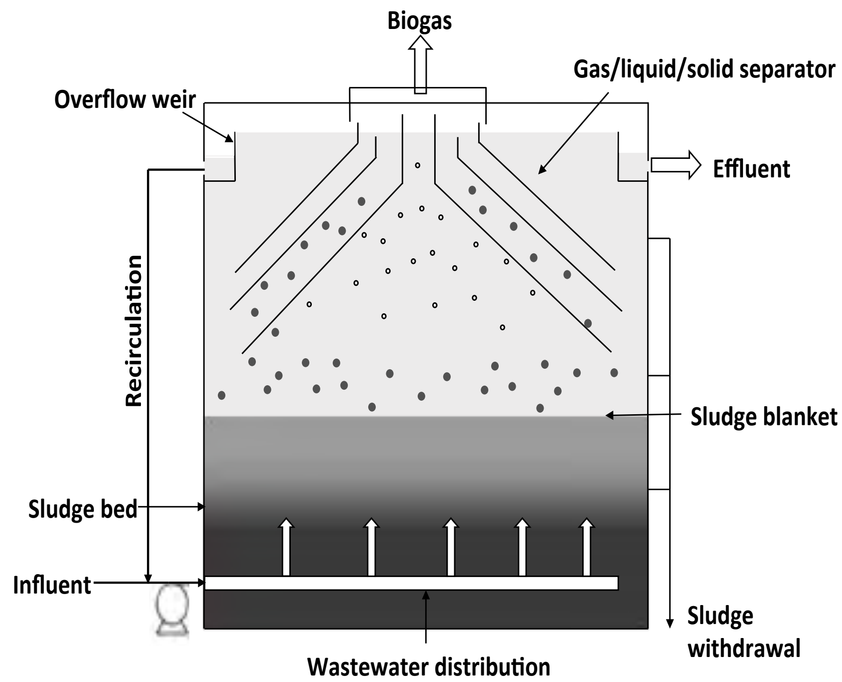
Anaerobic wastewater treatment

6-12 h HRT and 40-100 day SRT


2003-2006
PhD Thesis: AnMBR 1 treatment of low strength municipal wastewater: impact of temp.
2006-2009
PhD Thesis: Sludge free and energy free treatment
2009-2010
EPSRC funded project (post-doc): Low carbon WWT
2008-2012
PhD Thesis: anMBR 2 (aerobic vs anaerobic)
2010-2013
Research Fellow: Pilot-plant GanMBR and business case at YW
2013-2017
Phd Thesis: anMBR 3 (sludge bed, solids and fouling control)
2018
Phd Thesis: water re-use after anMBR
2019
PhD Thesis: AnMBR demonstration

Upflow anaerobic sludge blanket reactor (UASB)

- Maintains a high concentration of biomass through formation of highly settleable microbial aggregates
- The sewage flows upwards through a layer of sludge
- Separation between gas-solid-liquid takes place at the top of the reactor phase
- Recirculation enables solids to be recirculated to the sludge zone
- Widely used for treatment of municipal sewage in warm climates
- Number of studies at pilot-scale in temperate climates



Standard UASB performance in temperate climates

Number of studies (temperatures: 8-22°C)

Raw wastewater -14

Settled wastewater - 4

Settled WW (eff. averages):

$TSS_{eff.}$: 37 mg/L (71% removal)

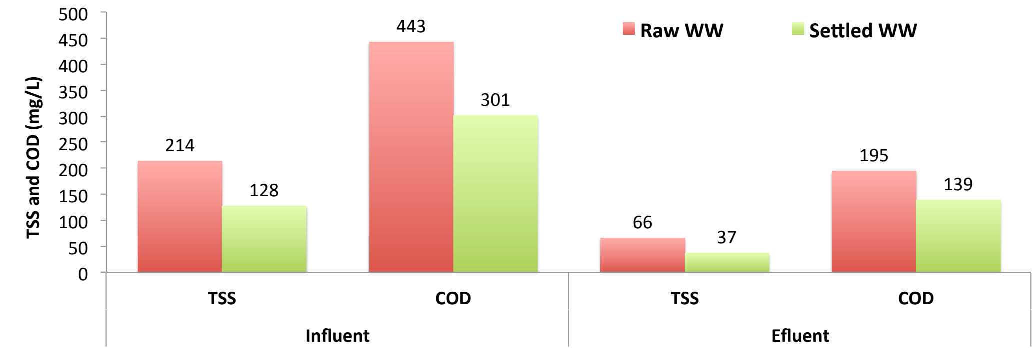
COD_{eff}: 139 mg/L (54% removal)

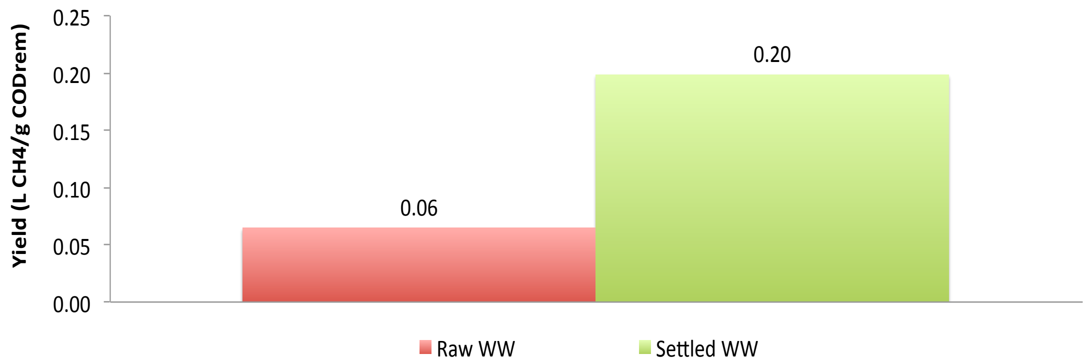
Desired performance:

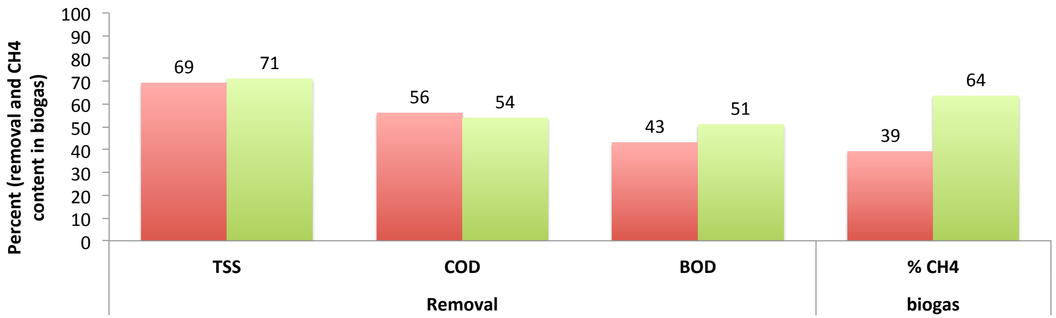
BOD_{eff}: 25 mg/L

COD_{eff}: 125 mg/L (>80% removal)

TSS_{eff}: 35 mg/L (>70% removal)



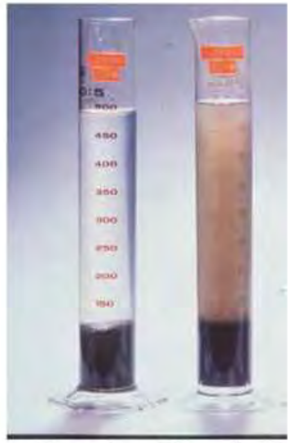




		Granular-UASB	Flocculent-UASB
Hydrolysis rate	%	23.0 ± 5.6	23.1 ± 7.4
Acidigenisis rate	%	37.9 ± 4.9	54.1 ± 5.5
Methanogenesis rate	%	43.1 ± 4.0	48.8±5.5

Comparison granular and flocculent UASB reactors for wastewater treatment in temperate climates (10C)

			Granular-UASB	Flocculent -UASB
	Temperature	°C	10.2 ± 1.5	10.2 ± 1.5
TSS	Influent	mg L^{-1}	113 ± 23	113 ± 23
	UASB effluent	mg L^{-1}	69 ± 11	75 ± 9*
	Removal	%	42 ± 13	39 ± 14*
COD_t	Influent	mg L^{-1}	213 ± 62	213 ± 62
	UASB effluent	mg L^{-1}	129 ± 19	140 ± 25*
	Removal	%	41 ± 14	36 ± 16*
SCOD	Influent	mg L^{-1}	72 ± 16	72 ± 16
	UASB effluent	mg L^{-1}	64 ± 13	60 ± 13
	Removal	%	18 ± 12	24 ± 14
BOD_5	Influent	mg L^{-1}	107 ± 22	107 ± 22
	UASB effluent	mg L^{-1}	84 ± 8	88 ± 10
	Removal	%	26 ± 17	19 ± 11

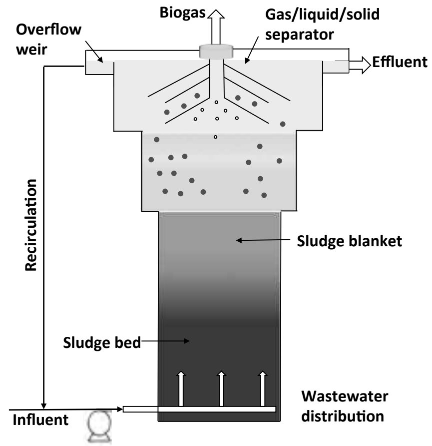


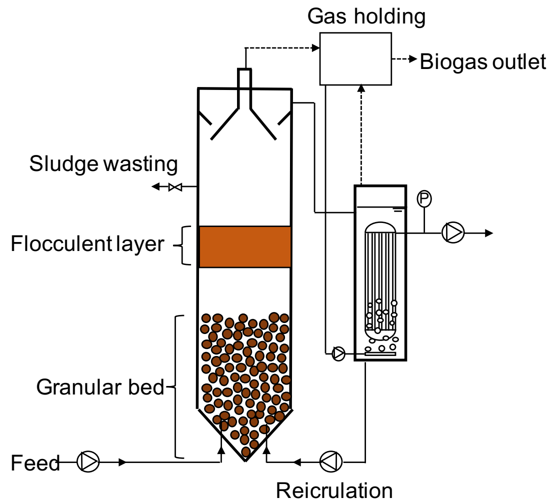
Granular Flocculent

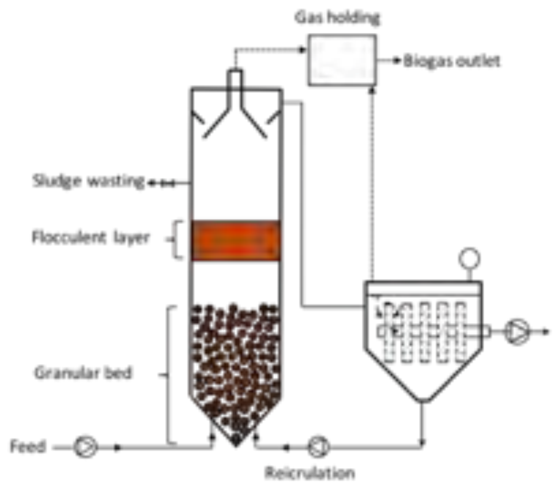
Wang KW, Soares A, Jefferson B, McAdam E. 2019. Comparable membrane permeability can be achieved in granular and flocculent anaerobic membrane bioreactor for sewage treatment through better sludge blanket control. Journal of Water Process. 28:181-189.

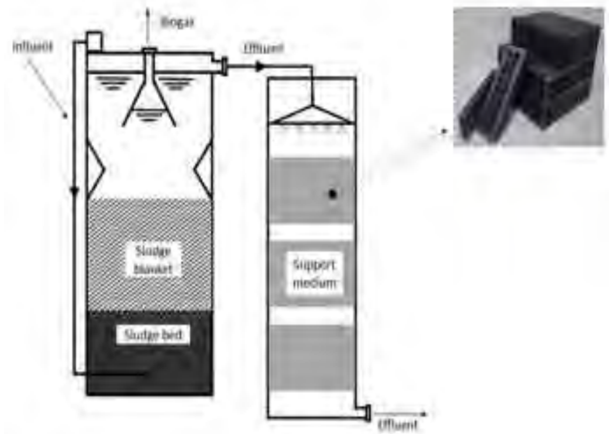
UASB configurations that can enhance solids retention

1. UASB with (2-3) three solid phase separators
2. UASB with increased diameter
3. UASB with support media (expanded bed biofilm reactor)
4. Package UASB coupled with lamella settler
5. Two stage UASB
6. Y shaped UASB
7. UASB combined with membrane filtration
8. UASB combined with microscreens/microstrainers
9. UASB combined with granular media filter
10. UASB combined with rapid filter/slow sand filter
11. UASB coupled with sponge media on top of the digester compartment
12. UASB coupled with sponge media filtration

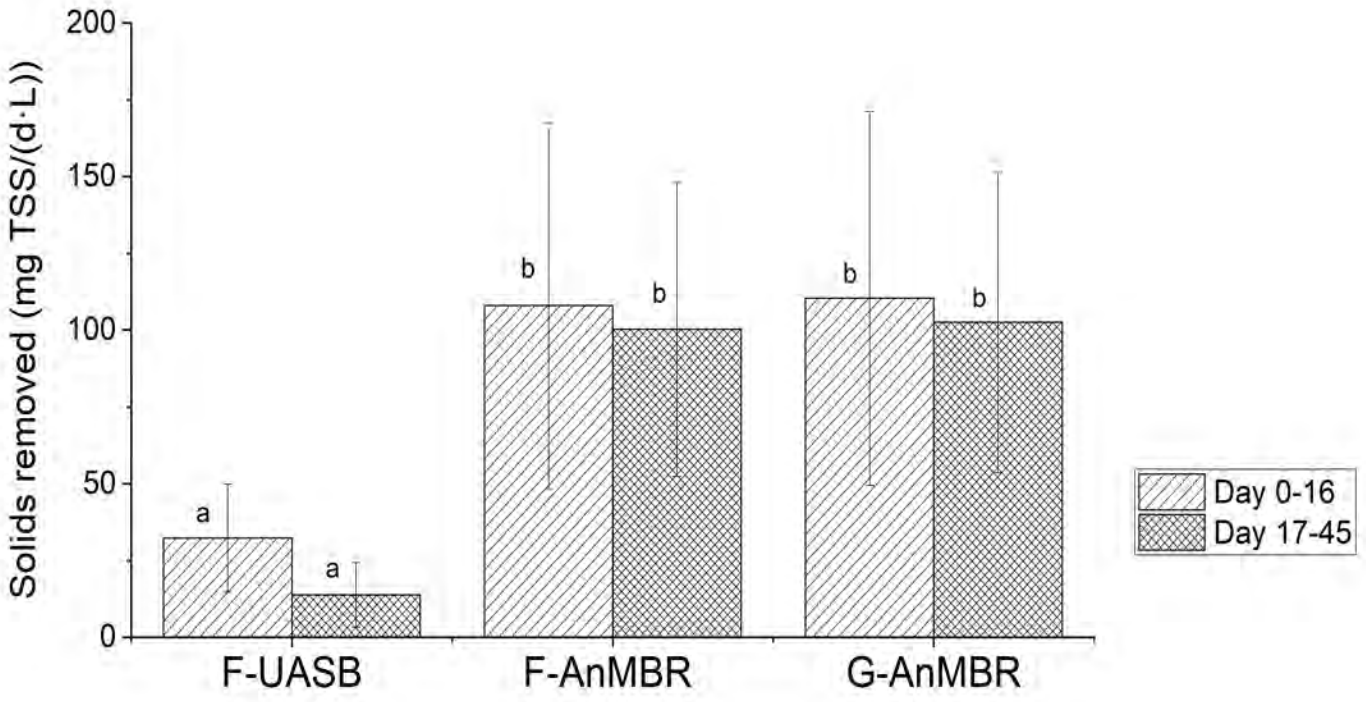






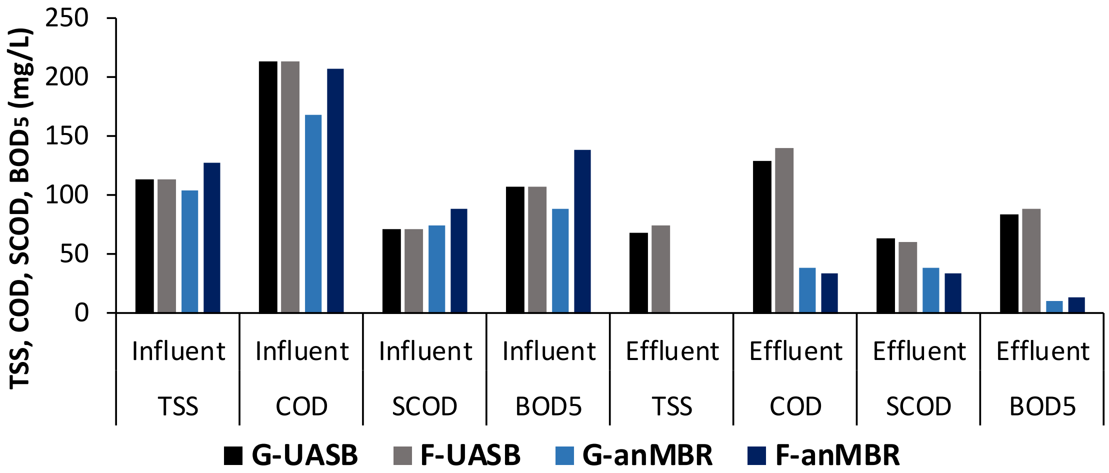


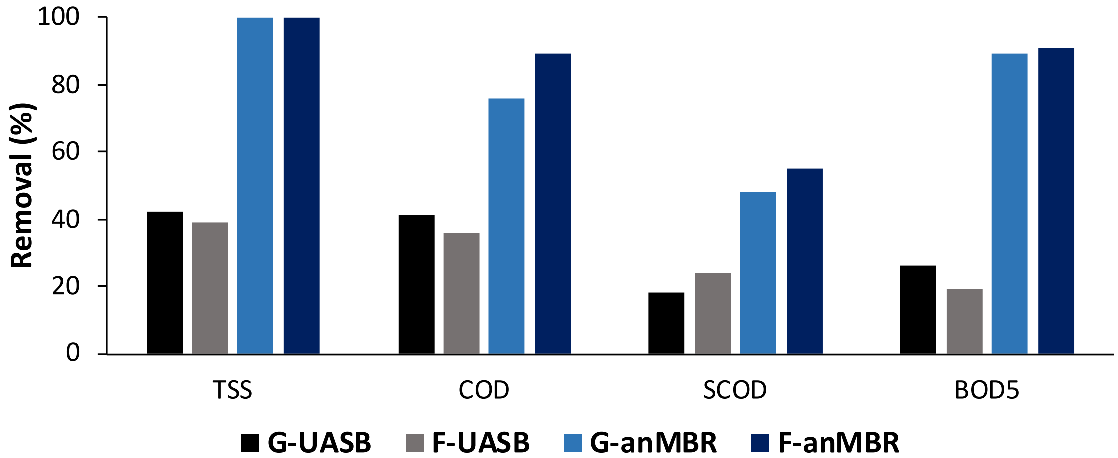
Solids capture in UASB



Ribera-Pi J, Campitelli A, Badia-Fabregat M, Jubany I, Martínez-Lladó X, McAdam E, Jefferson B, Soares A. 2020. Hydrolysis in upflow anaerobic sludge blanket reactors treating municipal wastewater under psychrophilic conditions: the importance of reactor configuration. Frontiers in Bioengineering and Biotechnology

UASB + MBR (anMBR) performance





UASB	Methane yield (m^3 CH_4/ kg COD $_{removed}$)
7◦C	0.13
20◦C	0.19
anMBR	
7◦C	0.19
20◦C	0.28

Municipal wastewater
8-12◦C
HRT 8 h
upflow velocity: 0.4 m/h

Wang KW, Soares A, Jefferson B, McAdam E. 2019. Comparable membrane permeability can be achieved in granular and flocculent anaerobic membrane bioreactor for sewage treatment through better sludge blanket control. Journal of Water Process. 28:181-189.

Ribera-Pi J, Campitelli A, Badia-Fabregat M, Jubany I, Martínez-Lladó X, McAdam E, Jefferson B, Soares A. 2020. Hydrolysis in upflow anaerobic sludge blanket reactors treating municipal wastewater under psychrophilic conditions: the importance of reactor configuration. Frontiers in Bioengineering and Biotechnology.

H2020 NEXT-GEN

- NextGen demonstrates innovative technological, business and governance solutions for water in the circular economy in ten high-profile, large-scale, demonstration cases across Europe, and we will develop the necessary approaches, tools and partnerships, to transfer and upscale.
- The resources include:

The consortium has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No. 776541.

#5.
Sperneal (UK)

Waste Water Treatment Plant

Circular solutions for

Wate[redacted] Materials [redacted] Energy [redacted]

Relevant data

Waste water plant serving the town of Redditch (Birmingham, UK): 92.000 PE

Relevant sectors

Agriculture

Domestic sector

Energy sector

Lead partners

Cranfield University

Resource recovery and innovation centre

WONDERFUL ON TAP SEVERN TRENT

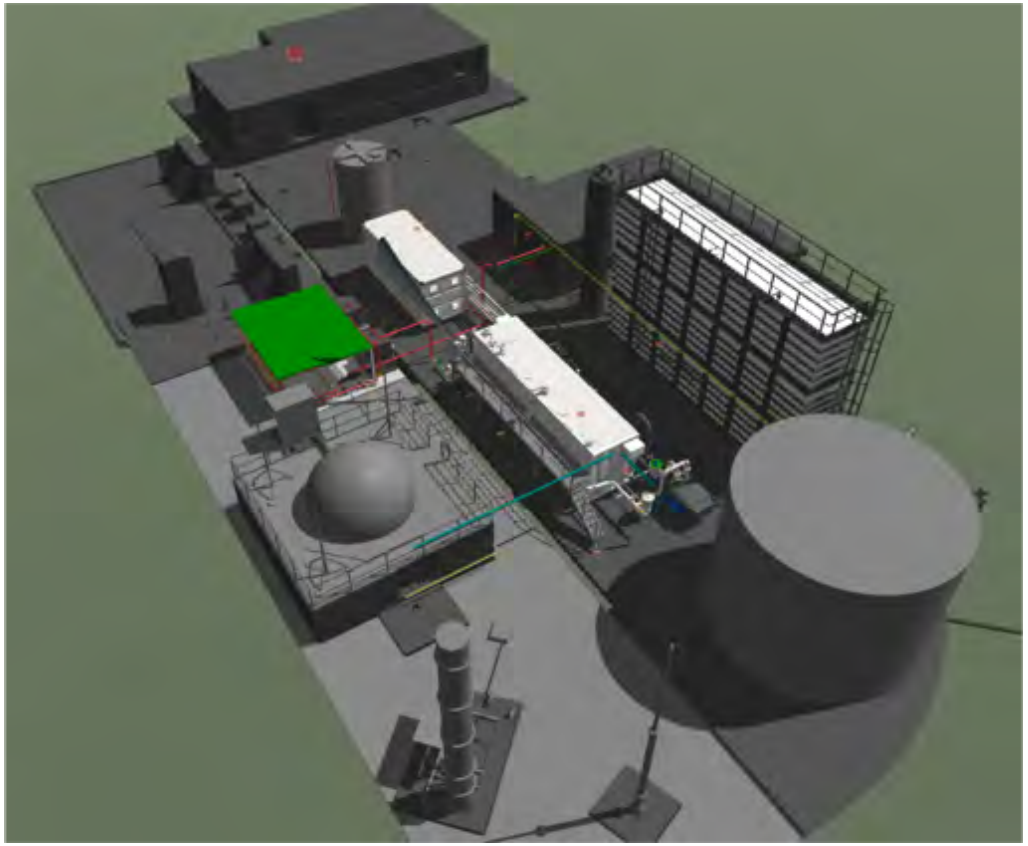
S[redacted]evern Tre[redacted]very and Innovation Centre" where emerging technologies compatible with a low energy, circular economy approach will be evaluated.

A multi-stream test bed facility was constructed in 2019 and this will incorporate **an anaerobic membrane bioreactor (AnMBR) to be commissioned in Summer 2020. The AnMBR will also comprise a membrane degassing unit to recover dissolved methane and ion exchange processes to recover nitrogen and phosphorus from the effluent.**

AnMBR combines several benefits such as:

- no aeration energy for removal of Chemical and Biological Oxygen Demand (COD/BOD)
- low sludge production and hence reduced downstream sludge treatment costs
- biogas production (production of electricity/heat
- pathogen and solids free effluent which can be re-used in a number of applications (e.g.: farming and industrial use).

Building in Spernal



- Construction and commissioning of resource recovery innovation center completed in October 2019 – drone footage on right

- AnMBR to be commissioned in Summer 2020 – fabrication of the UASB reactors (Waterleau) shown on left

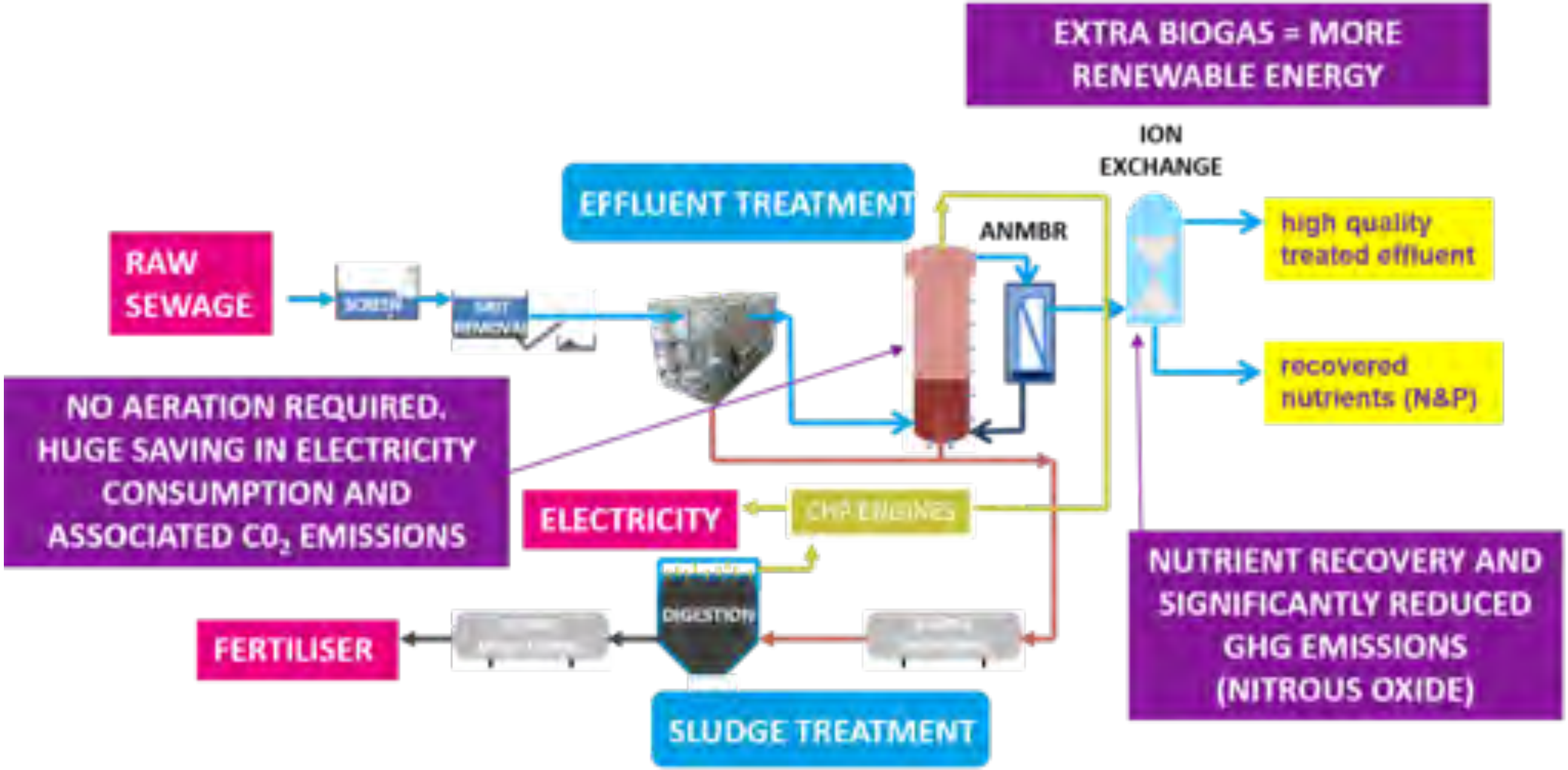
Video of R2IC in file sent via

https://youtu.be/BeETnMSnjss

The consortium has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No. 776541.

Cranfield University

NEXT-GEN Demonstration case Spernal WWTP



Pilot data on the UASB with the same

JUL-SEPT 2020 (T=18°C)		Pilot hall sewage characterisation		Removal rates (%)
		Influent	R1 UASB effluent	R1 UASB
COD	mg L^{-1}	153	56	63
sCOD	mg L^{-1}	36	29	19
BOD_5	mg L^{-1}	65	38	42
TSS	mg L^{-1}	117	37	68
VSS	mg L^{-1}	108	31	71
SO_4	mg L^{-1}	62	40	35

OCT 2020 – ongoing (T=13°C)		Pilot hall sewage characterisation		Removal rates (%)
		Influent	R1 UASB effluent	R1 UASB
COD	mg L^{-1}	181	100	45
sCOD	mg L^{-1}	44	39	11
BOD_5	mg L^{-1}	71	44	38
TSS	mg L^{-1}	111	41	63
VSS	mg L^{-1}	96	37	61
SO_4	mg L^{-1}	68	43	37

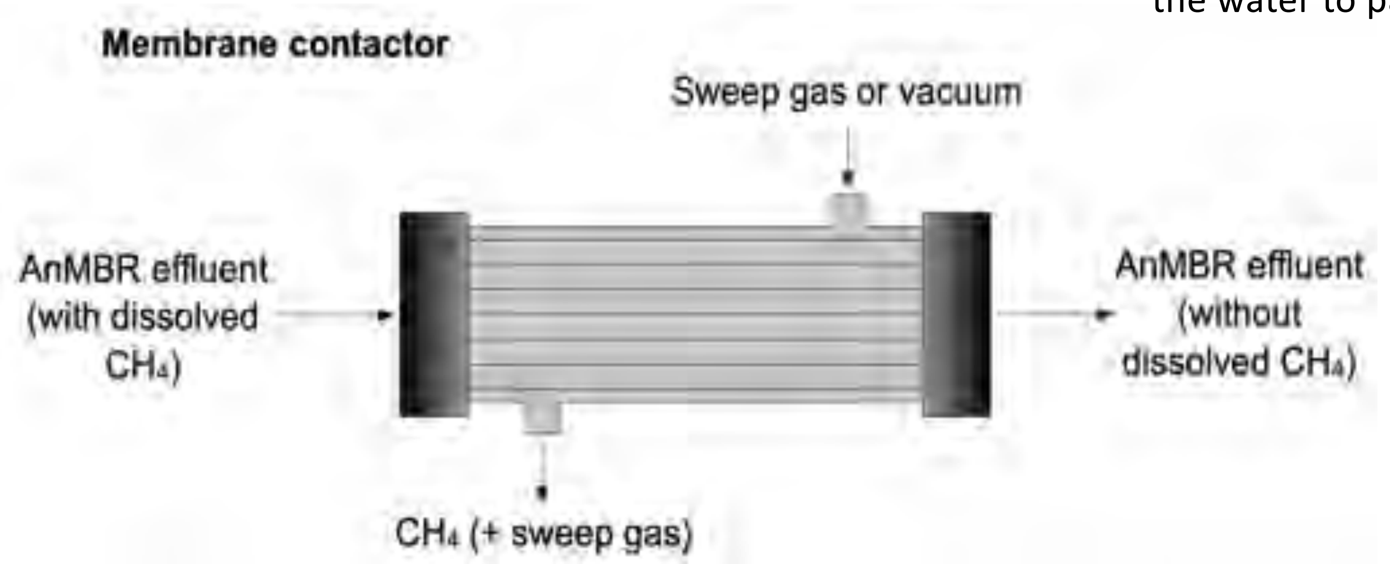
Gas sensors and dissolved methane probe to assist on the measurement of energy production in the AnMBR

OCT 2020 – ongoing (T=13°C)		R1 UASB
Biogas production	L d^{-1}	0.6
Dissolved CH_4/total CH_4	%	93.6
Methane yield	L CH_4/g COD	0.13

Degassing Unit

In the process, water passes through the outside (shell side) of the hollow fibres while a sweep gas (or vacuum) is applied to the inside (lumen side) of the fibres. Because the membrane is hydrophobic it allows direct contact between gas and water without dispersion

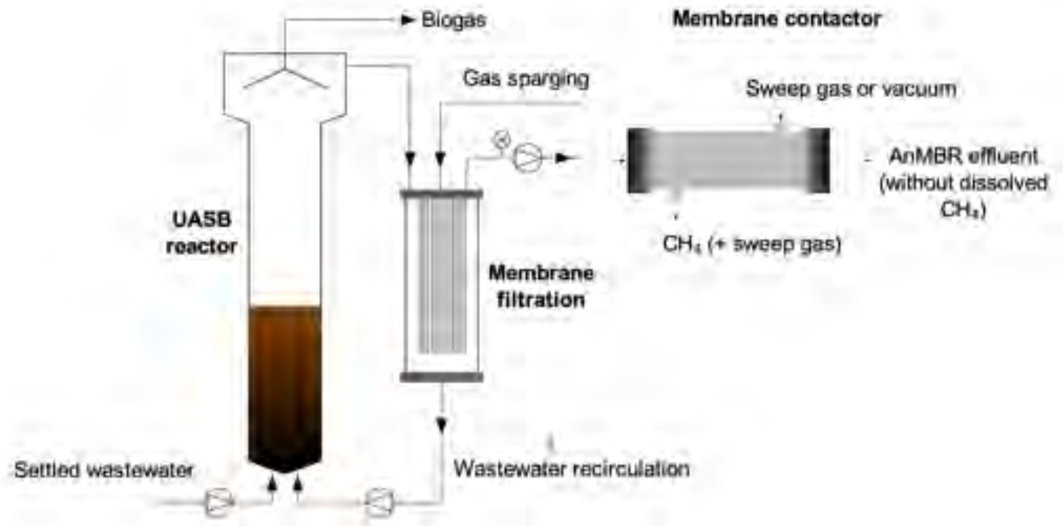
Applying a higher pressure to the water stream relative to the gas stream creates the driving force for dissolved gas in the water to pass through the membrane pores.

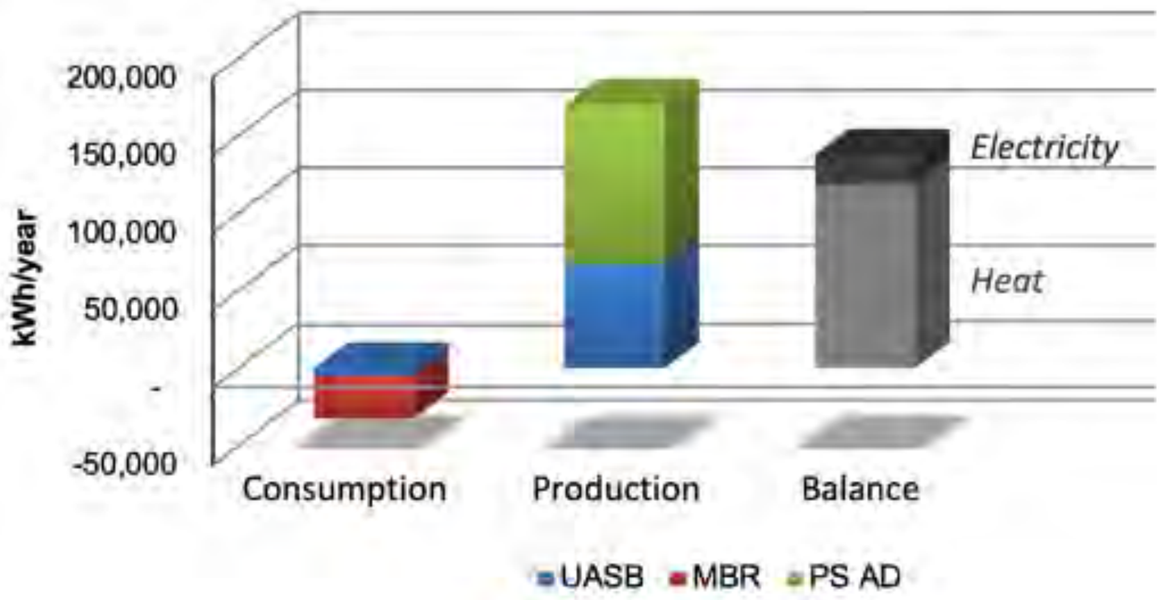


- **Technology provider – 3M (Membrana)**
- **The methane will be sent to the gas bag**

Energy balance in Spernal

- 360 m3/day WWTP
- anMBR energy consumption 0.25 kWh/m^3, production 0.2-0.5 kWh/m^3
- Heat recovery is of high relevance
- The anaerobic digestion of primary sludge balances energy and ensures solids management in the anMBR





Wang KW, Soares A, Jefferson B, McAdam E. 2019. Comparable membrane permeability can be achieved in granular and flocculent anaerobic membrane bioreactor for sewage treatment through better sludge blanket control. Journal of Water Process. 28:181-189.

Ribera-Pi J, Campitelli A, Badia-Fabregat M, Jubany I, Martínez-Lladó X, McAdam E, Jefferson B, Soares A. 2020. Hydrolysis in upflow anaerobic sludge blanket reactors treating municipal wastewater under psychrophilic conditions: the importance of reactor configuration. Frontiers in Bioengineering and Biotechnology.


Cranfield
Water
Thank You

Annex 4: Presentations – Heat recovery

The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

Online seminar on heat recovery

A. Kleyböcker, S. Casa Garriga, F. Fantone, C. Bruni

February, 26th 2021

Ultimate (June 2020 – May 2024):
Industry water-utility symbiosis for a smarter water society

- Promotion, establishment and extension of **Water Smart Industrial Symbioses**
- Development and demonstration of **innovative technologies** for symbioses
- **Assessment** of the technologies and development of **digital „support tools“**
- Development of **new business models** towards marketability

9 Symbioses between:

Industrial sectors
- Agro-food
- Beverage
- (Petro)chemical
- Biotech

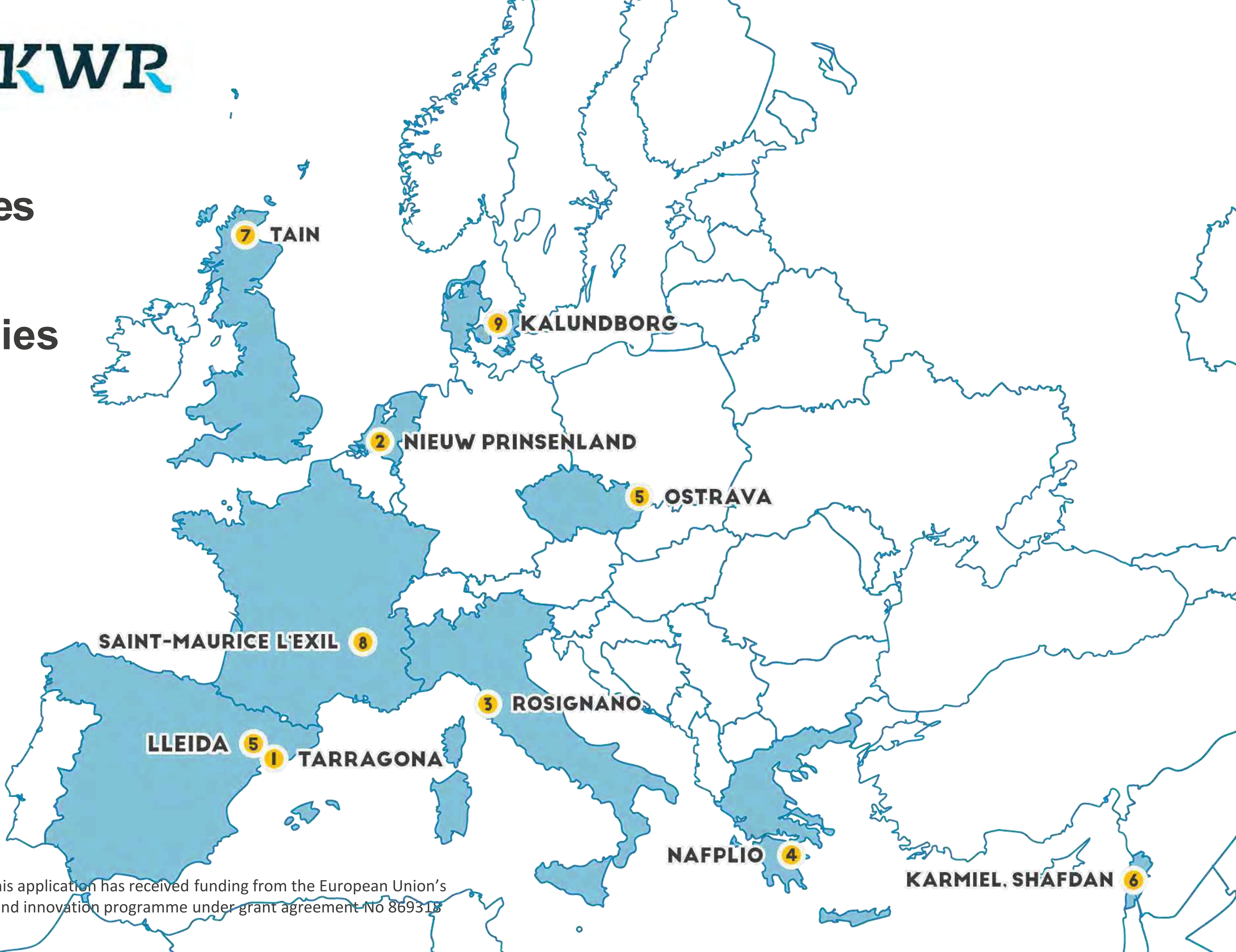
Service providers
- Municipal utility
- Multi-industry utility
- Specialized SME
- Water services provider

Coordinator: KWR

9 Case Studies

27 Partners

37 Technologies



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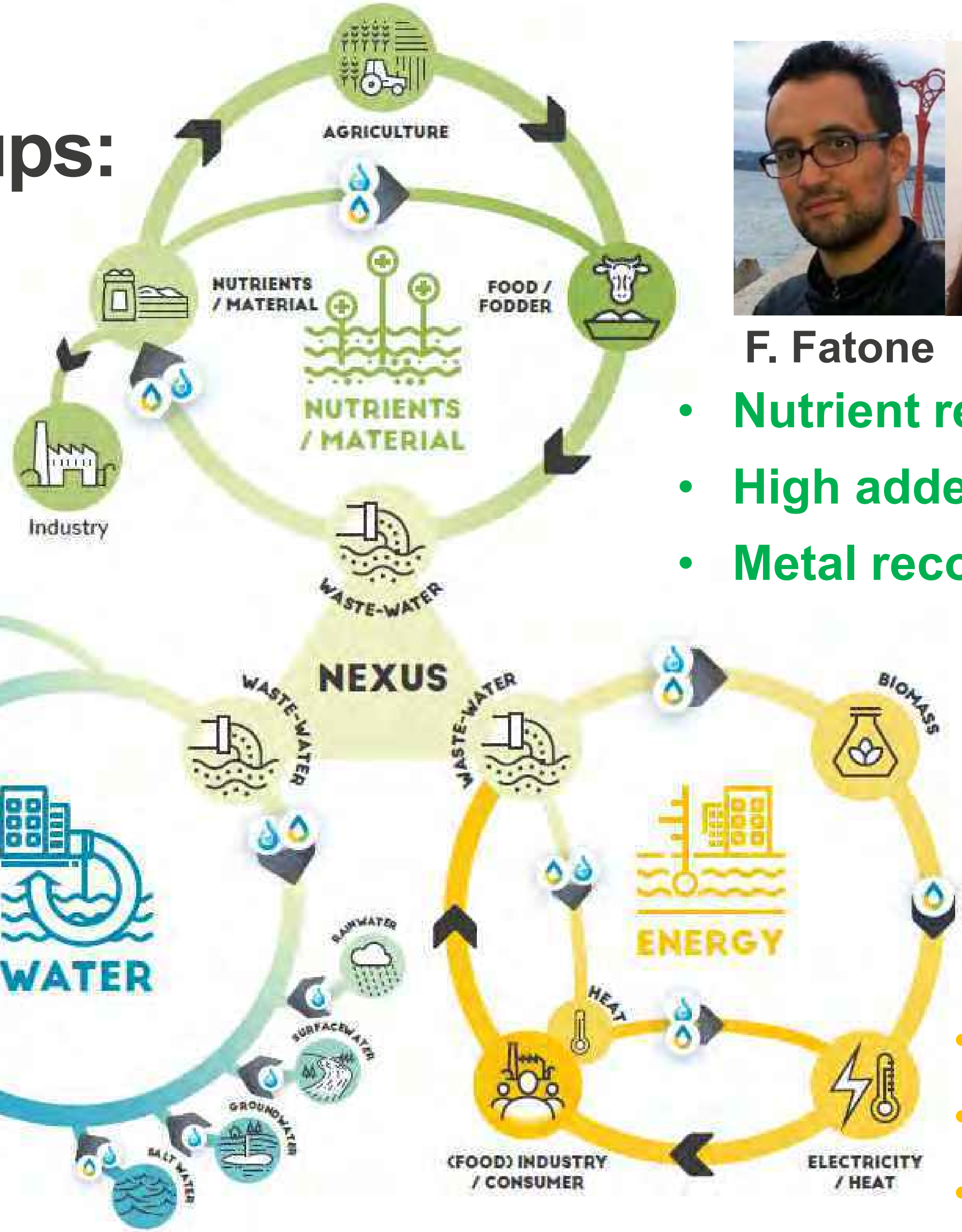
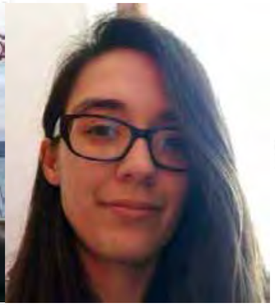
3 Cross-cutting Technology Groups: 9 Topics





F. Fatone C. Bruni

UNIVERSITÀ POLITECNICA DELLE MARCHE

- Nutrient recovery
- High added value products
- Metal recovery

eurecat
Centre Tecnològic de Catalunya

S. Casas

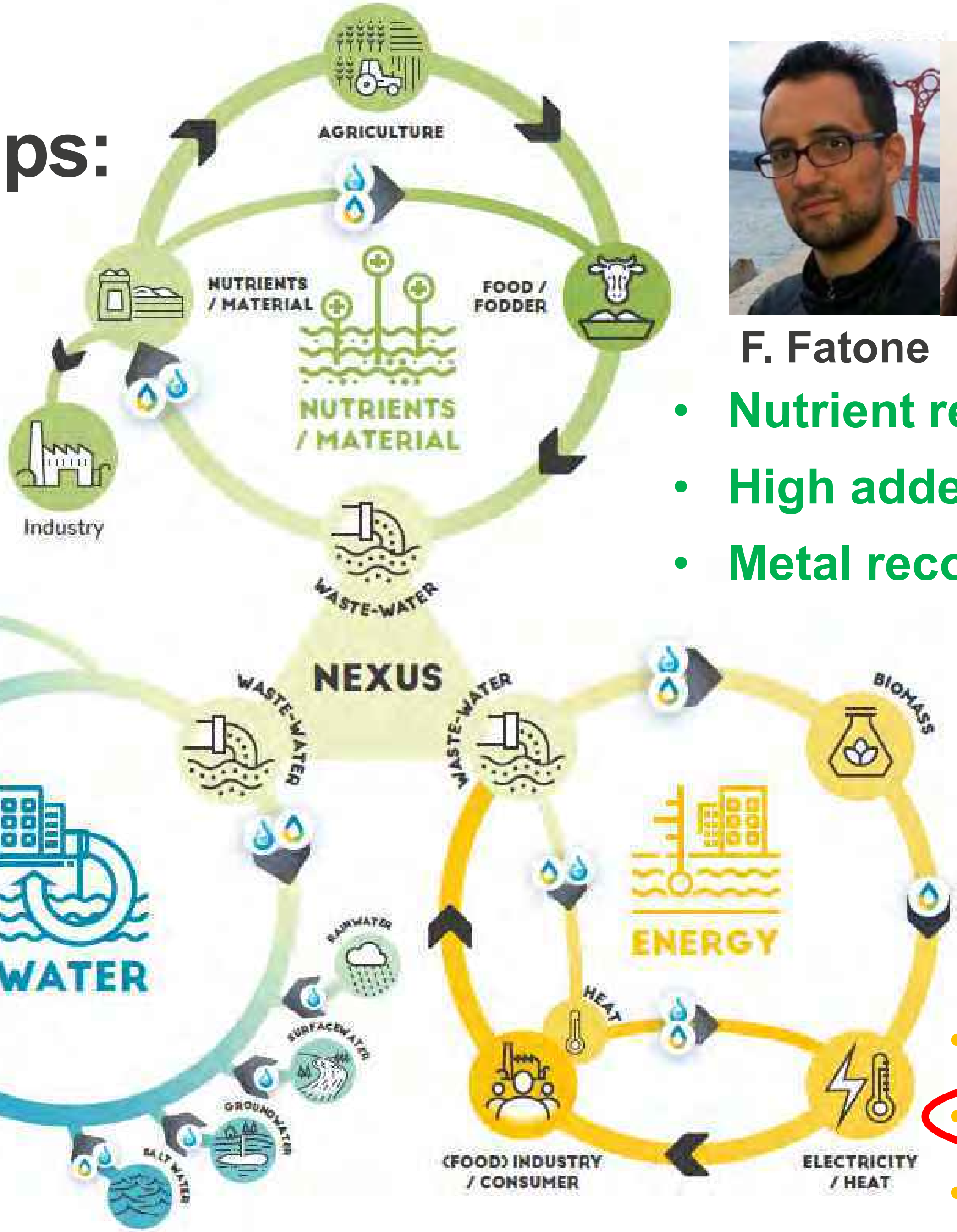
- Membrane technologies
- Adsorption technologies
- Advanced oxidation processes

A. Kleyböcker

KOMPETENZZENTRUM Wasser Berlin

- Biogas technologies
- Heat recovery
- Digitalization

3 Cross-cutting Technology Groups: 9 Topics



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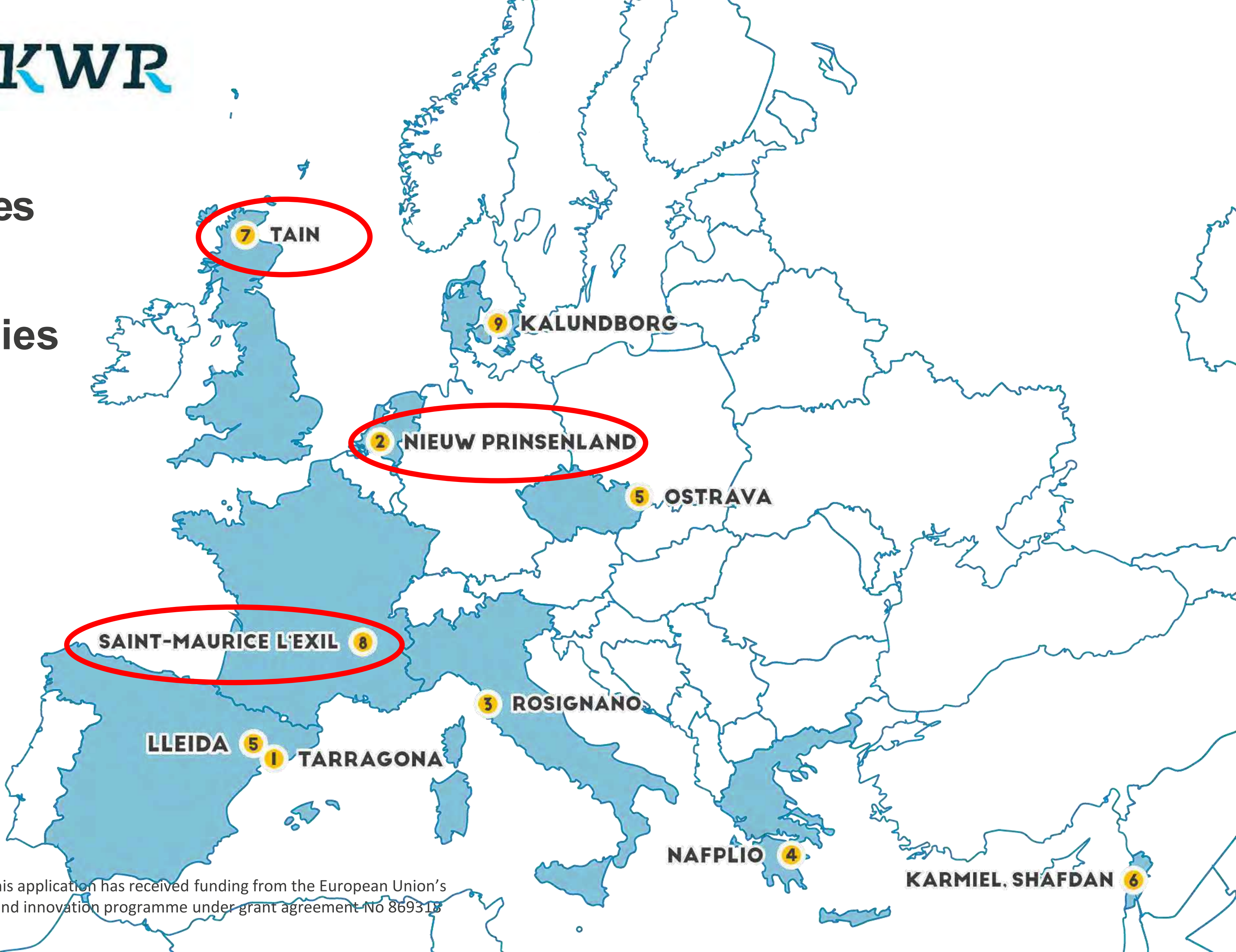

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Online seminar on heat recovery

10:15	**CS7 Tain**: Heat recovery from anaerobic membrane bioreactor effluent *Marc Pidou (Cranfield University)*
10:30	**CS8 Chemical platform of Roussillon**: Recovery of heat from flue gas washing water *Anne Reguer (IWS Chemicals, Recycling & Recovery Europe, Suez)*
10:45	**CS2 Nieuw-Prisenland**: High temperature aquifer thermal energy solution in greenhouses *Marette Zwamborn (KWR)*
11:00	Short break
11:05	**NextGen**: Aquifer thermal energy system at the greenhouse of Koppert-Cress *Martin Bloemendal (TU Delft & KWR)*
11:30	**BioKS**: How to avoid corrosion in aquifer thermal energy systems in Germany? *Hilke Würdemann (Merseburg University of Applied Sciences)*
11:55	**End**

26 February 2021

HT-ATES Aquifer thermal energy storage in greenhouses

ULTIMATE CS2 Nieuw-Prinsenland

Marette Zwamborn, KWR

KWR

Bridging Science to Practice

CS2: HT-ATES in greenhouses

Objective

- Demonstrate HT-ATES for greenhouses

Methodology

- Determine suitable aquifers
- Modelling studies (recovery efficiency)
- Cost-benefit analysis

→ Feasibility study

KPI's

- CO_2 reduction [t/a]
- Delivered heat cost [€/GJ]
- Heat recovery factor aquifer [-]

Website Heatstore (EU Geothermica)

Why HT-ATES in greenhouses

Why HT-ATES?

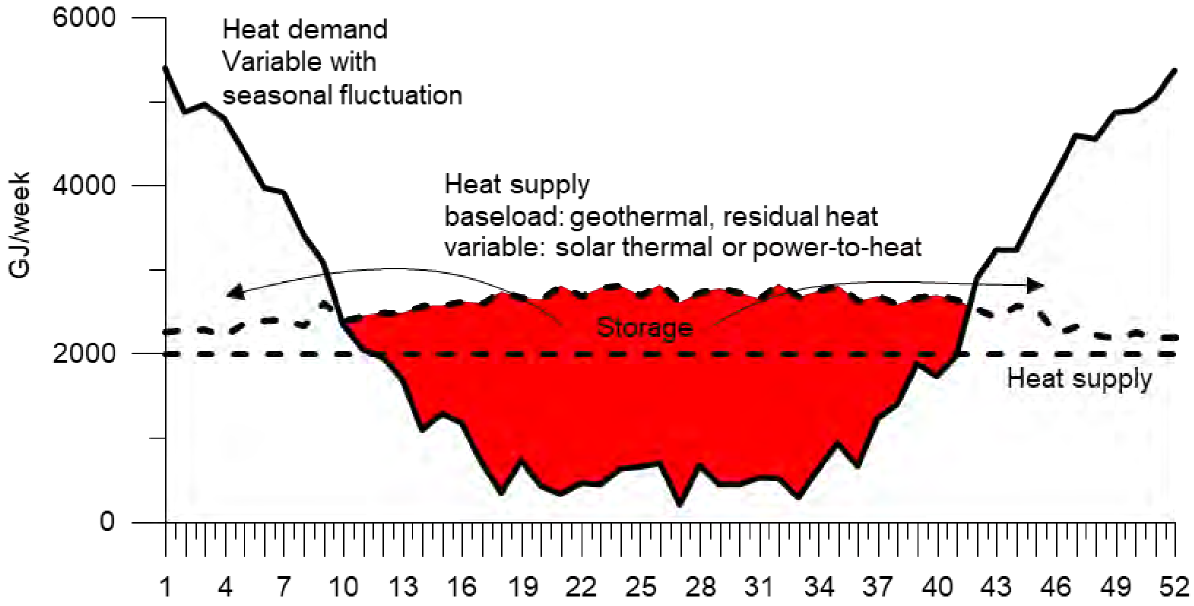
- Match heat demand and supply
- Seasonal storage, optimal use of sustainable energy

Heat demand in greenhouses:

- High demand in winter, low in summer

Heat supply:

↓ Gas (boiler of combined heat-and-power)
↑ Geothermal or residual heat (baseload)
↑ Solar thermal or power-to-heat (variable)



HT-ATES typical features

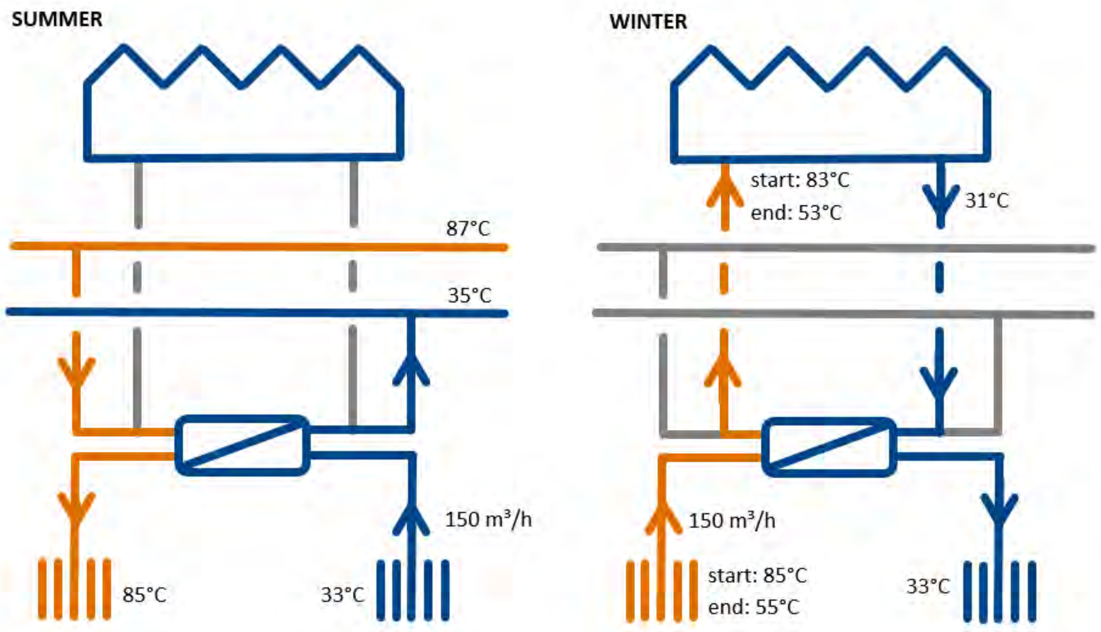
HT-ATES:

- Storage temperature up to 90°C
- Warm and cold well(s)
- Aquifer depth 100 – 500 mbgl

- Heat capacity 2 - 20 MW_{th}
- Heat storage 10.000 – 150.000 GJ/a
- Recovery efficiency 10 - 90%

Current research projects on HT-ATES:

- HEATSTORE, Nextgen, WINDOW, WarmingUP
- HT-ATES is not a proven technique yet



Website Heatstore (EU Geothermica)

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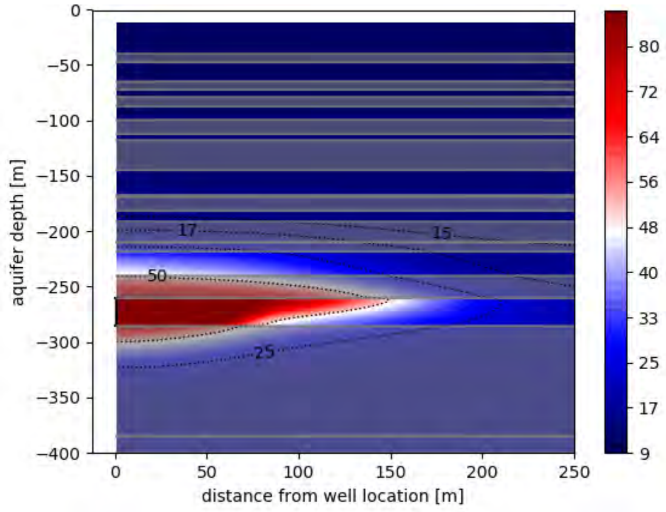
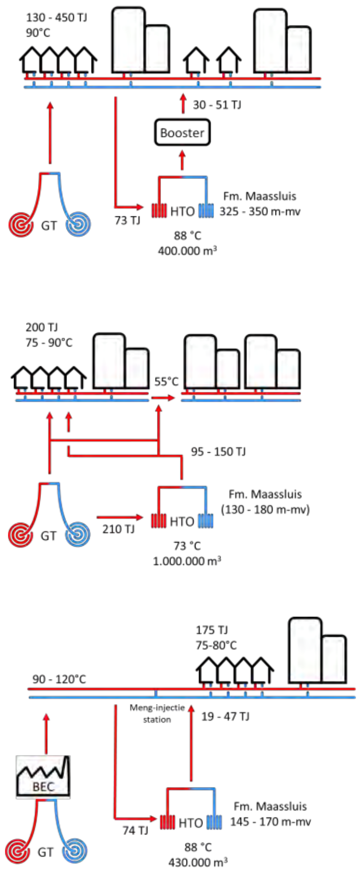
Results from current research

WARMING UP





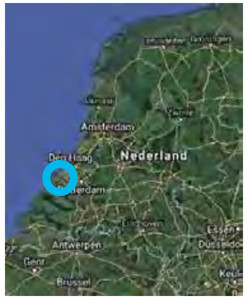
Sustainable energy for greenhouse area Westland

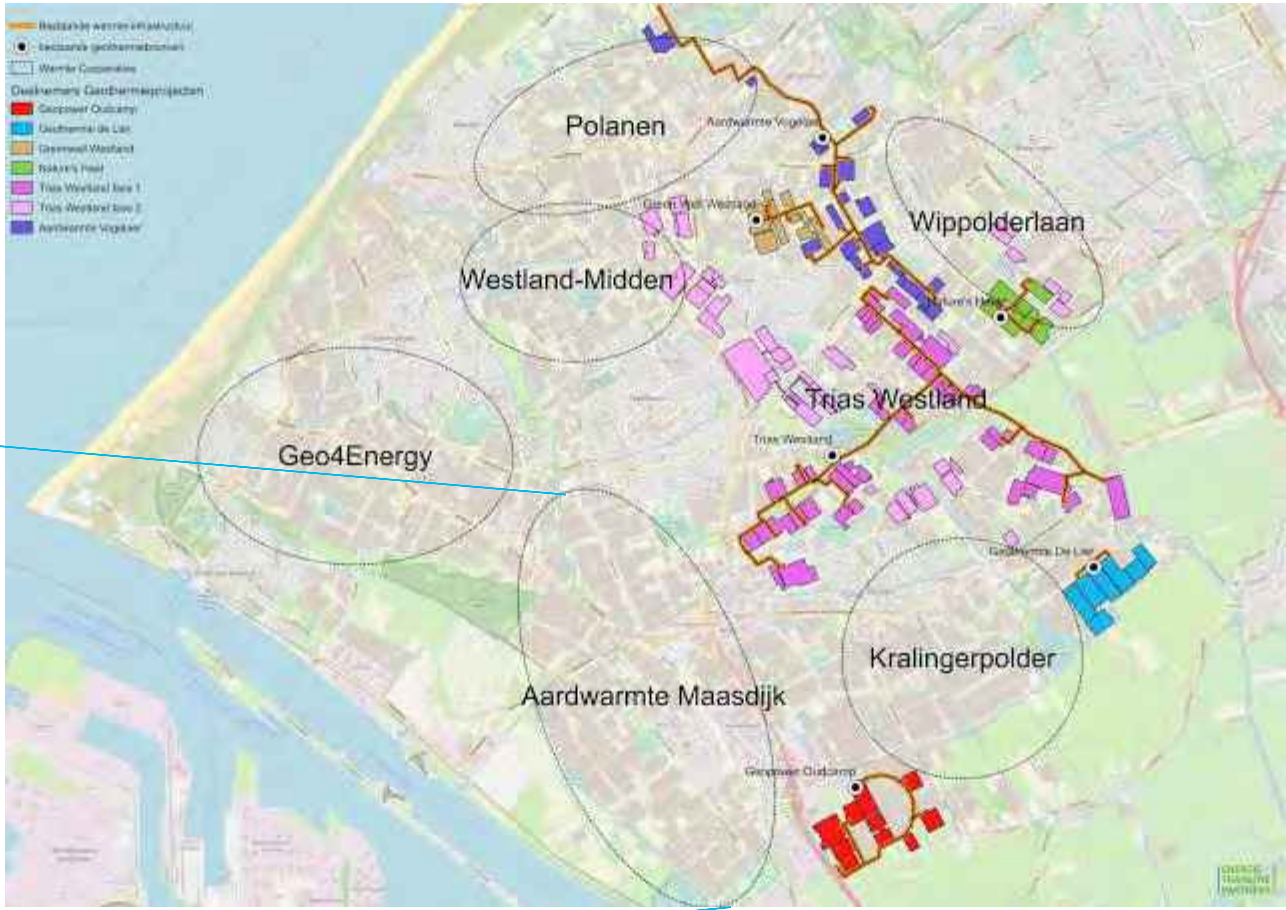
Combination of geothermal system and HT-ATES:

- Expected to be a winning combination!

Development of geothermal energy systems:

- Trias Westland
- Polanen
- Maasdijk





Pilot Westland (Maasdijk) determine suitable aquifers

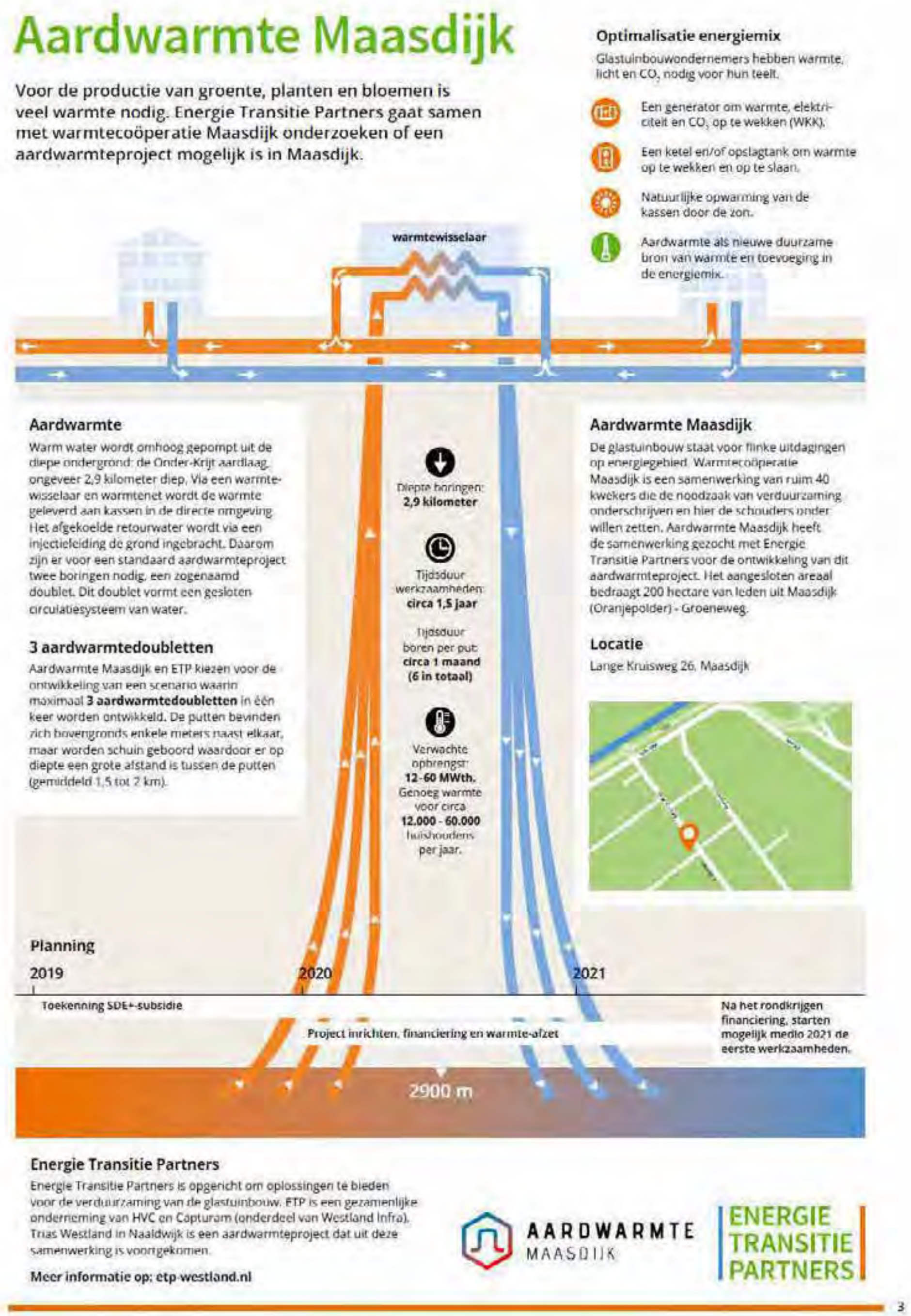
Determine suitable aquifers:

- Develop a cost-effective method
- Combine drilling of a geothermal well with the screening of potential HT-ATES aquifers
- Geohydrological riks aspects are seized
- No separate test drilling needed

Challenge while drilling the geothermal well:

Dependency on time schedule

Possible measurements



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KWR

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ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

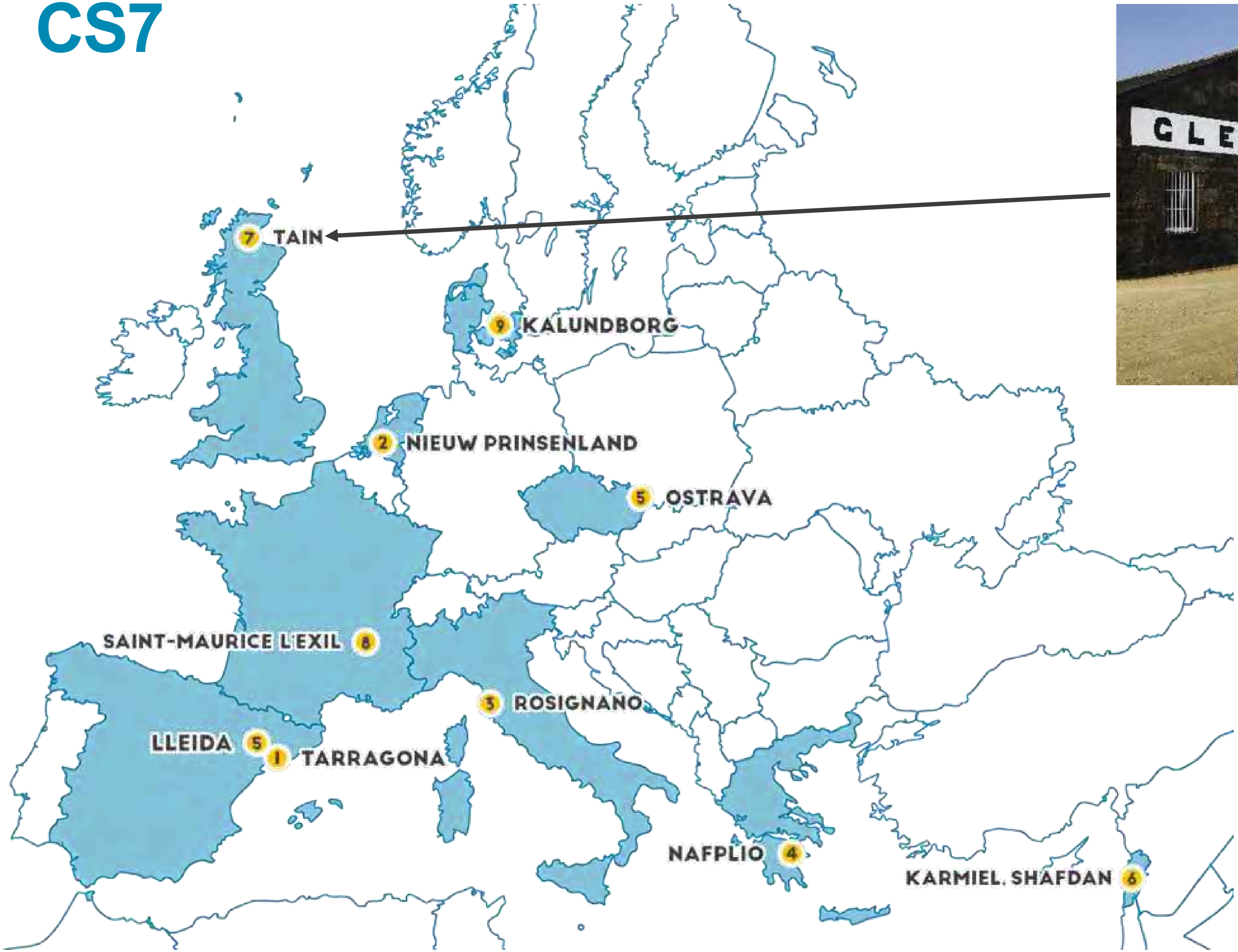
CS7 – Tain (Glenmorangie distillery)

Cranfield University

Aquabio

Meeting: October, 30th 2020

CS7

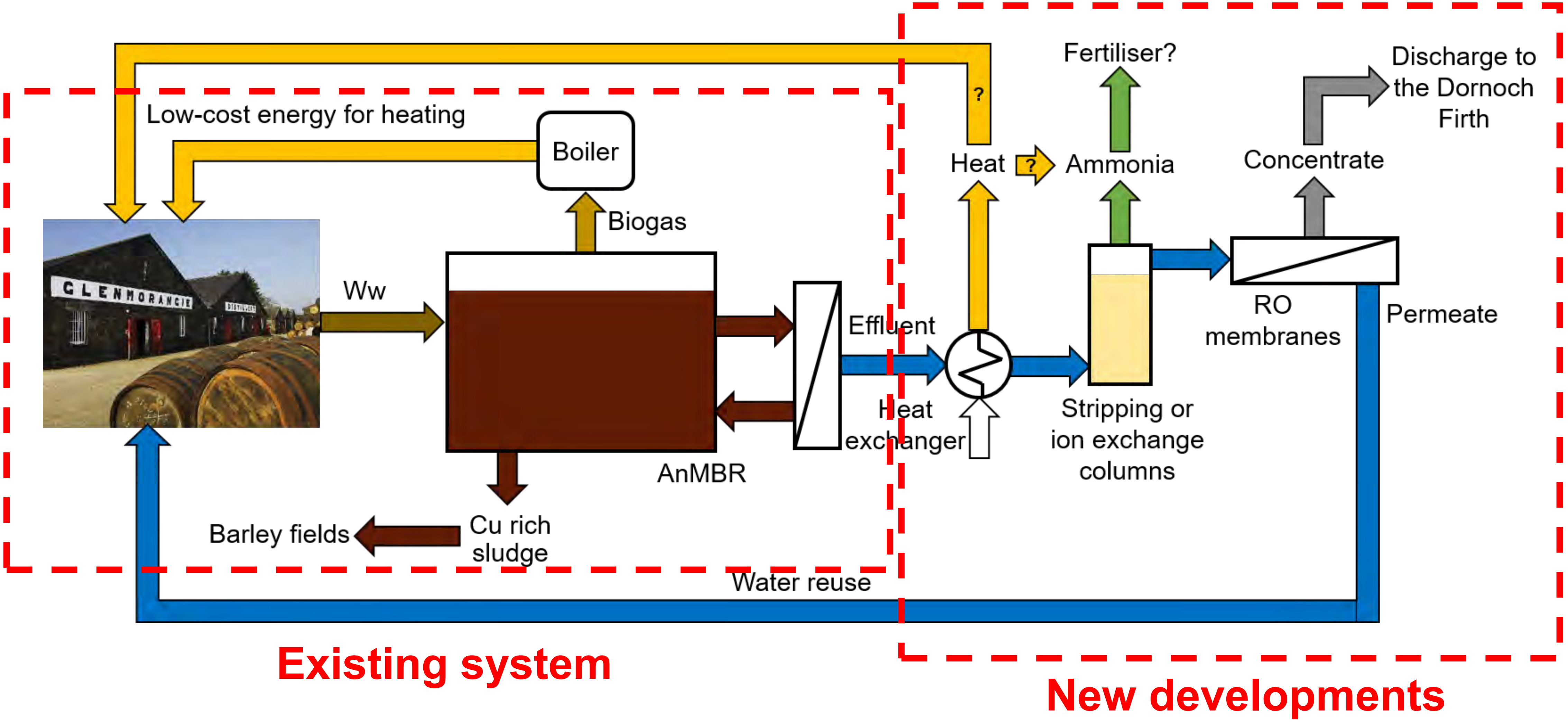


7 TAIN
9 KALUNDBORG
2 NIEUW PRINSENLAND
5 OSTRAVA
SAINT-MAURICE L'EXIL 8
3 ROSIGNANO
LLEIDA 5
1 TARRAGONA
NAFPLIO 4
KARMIEL, SHAFDAN 6

GLENMORANGIE

GLENMORANGIE
THE ORIGINAL

Treatment systems



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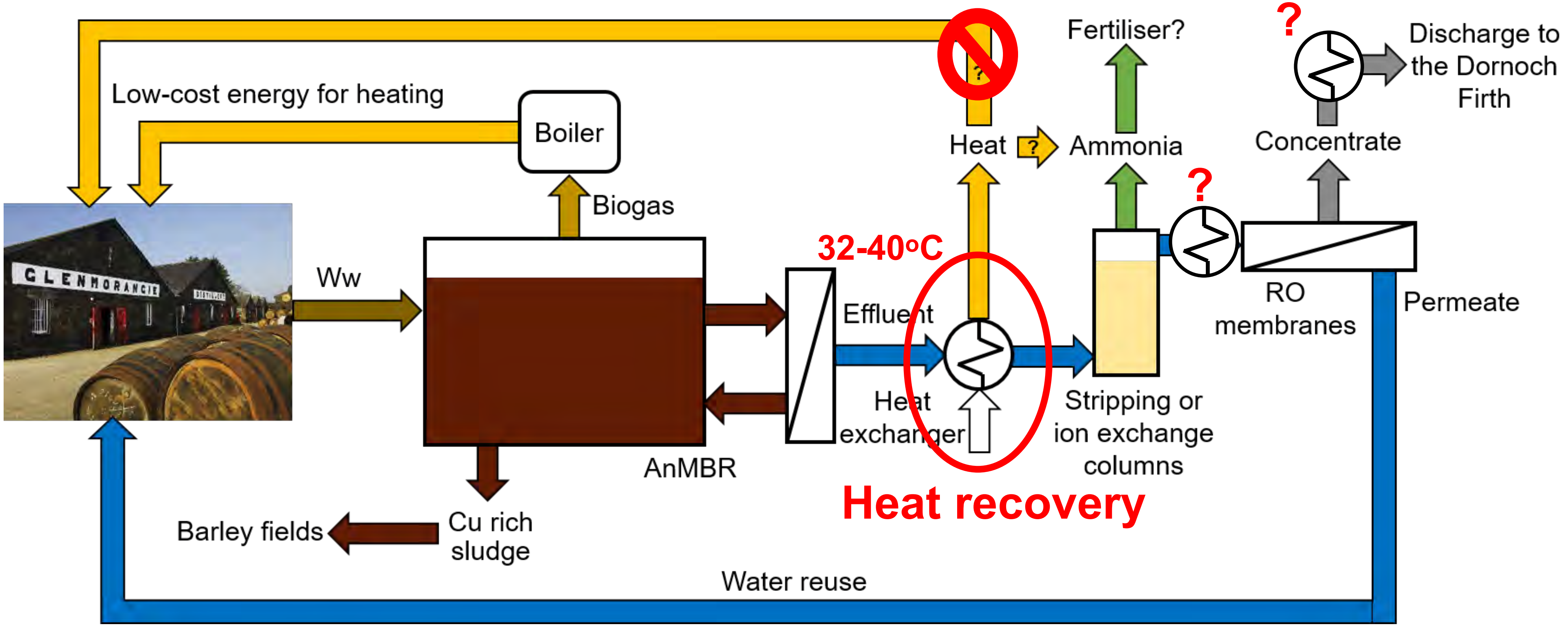
Treatment systems



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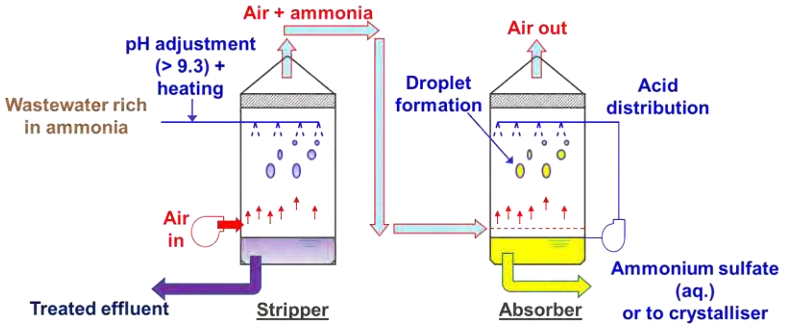
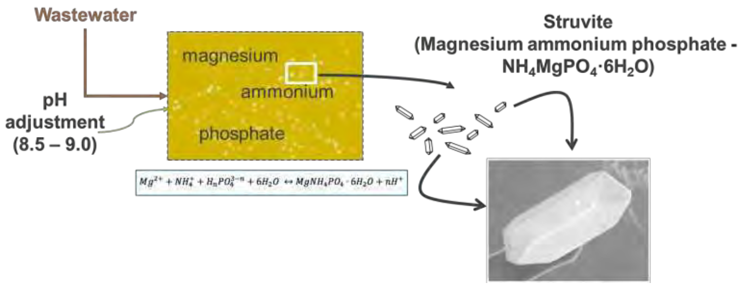
Impact of temperature: Ammonia recovery

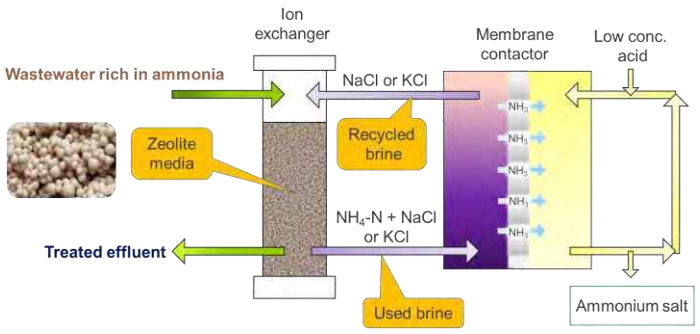
Stripping

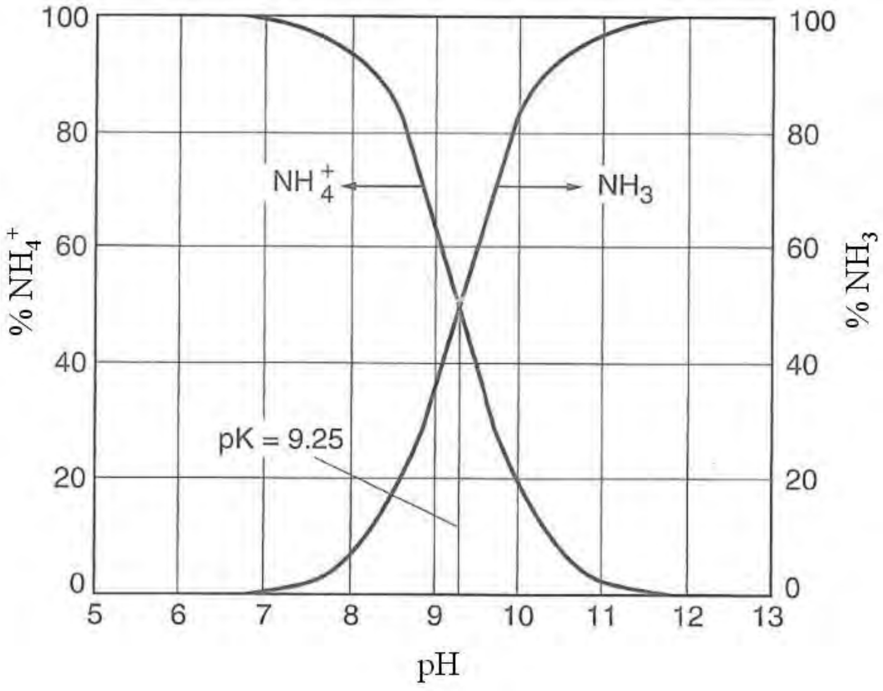


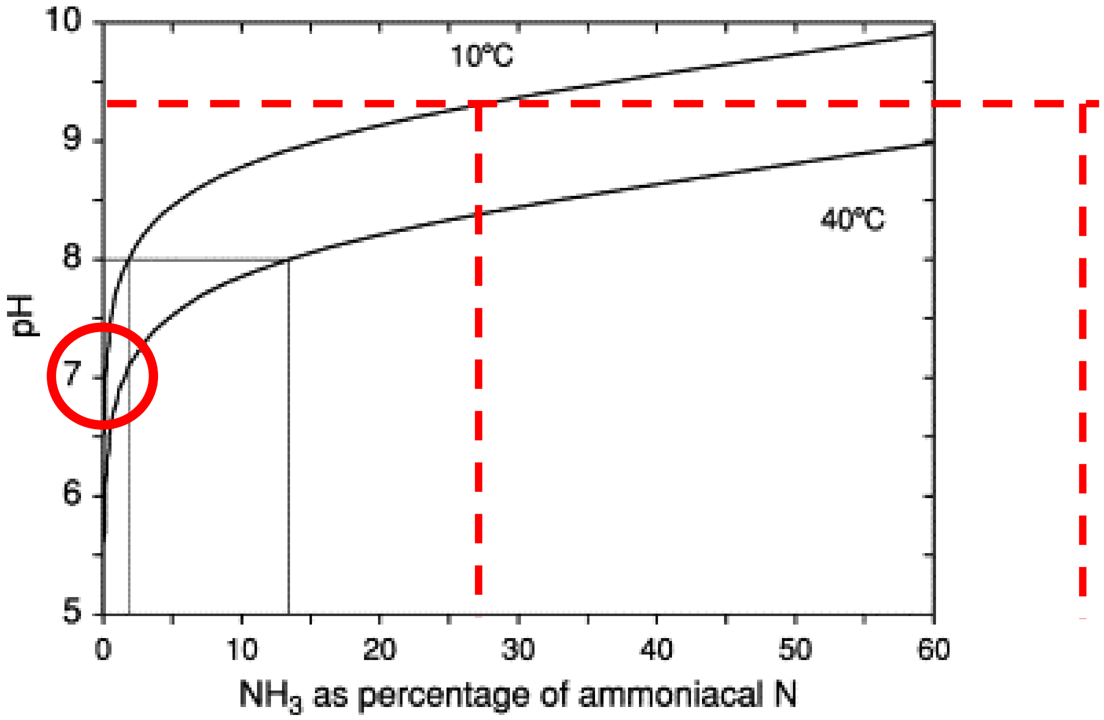
Precipitation



Ion exchange







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https://www.sciencedirect.com/topics/earth-and-planetary-sciences/ammonia

Impact of temperature: RO membranes

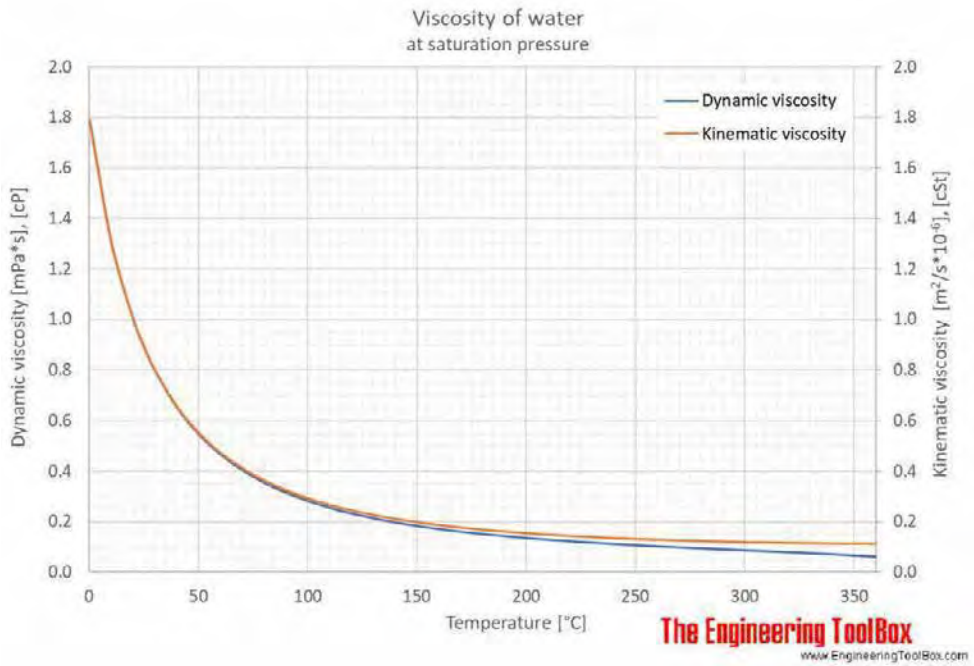
$$J = \frac{Q_p}{A} = \frac{P - \pi}{\eta \cdot R}$$

Flux

Pressure

Viscosity

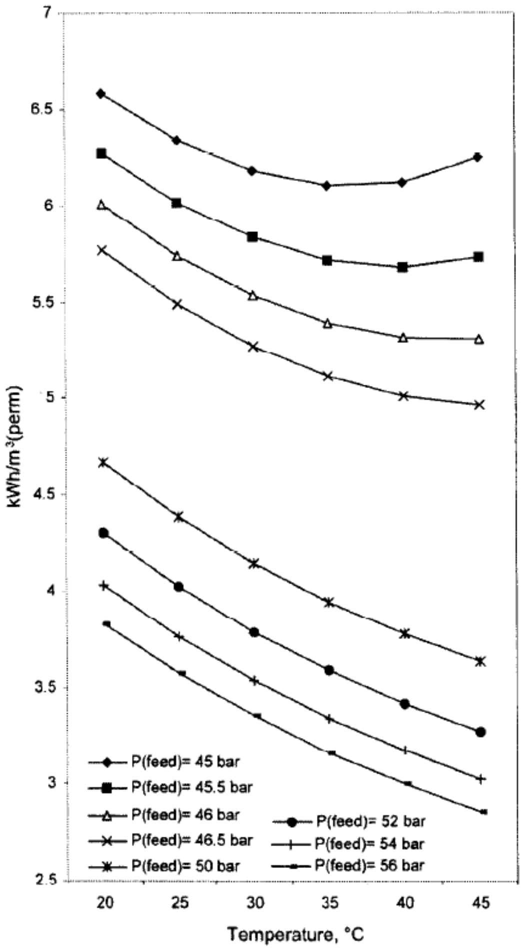
Resistance



https://www.engineeringtoolbox.com/water-dynamic-kinematic-viscosity-d_596.html

Temperature, °C	TDS, mg/l	Pressure, bar
5	12	27.3
10	13	23.1
15	14	19.7
20	16	17.0
25	17	14.8
30	19	14.8
35	21	11.9
40	23	10.8
45	26	9.8
50	28	9.0
55	31	8.3
60	35	7.7
65	38	7.2
70	43	6.8

https://www.researchgate.net/publication/264420571_Performance_of_Reverse_Osmosis_Units_at_High_Temperatures



https://www.sciencedirect.com/science/article/pii/S0011916403800413?via%3Dihub

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It's all about trade-offs!

ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

Thank you!

ULTIMATE – CS 8
SUEZ RR IWS CHEMICALS FRANCE, CHEMICAL PLATFORM OF ROUSSILLON

CS Meeting on « Heat Recovery »

26/02/2021

suez

Contents

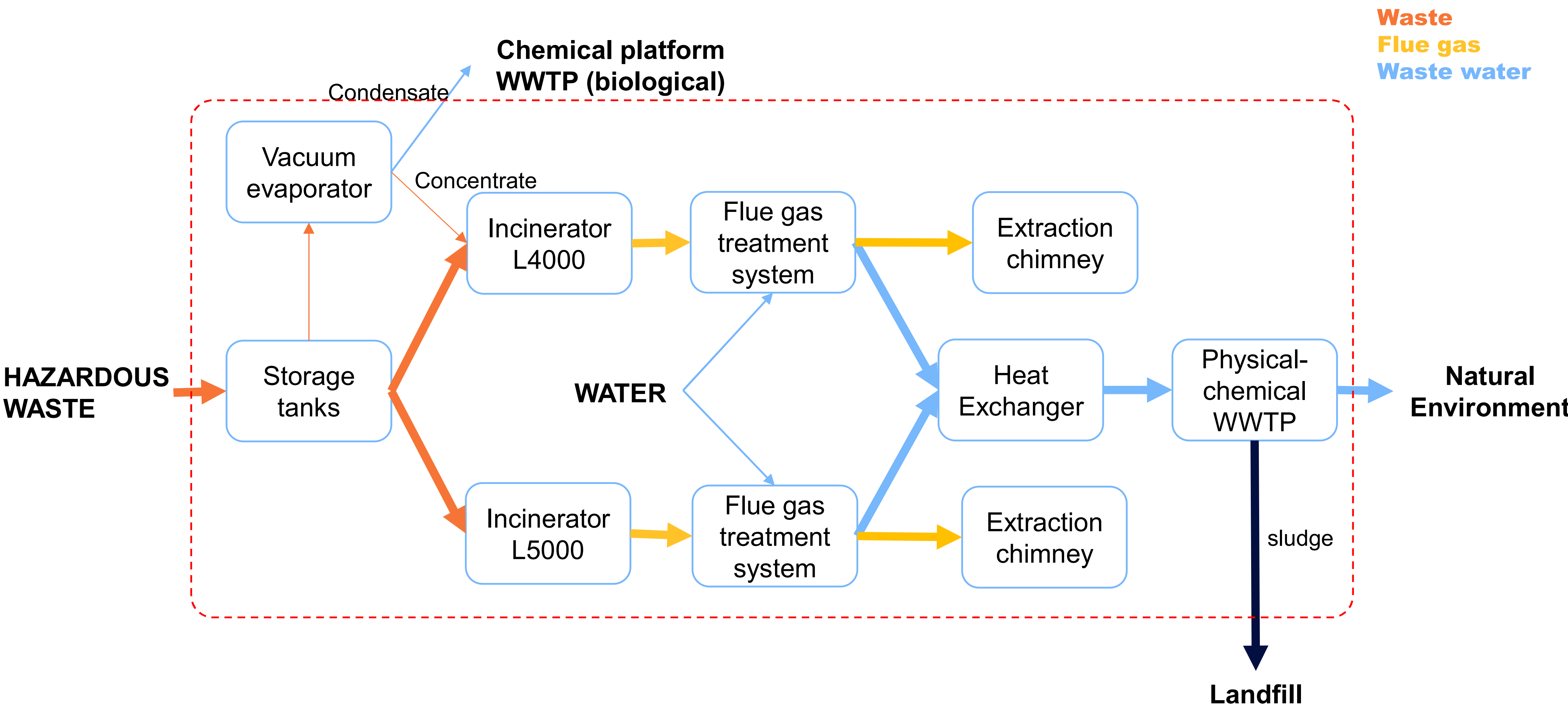
The project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 859318

1.

Situation before ULTIMATE

Situation before ULTIMATE

THERMAL TREATMENT OF INDUSTRIAL HAZARDOUS WASTE



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Situation before ULTIMATE

VALORISATION

No steam production, due to the high ash content of waste

Heat recovery from water used for flue gas treatment to evapo-concentrate a few part of aqueous waste

No material recovery

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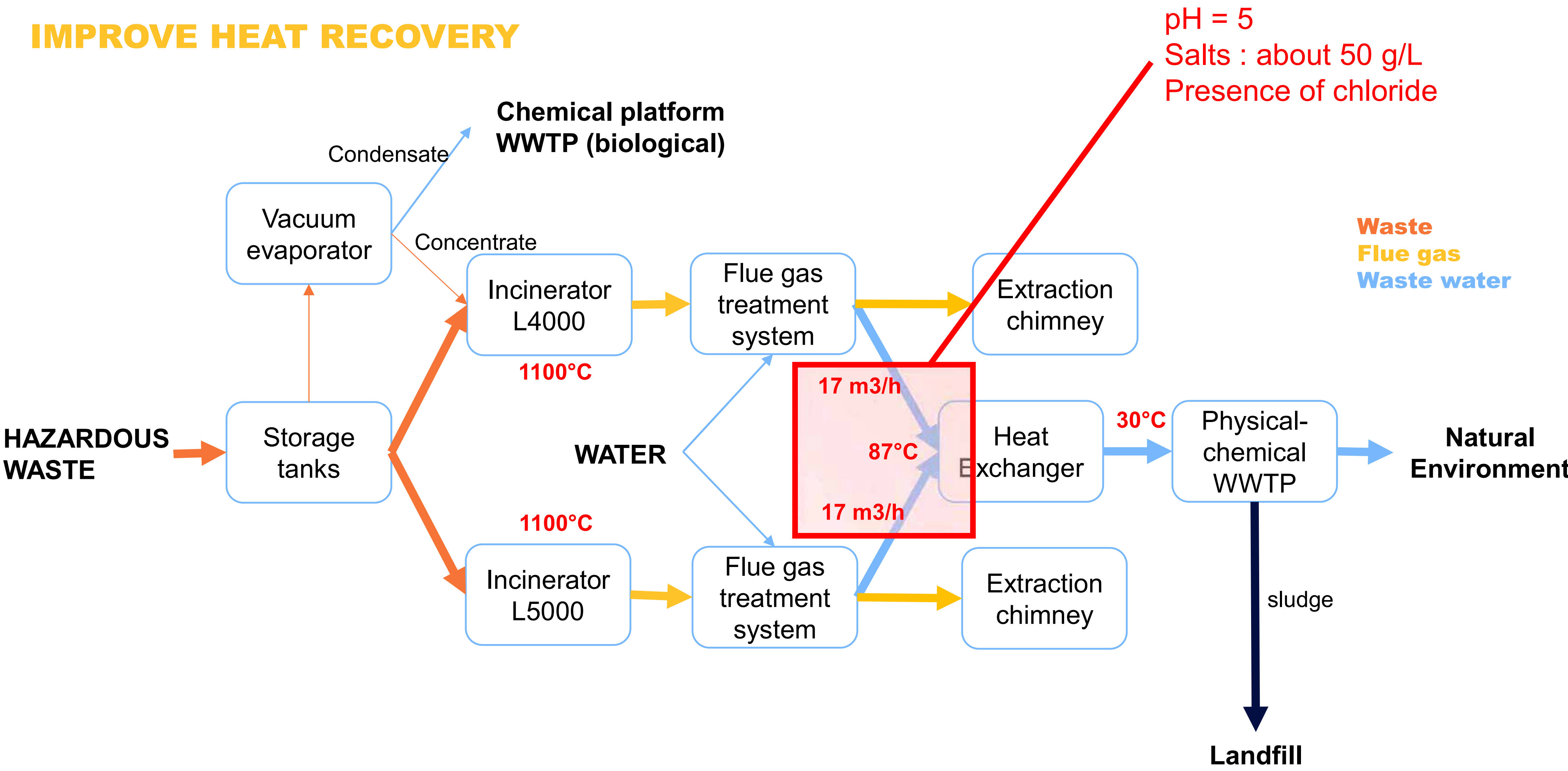
2.

Objectives of ULTIMATE

Objectives of ULTIMATE

IMPROVE HEAT RECOVERY



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Objectives of ULTIMATE

ENERGY USE ON SITE

Electricity

- For equipment : pumps, agitators…
- For instrumentation : valves, sensors…
- For electric tracing of pipes
- For lighting…

Vapor

- To preheat combustion air
- Pipe cleaning
- …

→

FORM OF ENERGY RECOVERED

Electricity

Vapor

Heat

The project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 859318

Objectives of ULTIMATE

SOME IDEAS :

Combustion air preheating (via heat exchanger)

Sludge preheating to improve dryness of the pressed sludge at the filter press outlet

Power generation by the mean of :

- **Organic Rankine Cycle**
- **Stirling engine**
- **Thermoelectric generators**
- **...**

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Objectives of ULTIMATE

EVALUATE THE POTENTIAL RECOVERY OF THERMAL ENERGY :

Feasibility study report including :

- **a technical solution (or advantages and disadvantages matrix)**
- **investment cost and operating cost (€)**
- **recovery form (electricity, steam, heat) and use**
- **energy recovery rate (%)**
- **reduction of energy consumption (%) and resulting profits (€)**

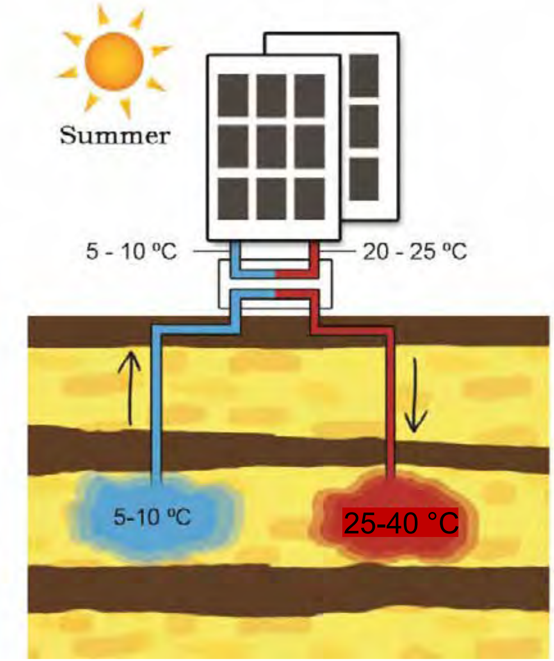
The project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 859318

THANKS FOR YOUR ATTENTION

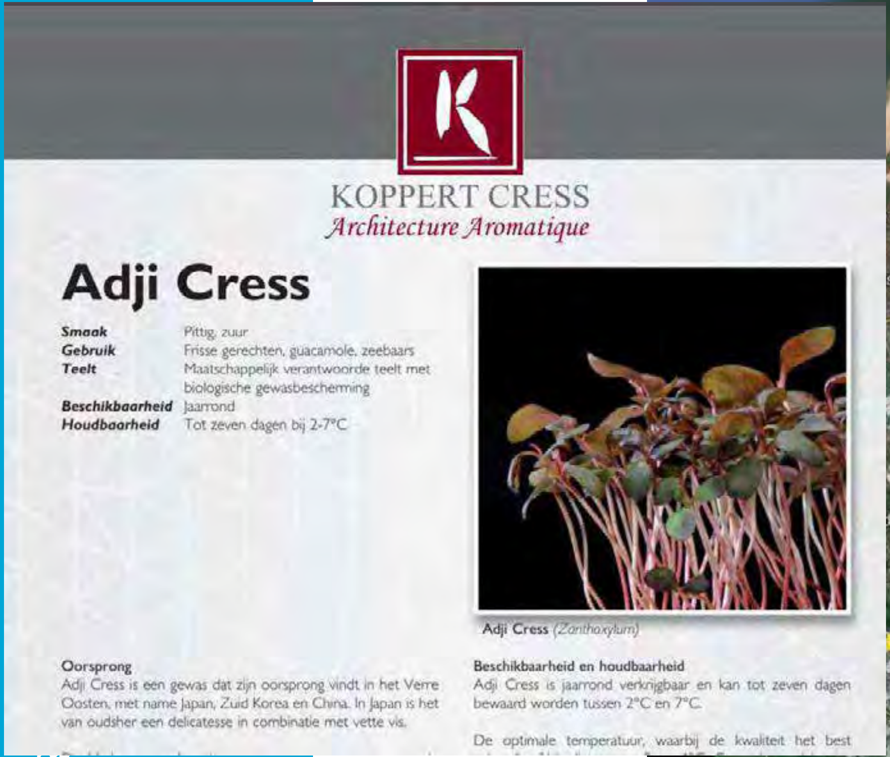
SUEZ.com

(HT-)ATES system of Koppert-Cress

Dr. Martin Bloemendal
26-02-2021



Koppert-Cress (KC) pilot


KOPPERT CRESS
Architecture Aromatique

Adji Cress

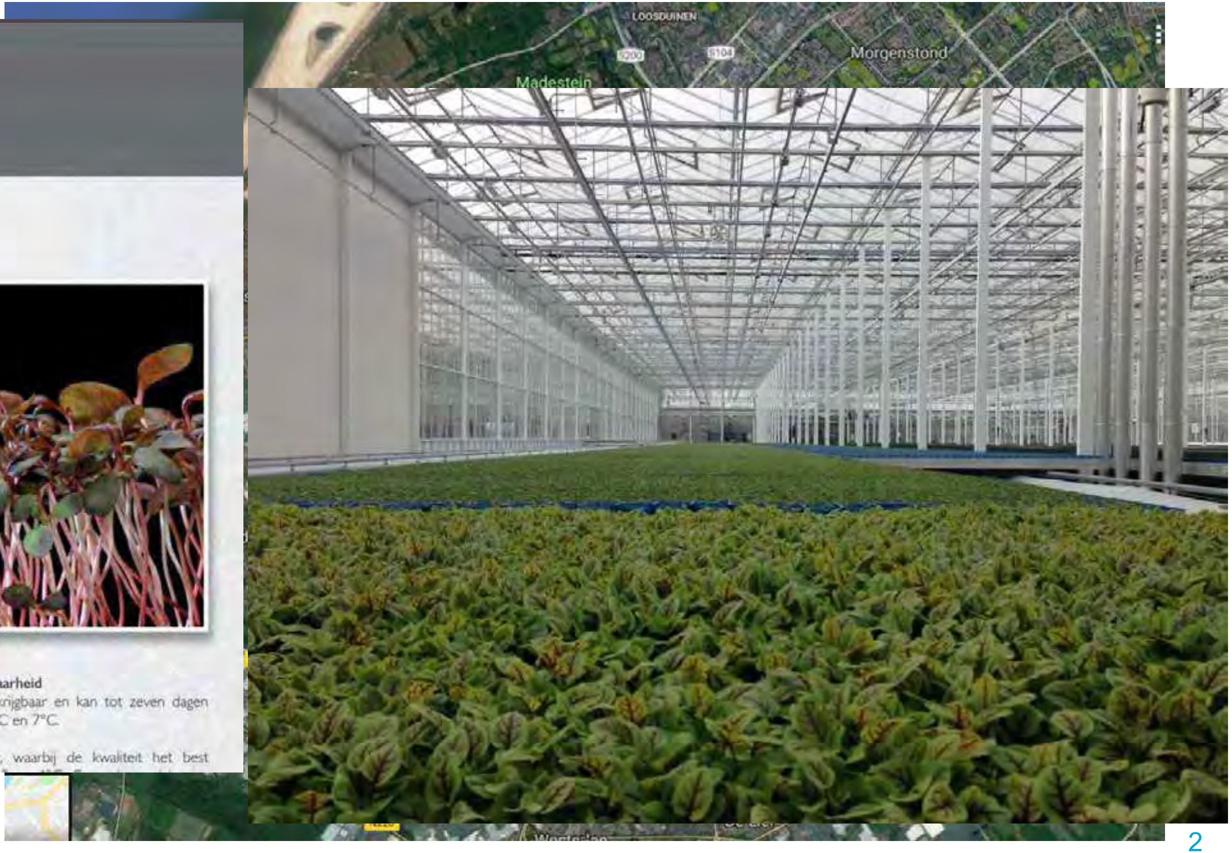
Smaak	Pittig, zuur
Gebruik	Frisse gerechten, guacamole, zeebaars
Teelt	Maatschappelijk verantwoorde teelt met biologische gewasbescherming
Beschikbaarheid	Jaarrond
Houdbaarheid	Tot zeven dagen bij 2-7°C

Adji Cress *(Zanthoxylum)*

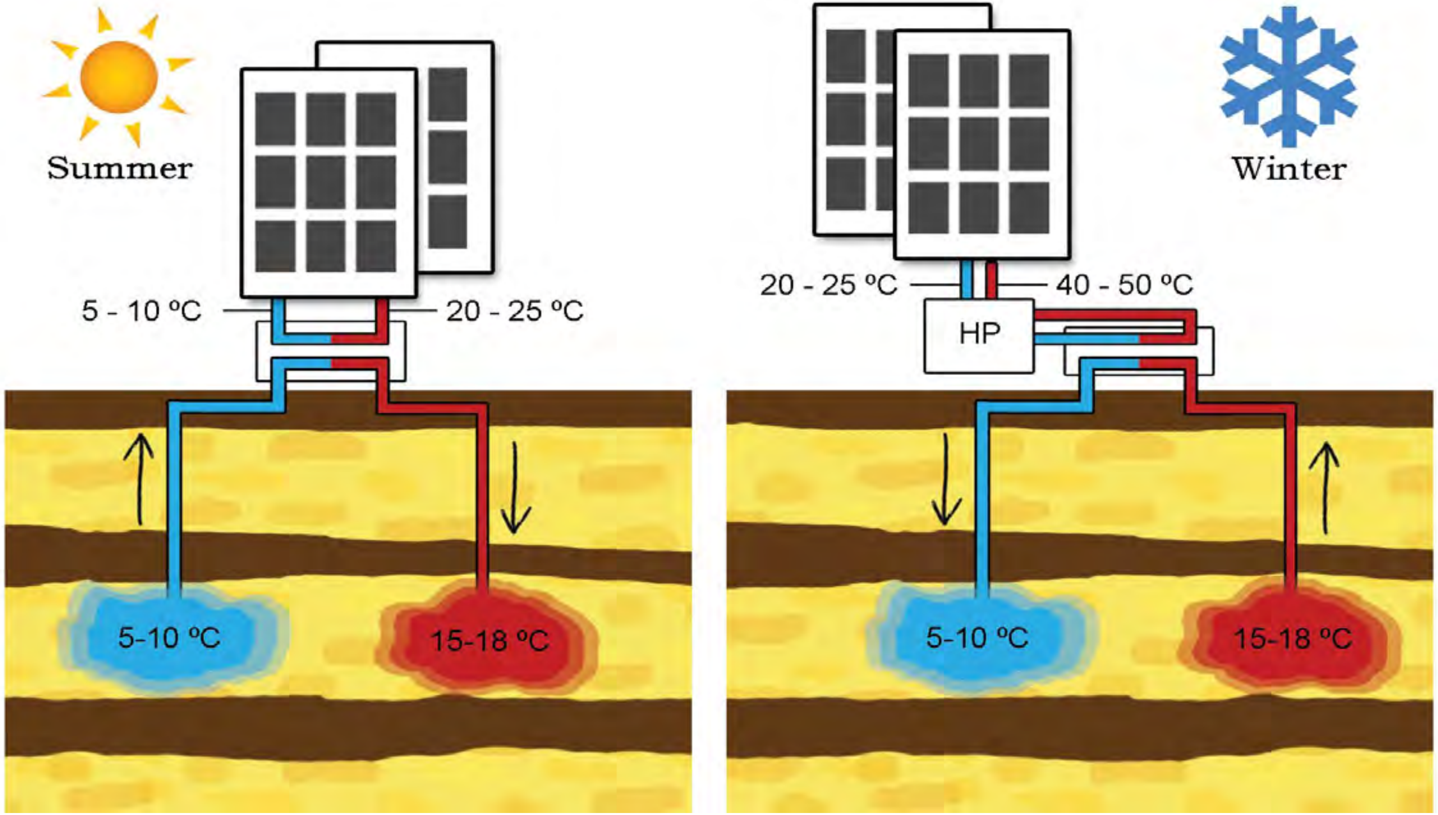
Oorsprong
Adji Cress is een gewas dat zijn oorsprong vindt in het Verre Oosten, met name Japan, Zuid Korea en China. In Japan is het van oudsher een delicatesse in combinatie met vette vis.

Beschikbaarheid en houdbaarheid
Adji Cress is jaarrond verkrijgbaar en kan tot zeven dagen bewaard worden tussen 2°C en 7°C.

De optimale temperatuur, waarbij de kwaliteit het best



ATES



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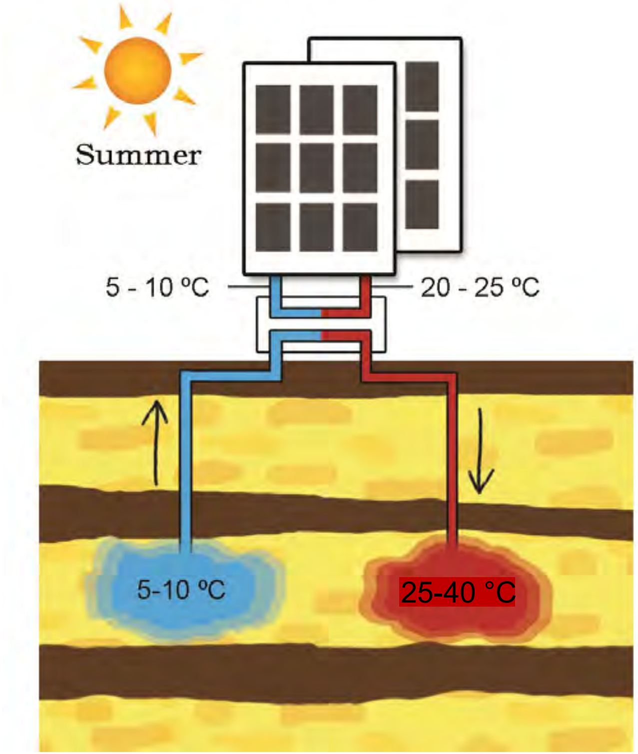
Koppert-Cress: HT-ATES pilot

- >25°C
- Permitted
  as “pilot-project”
- max 40°C
- Goal: Performance & monitor impact



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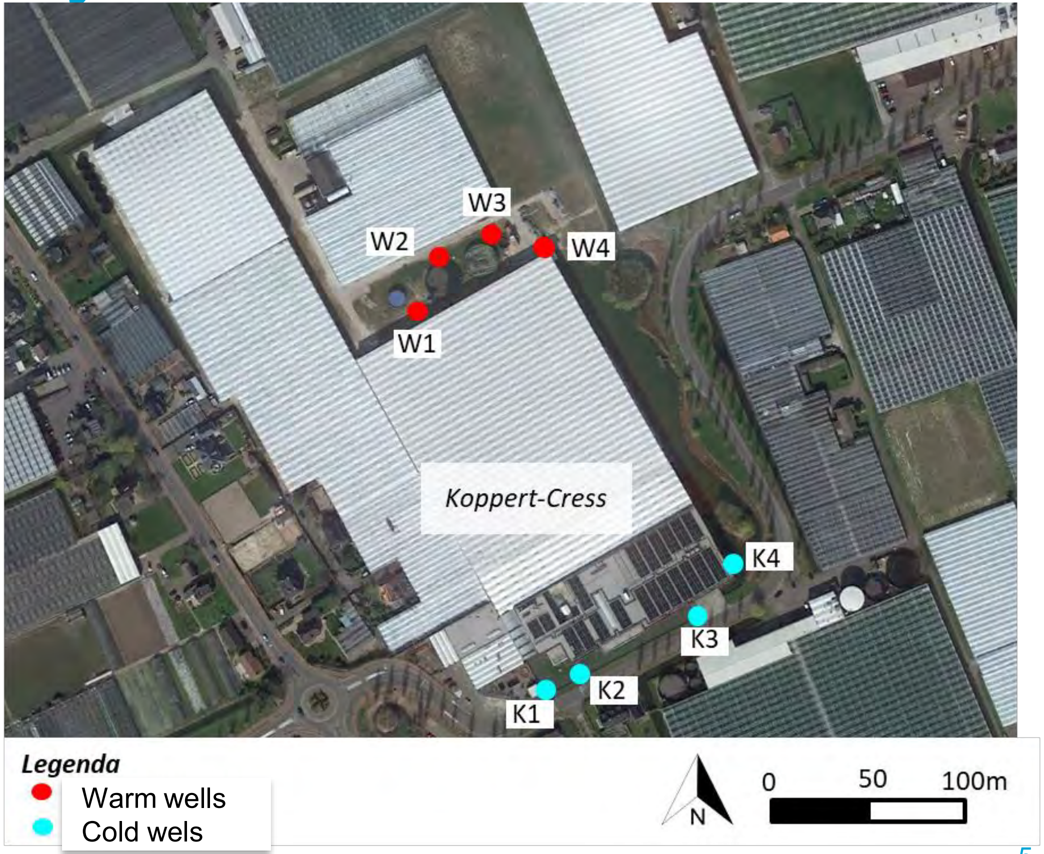
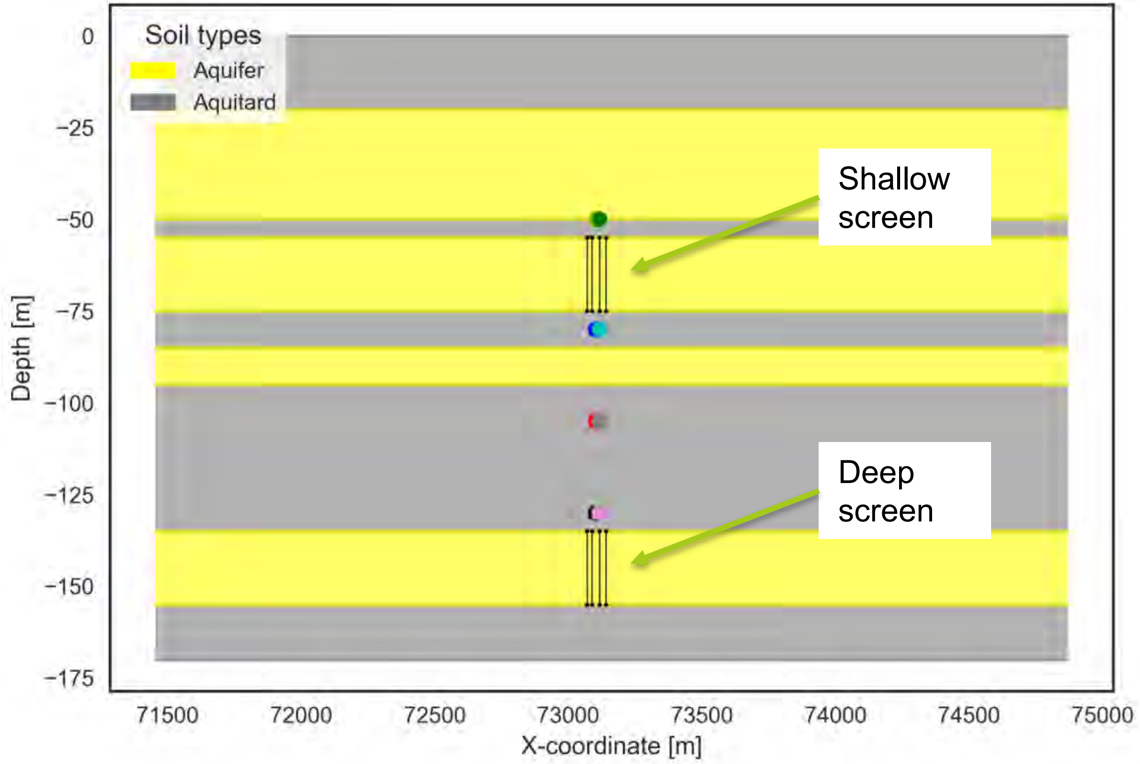
The ATES system of KC



KWR

TU Delft

The ATES system of KC



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The transition to HT-ATES

- Heating demand > Cooling demand
  - System not in balance
- Add extra (HT) heat
- Transition: storage temperature increases after 2015

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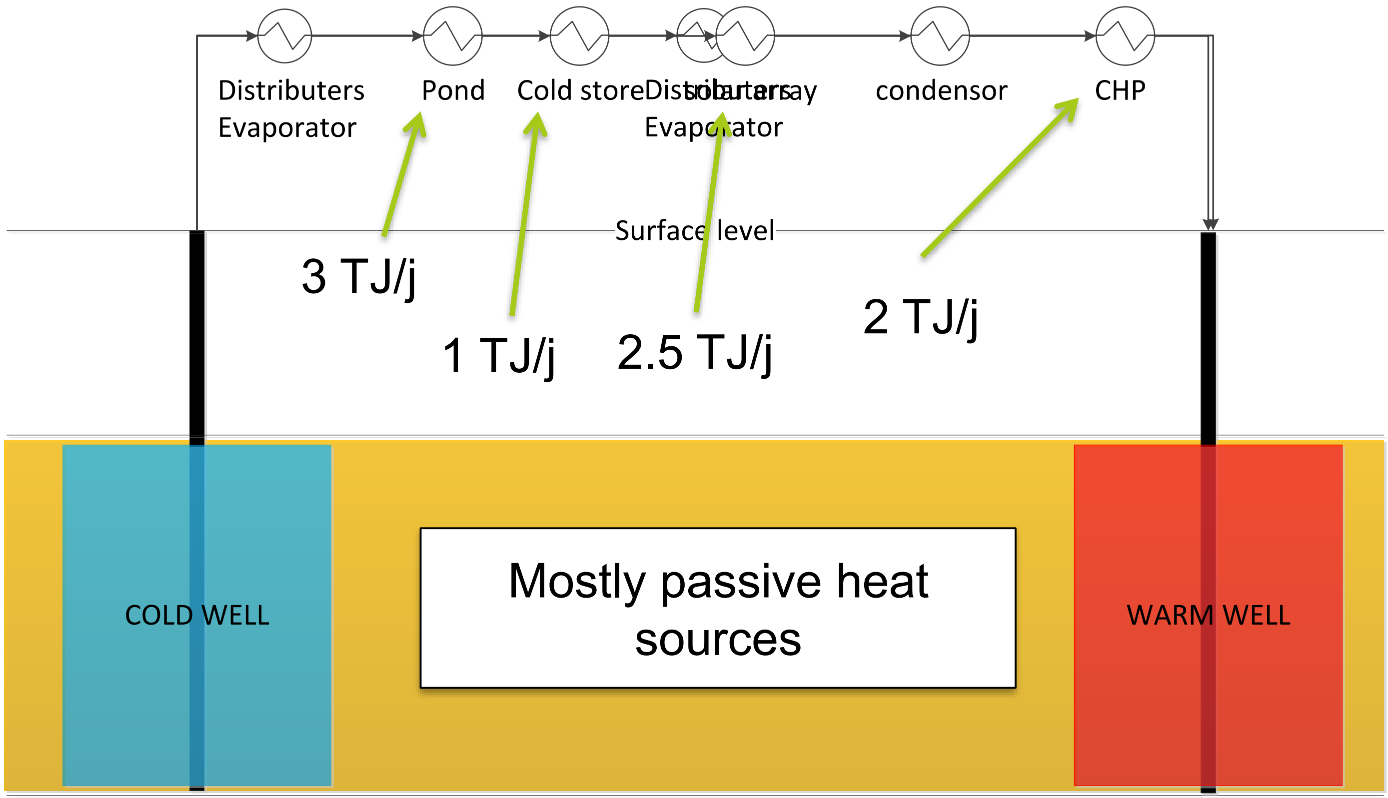
Extra heat and higher temperature



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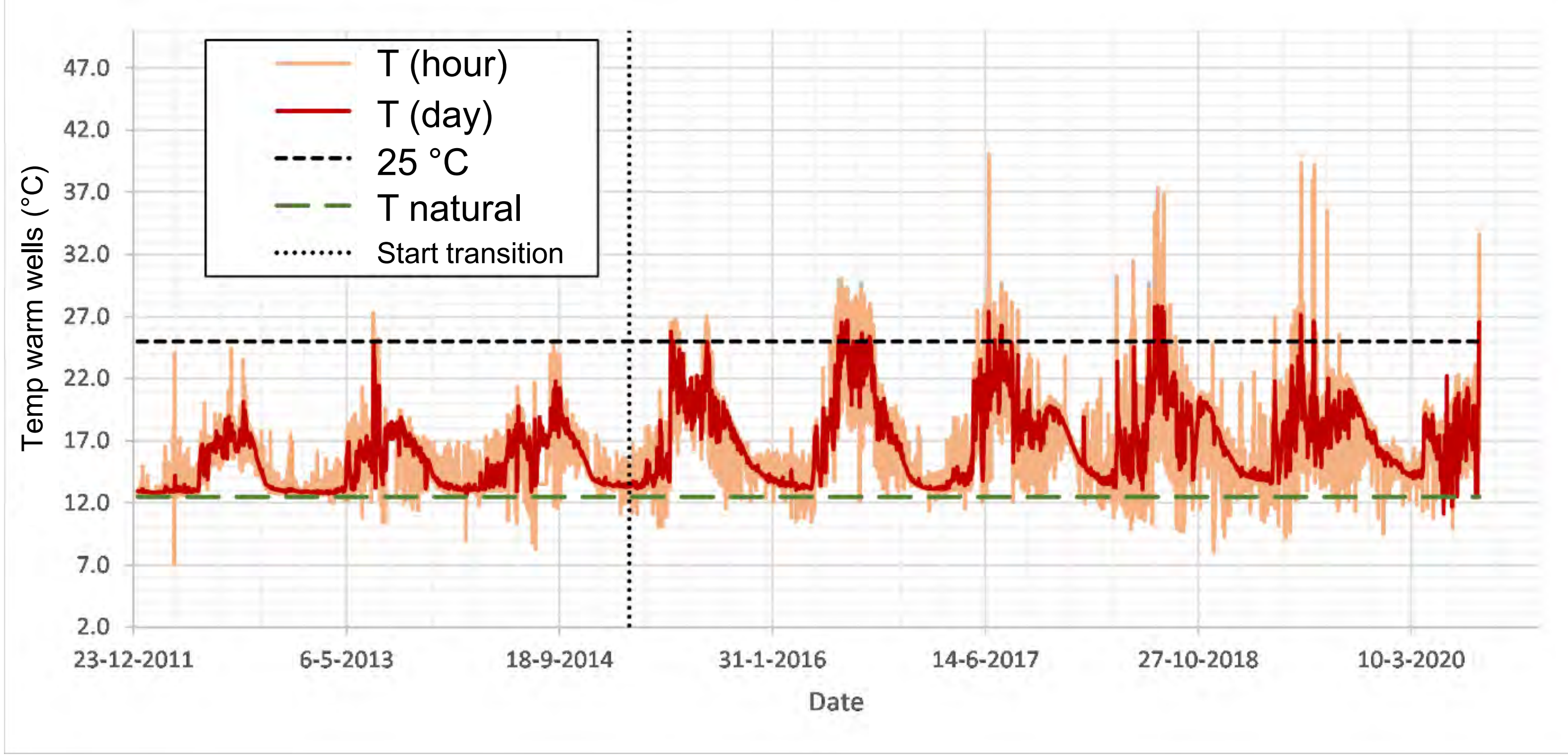
TUDelft

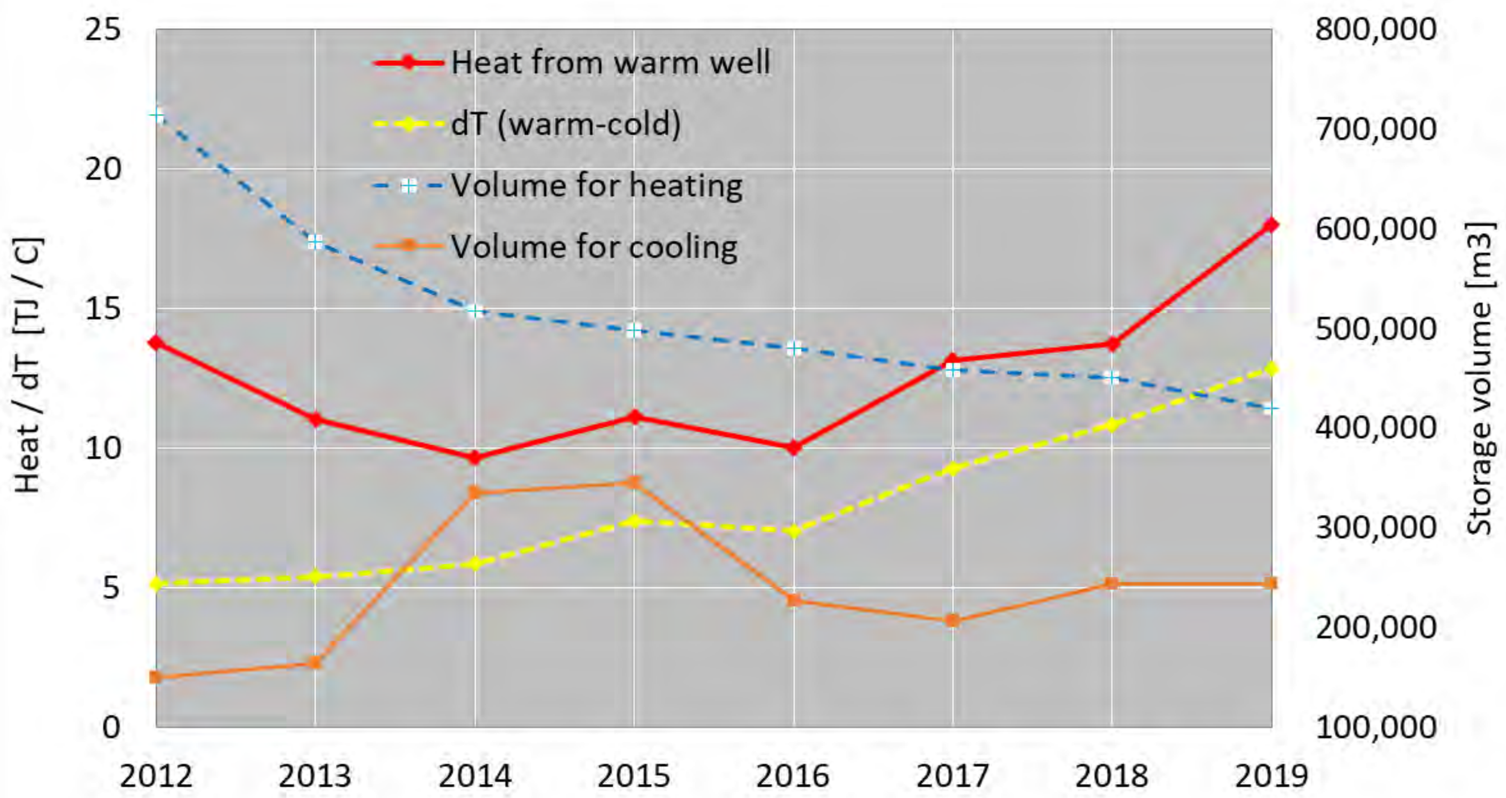
Increasing T_{in} & ΔT



KWR

TUDelft

Increasing T_{in} & ΔT



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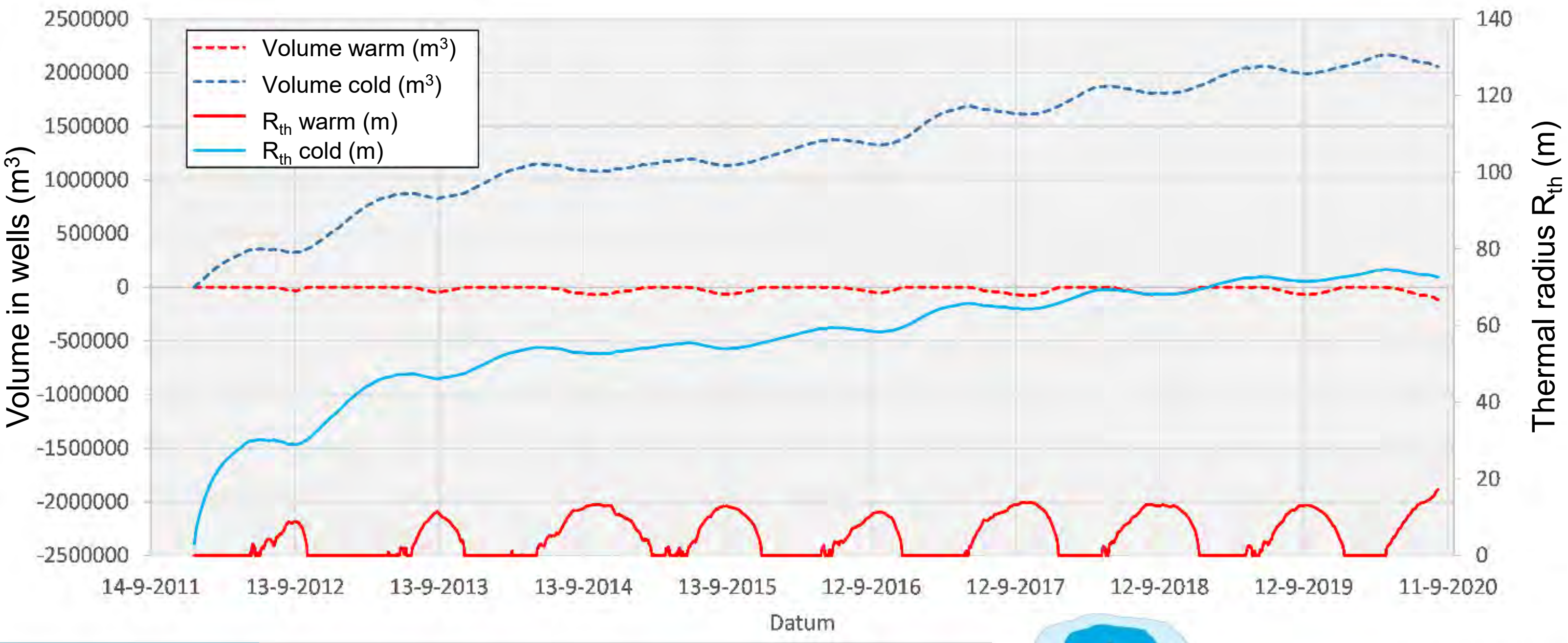
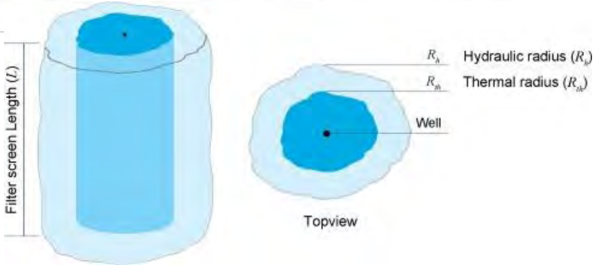
ATES system not in balance





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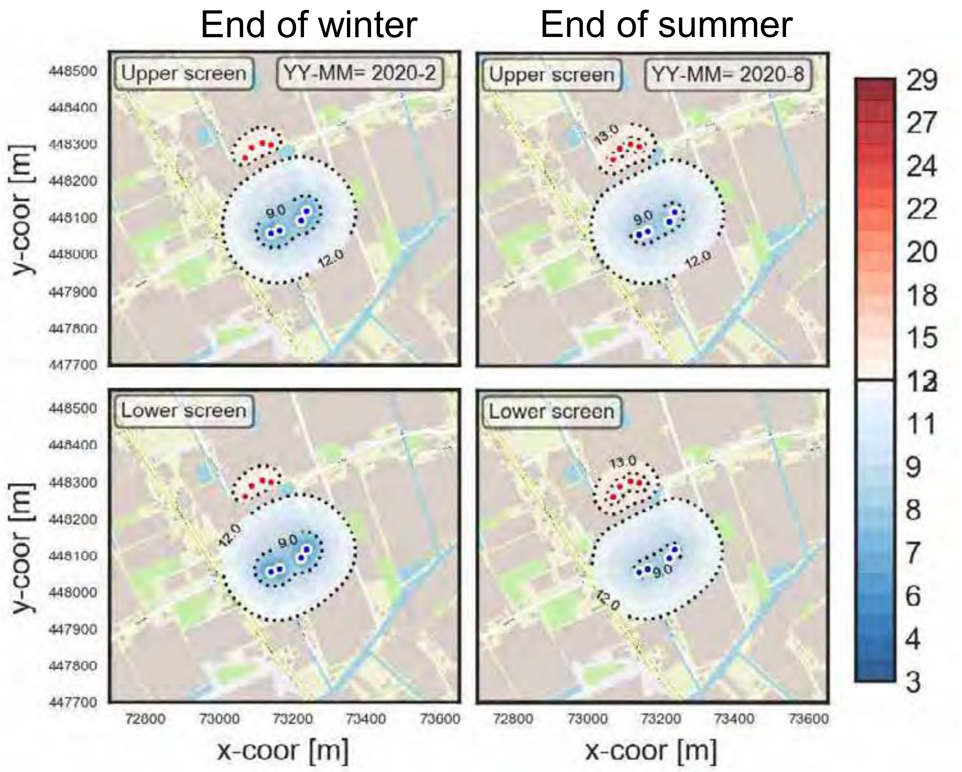
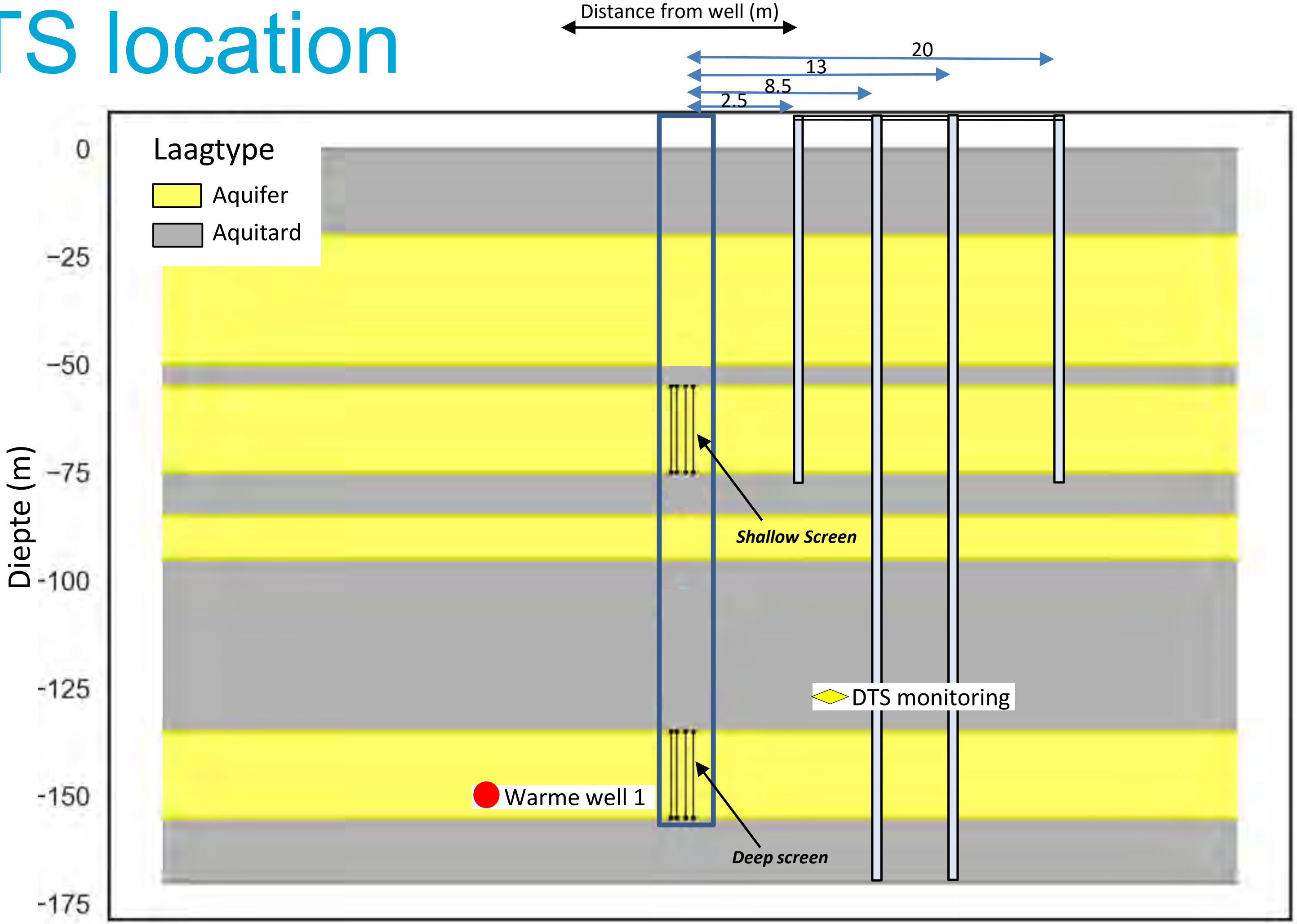
ATES system not in balance



nitoring system

TU Delft

DTS location



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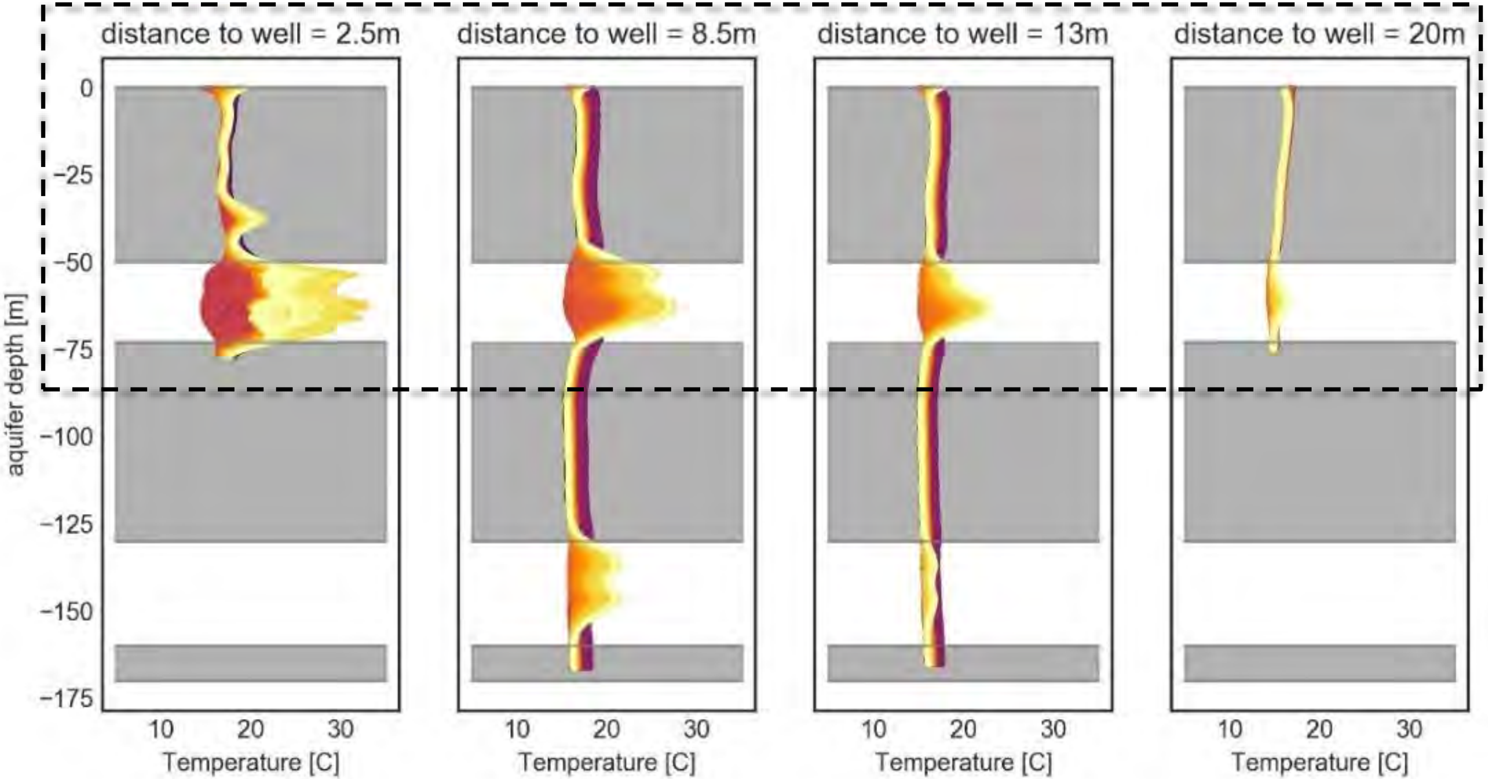
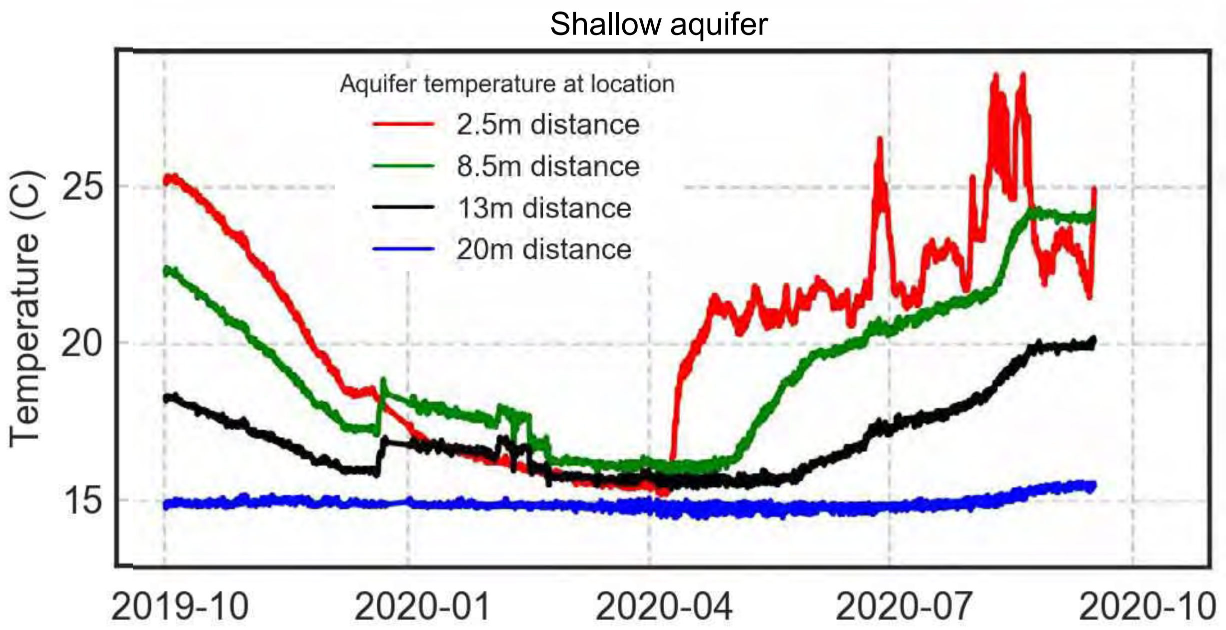
DTS monitoring



Summer 2020

Thermal impact: horizontal



<u>Long-term horizontal impact is small</u>

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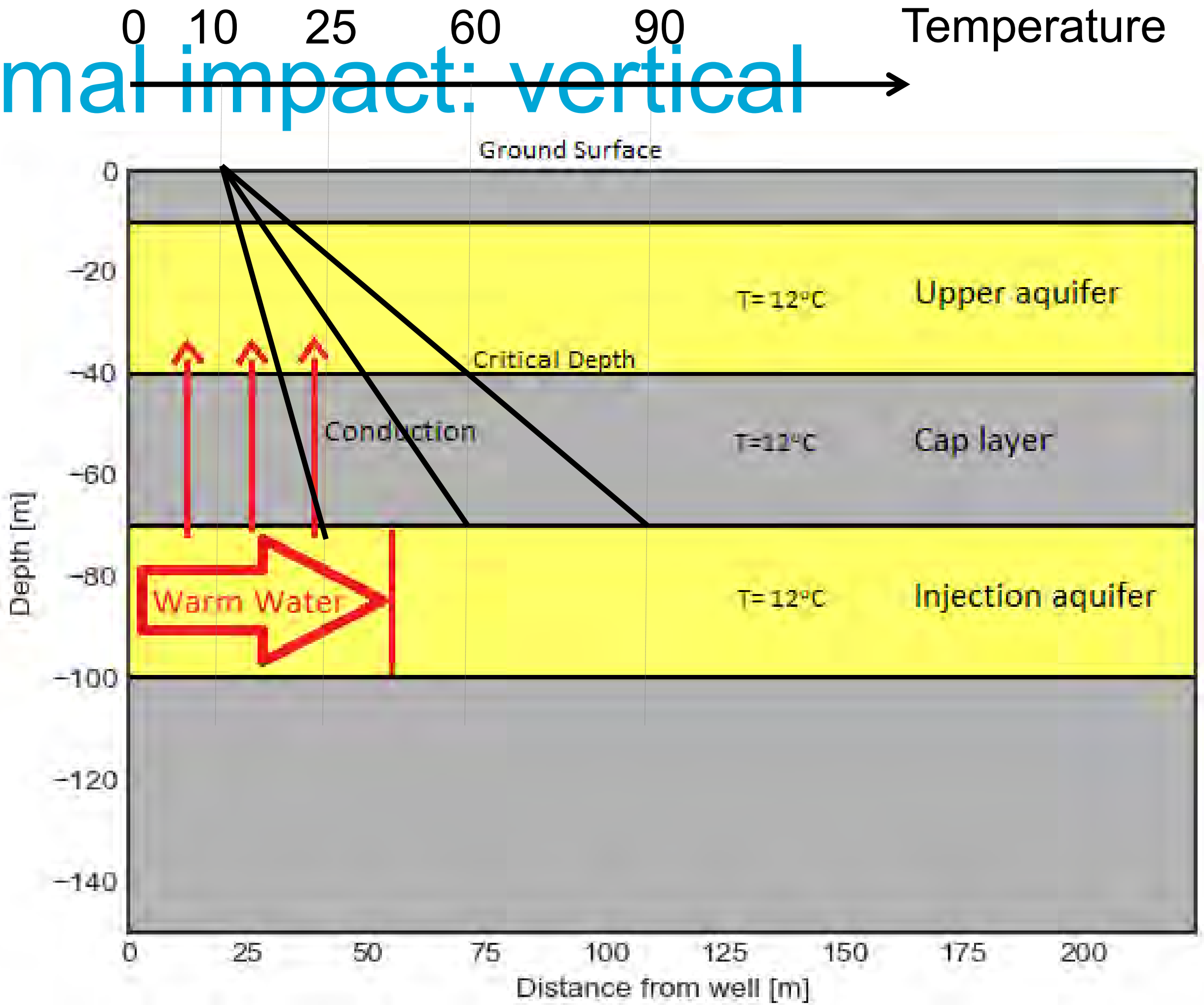
TU Delft

Thermal impact: vertical

Reference:
Steady state conduction through clay layer



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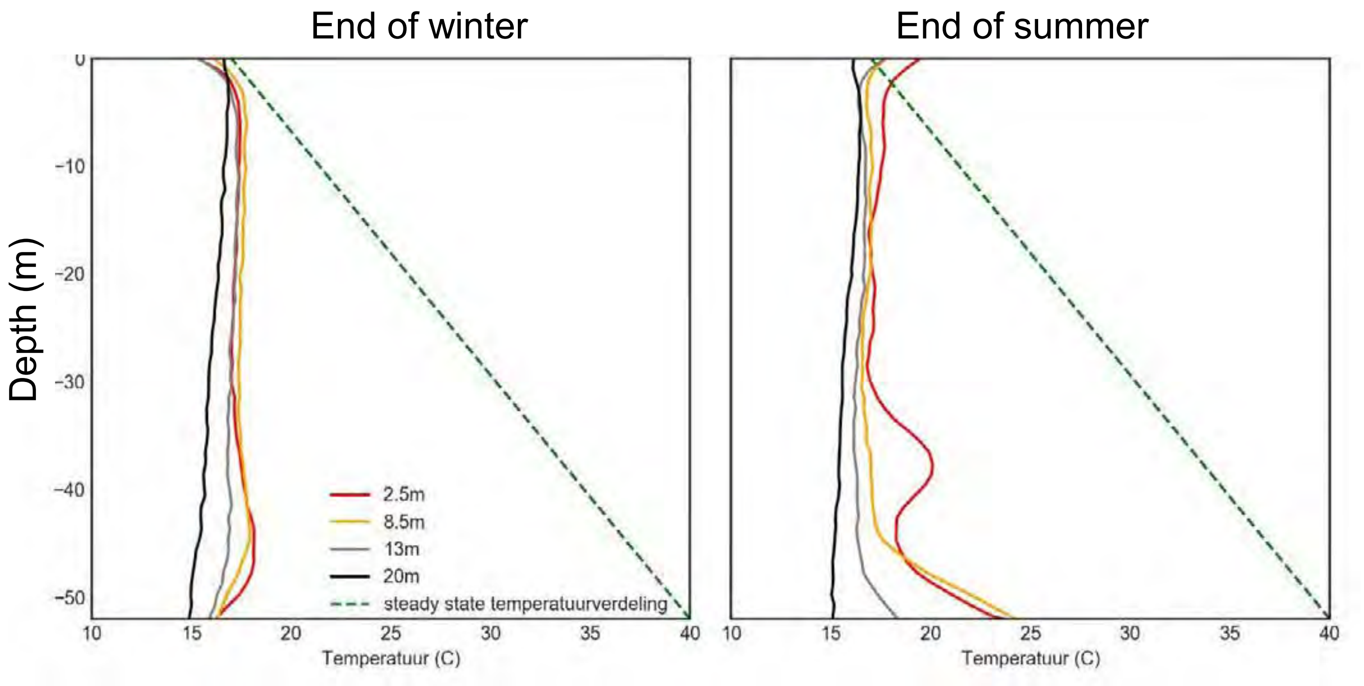
Thermal impact: vertical



<u>Long-term vertical impact is small</u>

KWR

TU Delft

Conclusions

- Inbalanced system can be efficiently compensated with external heat
- Thermal impact is small
  - All heat is extracted
  - <40C
- DTS Monitoring:
  - Suitable to measure temporal Temp differences

KWR

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What else did we investigate?

- Performance of heating/cooling system
  - 10% lower operational costs
  - 30-70% less GHG
- Groundwater monitoring
  - Chemical analysis
  - Micro-biological analysis

https://library.kwrwater.nl/publication/61755396/

Future research for this case-study

The transition is not done yet…

- Future: more heat available (geothermal energy)
- More heat in warm wells: balance
- Long-term heating of subsurface around warm wells
- Continue monitoring → to be continued!

KWR
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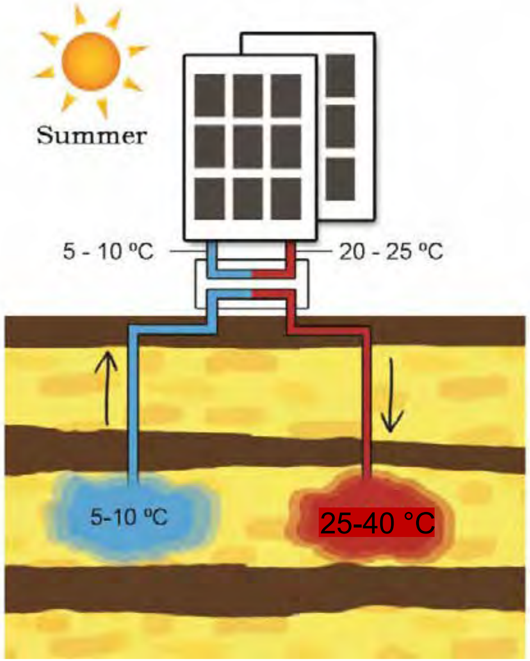
(HT-)ATES system of Koppert-Cress

Dr. Martin Bloemendal
Martin.Bloemendal@kwrwater.nl
+31625179849



The content of this presentation: *Bloemendal, J.M.Beernink, S. Bel, N. van Hockin, A.E.Schout, G. (2020). Transitie open bodemenergiesysteem Koppert-Cress naar verhoogde opslagtemperatuur. Evaluatie van energiebesparingen en grondwatereffecten. KWR RAPPORT - KWR 2020.156*

Contributions from: Stijn Beernink & Niels Hartog

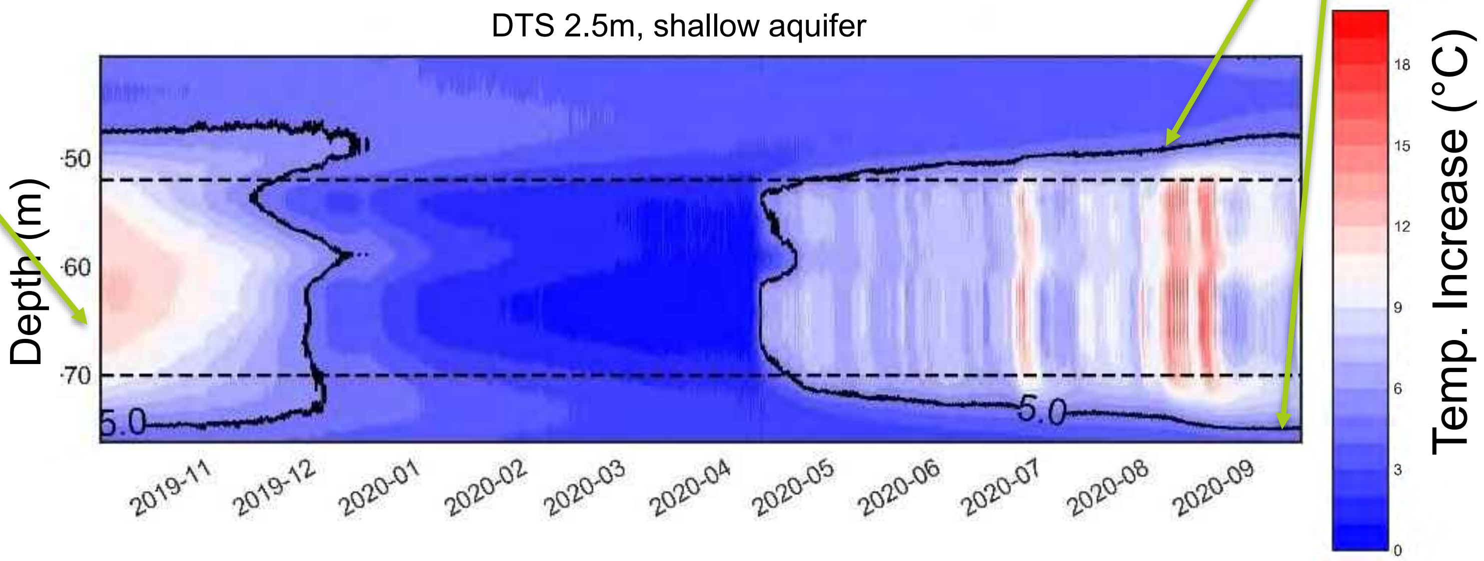
KWR

TU Delft

Thermal impact: vertical

aquifer

aquitards



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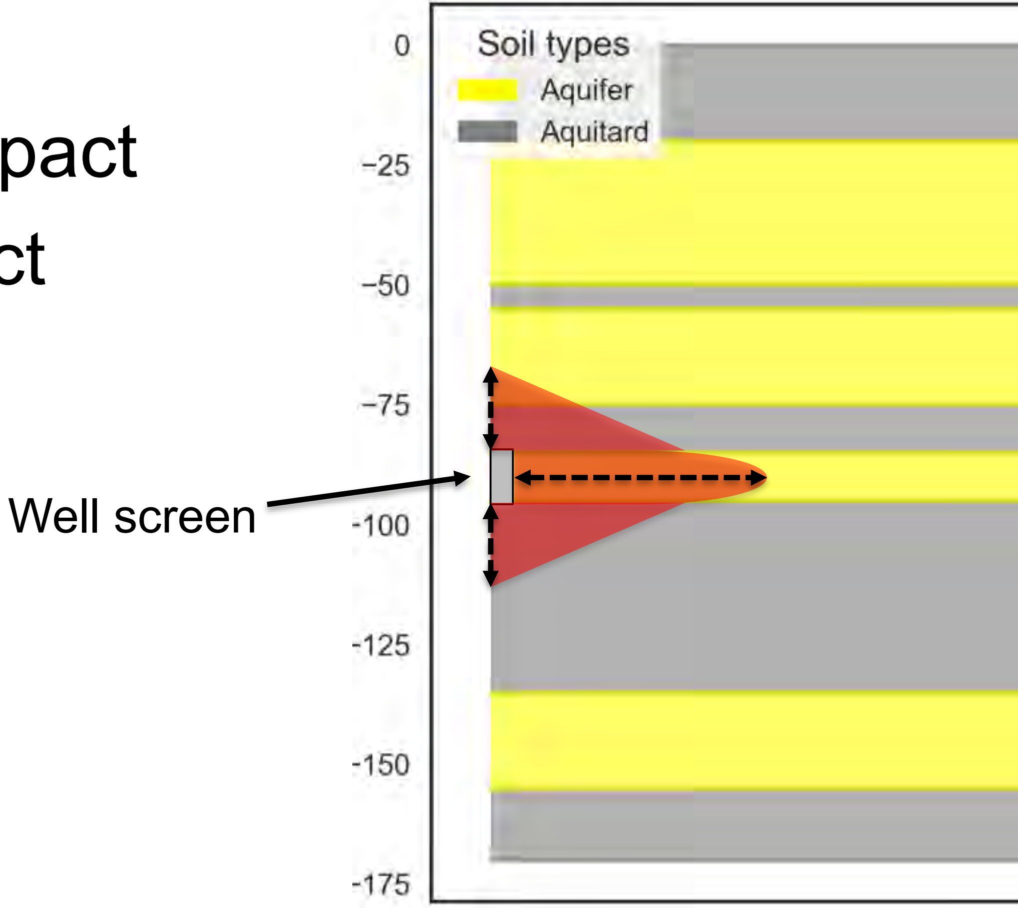
From temperature data to thermal impact

- Horizontal impact
- Vertical impact



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TUDelft

How to avoid corrosion and scaling in ATES systems in Germany?

Hilke Würdemann, Christoph Otten, Beate Dassler, Tobias Lienen, Anne Kleyböcker, Anja Narr, Anke Westphal, Stephanie Lerm and Sebastian Teitz

Hochschule Merseburg

HOME HOCHSCHULE MERSEBURG University of Applied Sciences

Microorganisms (MO) vs. technical applications

- Development of biofilms → Clogging of pipes, filters, heat exchangers
- Interaction of metal surface, chemical corrosion products, MO, metabolites → Microbial induced/influenced corrosion
- Mineral precipitation → Loss of well injectivity
- Mineral dissolution → Increase in porosity and permeability
- Degradation of scaling inhibitors → Less environmental impact

gefördert vom Bundesministerium für Wirtschaft und Energie aufgrund eines Beschlusses des dt. Bundestags

PtJ Projektträger Jülich Forschungszentrum Jülich

Würdemann *et al.* 2016

Molecular biological analysis: characterization of the microbial community composition and quantification

Samples

→

DNA

PCR →

DNA-Fragment Amplification

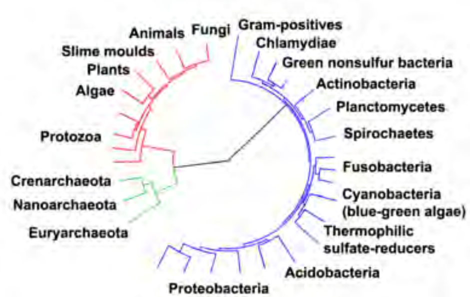
Genetic Fingerprinting

MO1
MO2
MO3
MO4

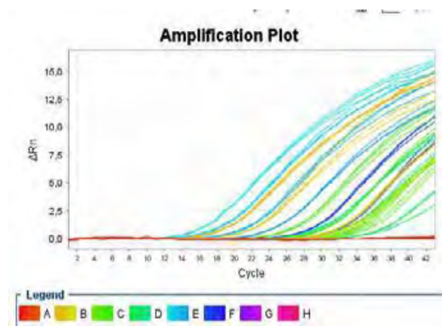
Sequenzing

↓

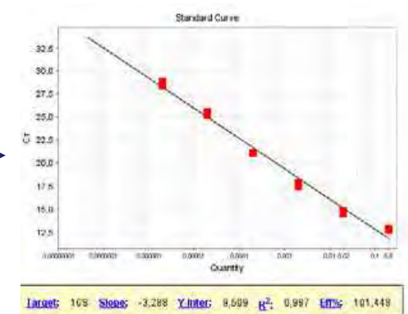
DNA Data base



Quantitative real-time PCR

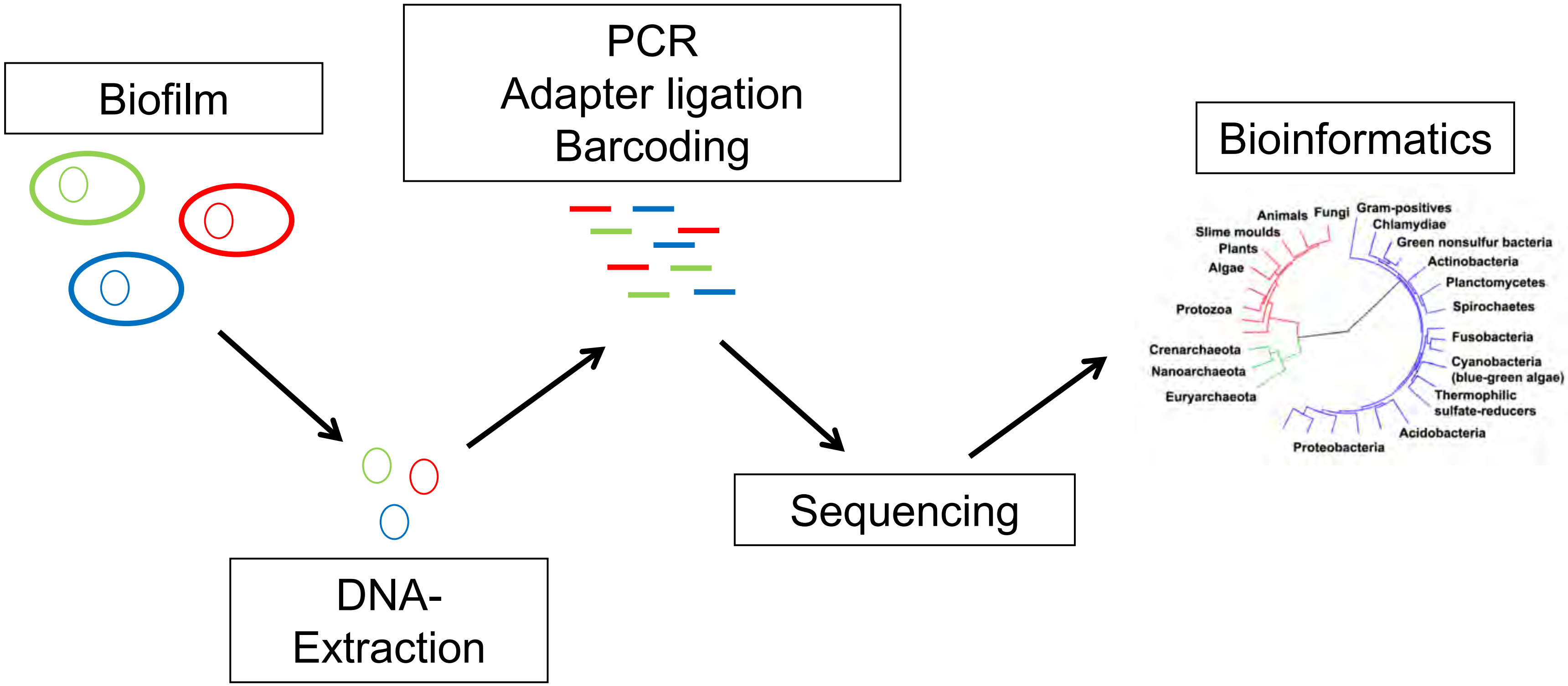


→



- Relative quantification related to the total community
- Absolute quantification of species or groups

Microbiom analysis of Fluids and Biofilms



gefördert vom Bundesministerium für Wirtschaft und Energie aufgrund eines Beschlusses des dt. Bundestags

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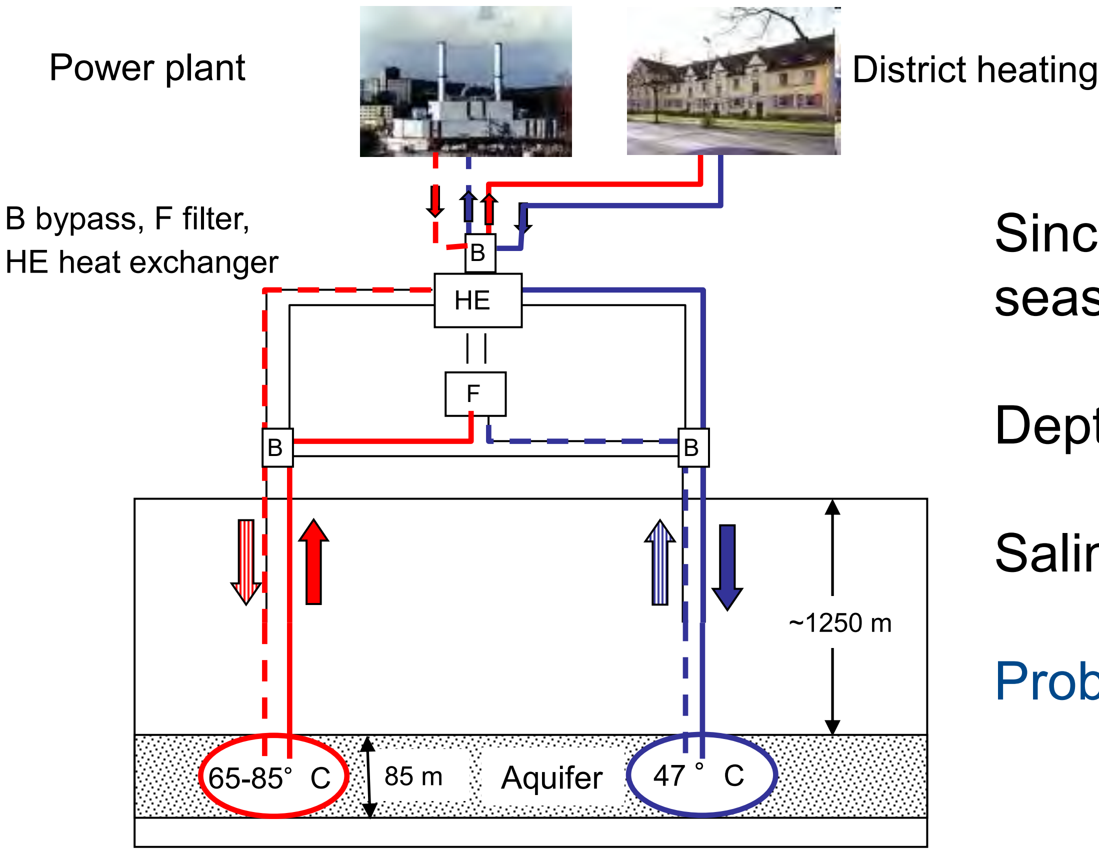
HoME Hochschule Merseburg University of Applied Sciences

Geothermal Heat Store Neubrandenburg



Schematic illustration

Since 2004 operated in seasonal mode (charge/decharge)

Depth: 1,250 m

Salinity: 130 g/L

Problems: Corrosion in the “Cold“ well

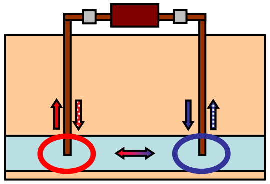
Lerm *et al.* 2014

2007-2011	T [°C]	pH [-]	Na^+ [$g\ l^{-1}$]	Cl^- [$g\ l^{-1}$]	NO_3^- [$mg\ l^{-1}$]	SO_4^{2-} [$mg\ l^{-1}$]	Fe^{2+} [$mg\ l^{-1}$]
Cold well (CW)	46.7	6.1	47.0	78.5	b.d.l.	912	16.9
Warm well (WW)	73.2	6.0	47.2	78.5	b.d.l.	983	14.7

Corrosion and Scaling in the “cold well”

Microorganismen involved?

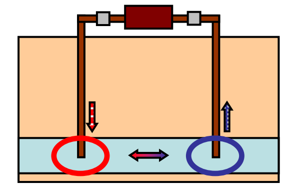
Effects of plant downtime



Causes	Date	Duration days]
Restart after pumping test	Apr 11	6
Technical defect during charge mode	Sept 11	28
Change of operation mode	Mar 12	7
Technical defect during charge mode	Aug 12	19
Change of operation mode	May 13	10
Technical defect during charge mode	Jun 13	32

Westphal *et al.* 2016

Geothermal fluid and mineral properties – during restart –



Measurements after restart after produced volume [m^3]	SO_4^{2-} [$mg\ l^{-1}$]	Fe^{2+} [$mg\ l^{-1}$]	H_2S [$\mu g\ l^{-1}$]	DOC [$mgC\ l^{-1}$]	Particle load [$g\ m^{-3}$]	$\delta^{34}S_{SO4}$ (‰ CDT)
5-30	1600 ↑↑	22 ↑	375 ↑↑	98.8 ↑↑	50,000 ↑↑	25 ↑
30-490	980	17	180	2.6	0.1	----

↑ **Increased concentrations after downtime**

Westphal *et al.* 2016

Sulfate reducing and fermentative bacteria dominant members of the microbial community

Sulfate reducing bacteria (SRB)

Fermentative bacteria

Sulfur oxidizing bacteria (SOB)

→ Oxygen ingress

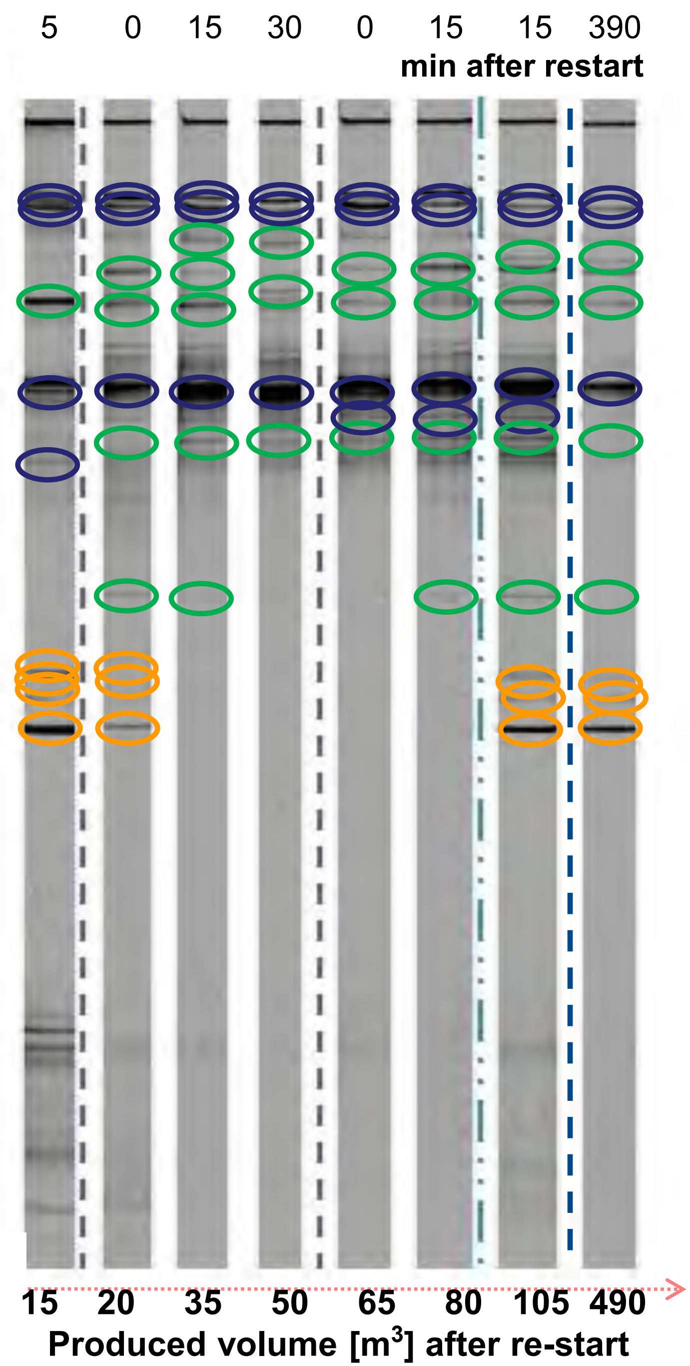
→ Sulfur cycling

→ Increased corrosion rates

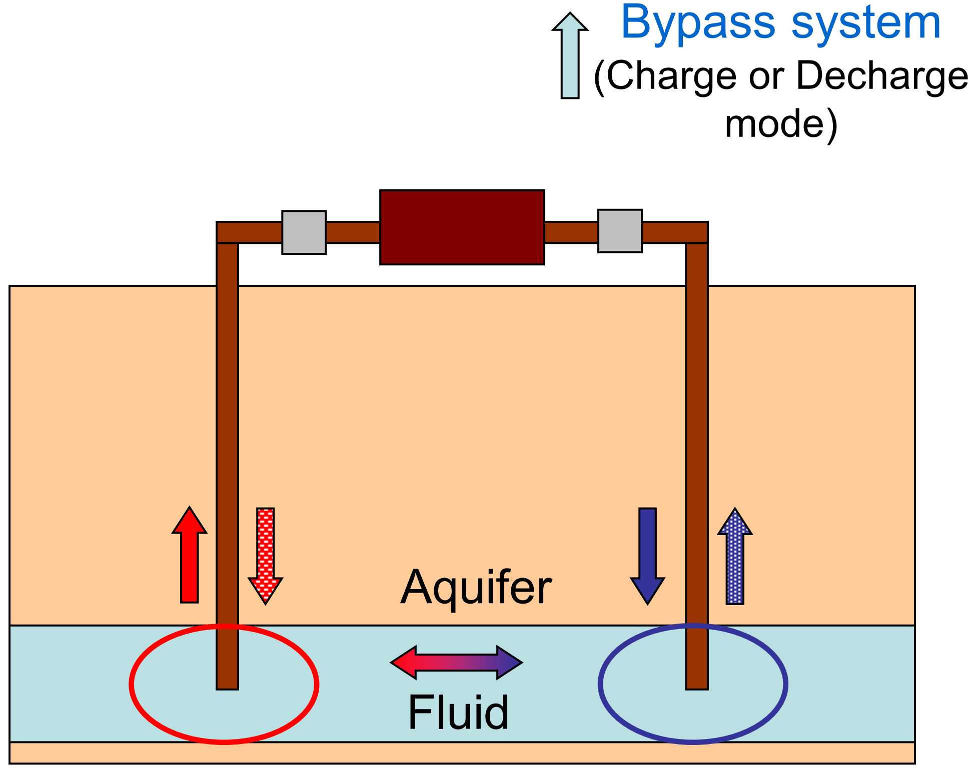
Westphal *et al.* 2016

Short stop of operation (< 3h)

Long stop of operation (19h)

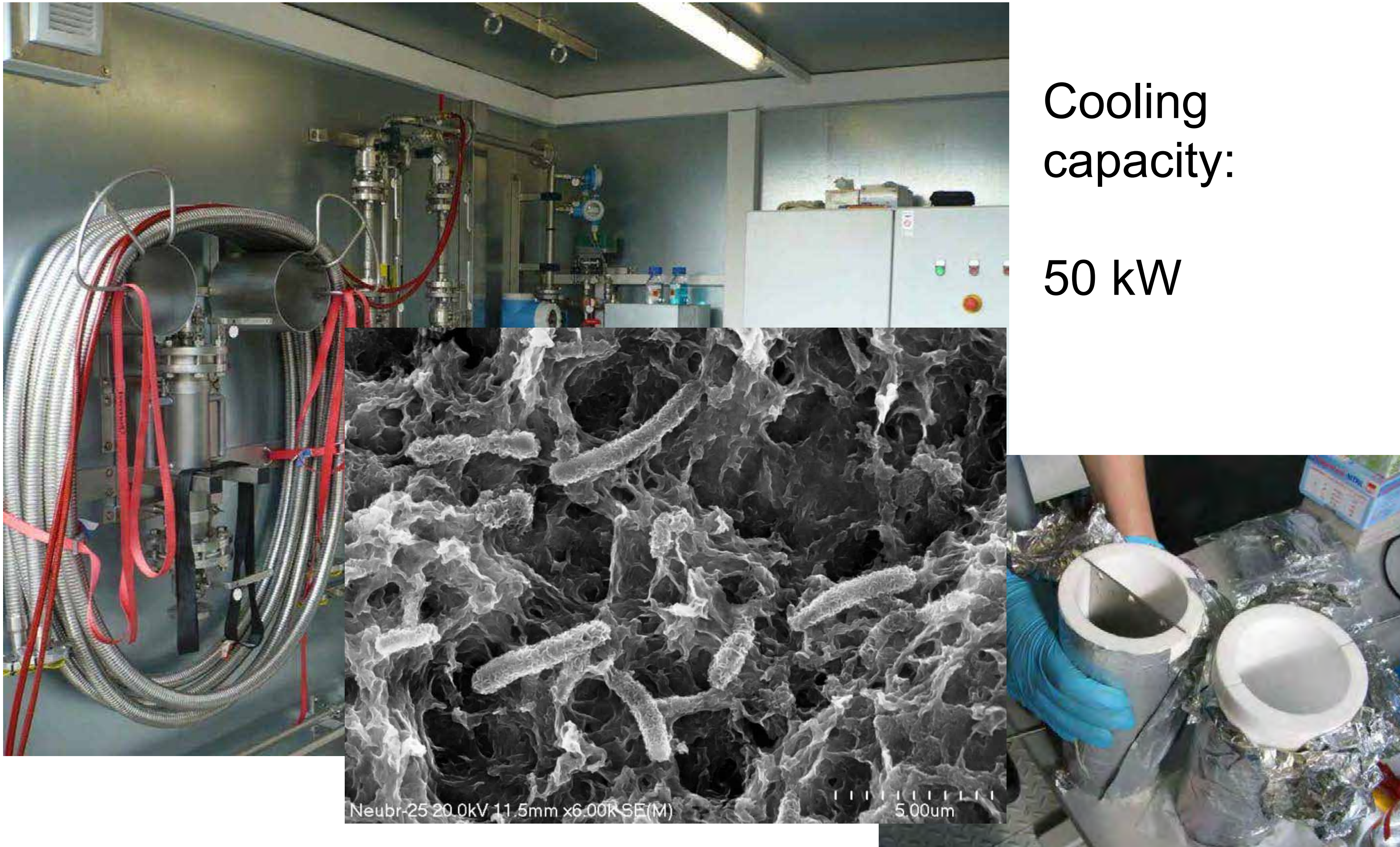


Geothermal Heat Store Neubrandenburg



2007-2011	T [°C]	pH [-]	Na^{+} [g l^{-1}]	CL^{-} [g l^{-1}]	NO_3^{-} [mg l^{-1}]	SO_4^{2-} [mg l^{-1}]	Fe^{2+} [mg l^{-1}]
Cold well (CW)	46.7	6.1	47.0	78.5	b.d.l.	912	16.9
Warm well (WW)	73.2	6.0	47.2	78.5	b.d.l.	983	14.7

Bypass system to study temperature effects on corrosion rate

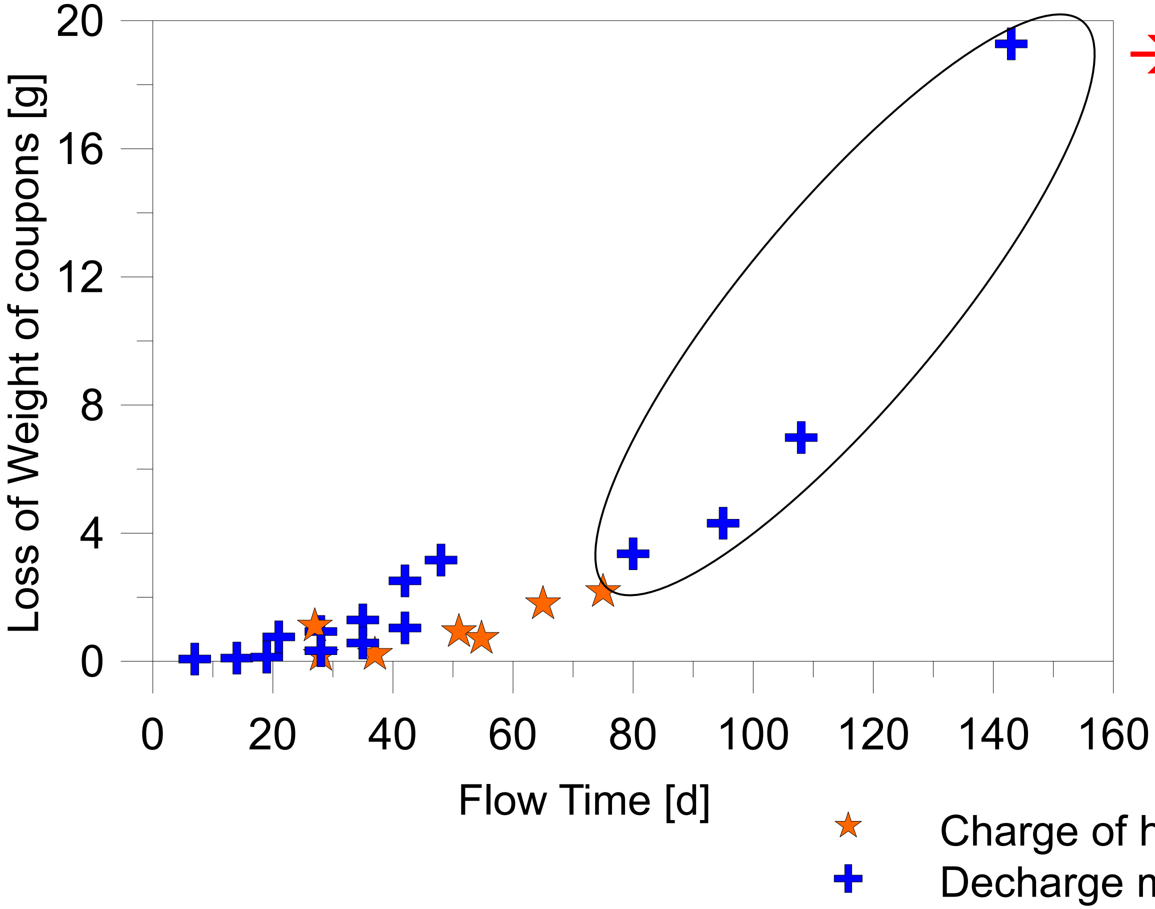


Cooling capacity:

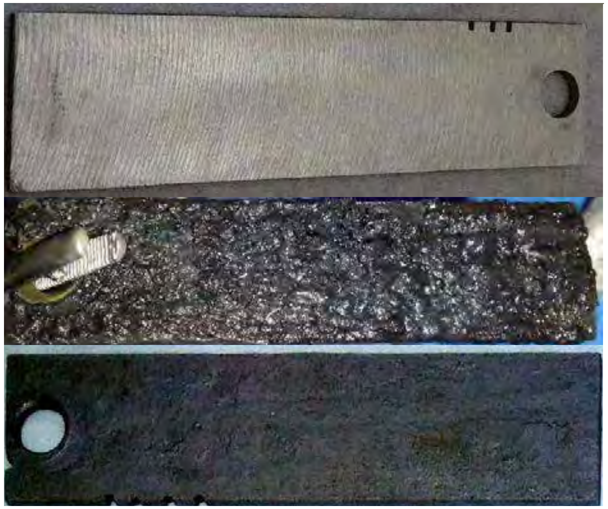
50 kW

Kleyböcker *et al.* 2017

Corrosion over Exposure Time (Flow Time)



→ Change of flow direction and different plant down times



Coupons exposed to geothermal fluid (59 days) in the bypass system:
- Effect of heat shock -

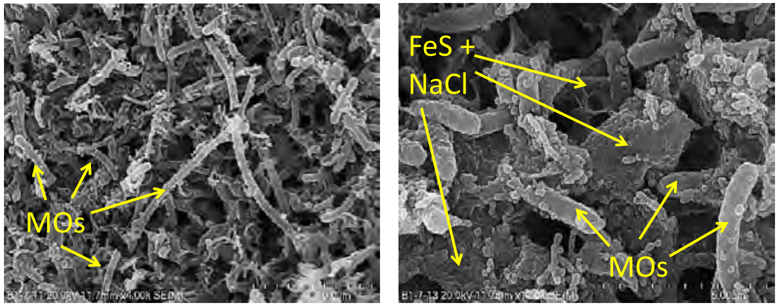
Vessel A:
Coupons: 2
Temperature: 40 °C

Vessel B:
Coupons: 2
Temperature: 40 °C & every 14 days: 78 °C (6 h)

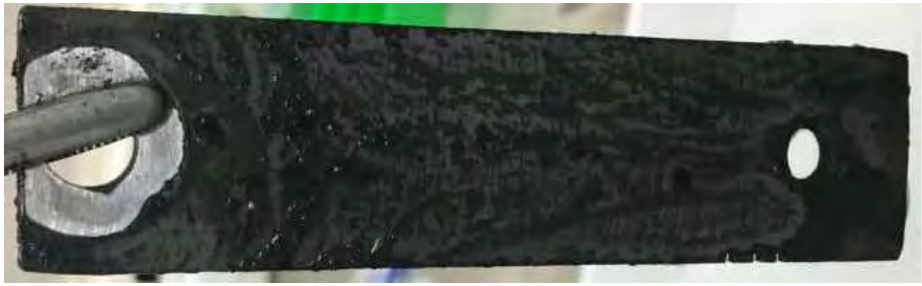
Kleyböcker *et al.* 2017

Temperature experiment (59 days): Shock temperature every 14 days

Vessel 1: T= 40 °C



Vessel 2: T= 40 °C & 78 °C (6 h)



→ Thinner biofilm layer after shock temperature

Kleyböcker *et al.* 2017

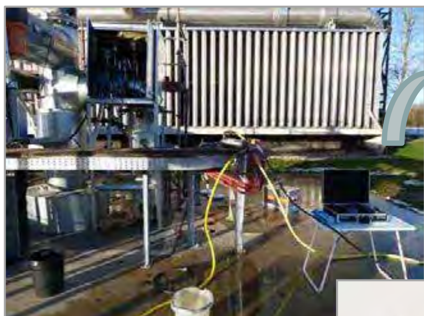
Summary - Heat Store Neubrandenburg

- Growth of SOB indicates oxygen ingress during the downtime phase. The fast decline of SOB after plant restart indicates the exclusive affection of the well.
- Interaction of SRB and SOB might have enhanced the corrosion processes occurring in the geothermal plant.
- Heat shock is a promising procedure to reduce biofilms and corrosion.

Geothermal Plant Unterhaching

Use of a scaling inhibitor to avoid scaling

Production well

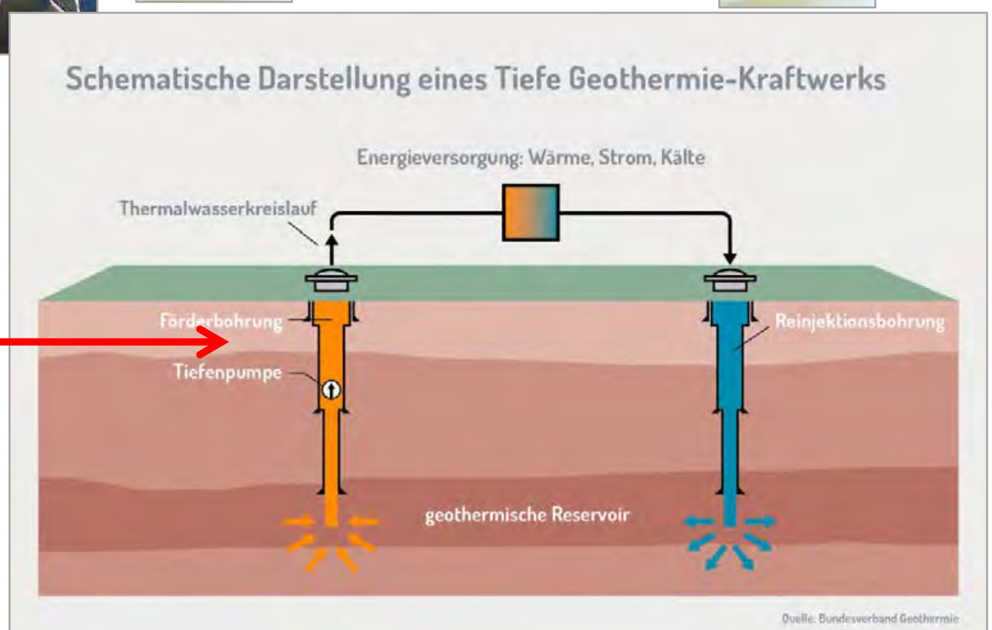


After heat exchanger

Injection well

Dosage of Inhibitor

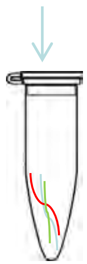
- NC47.1 B
- Polycarboxylat
- Since August 2017
- 5 mg/L -10 mg/L

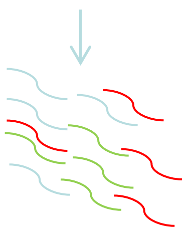


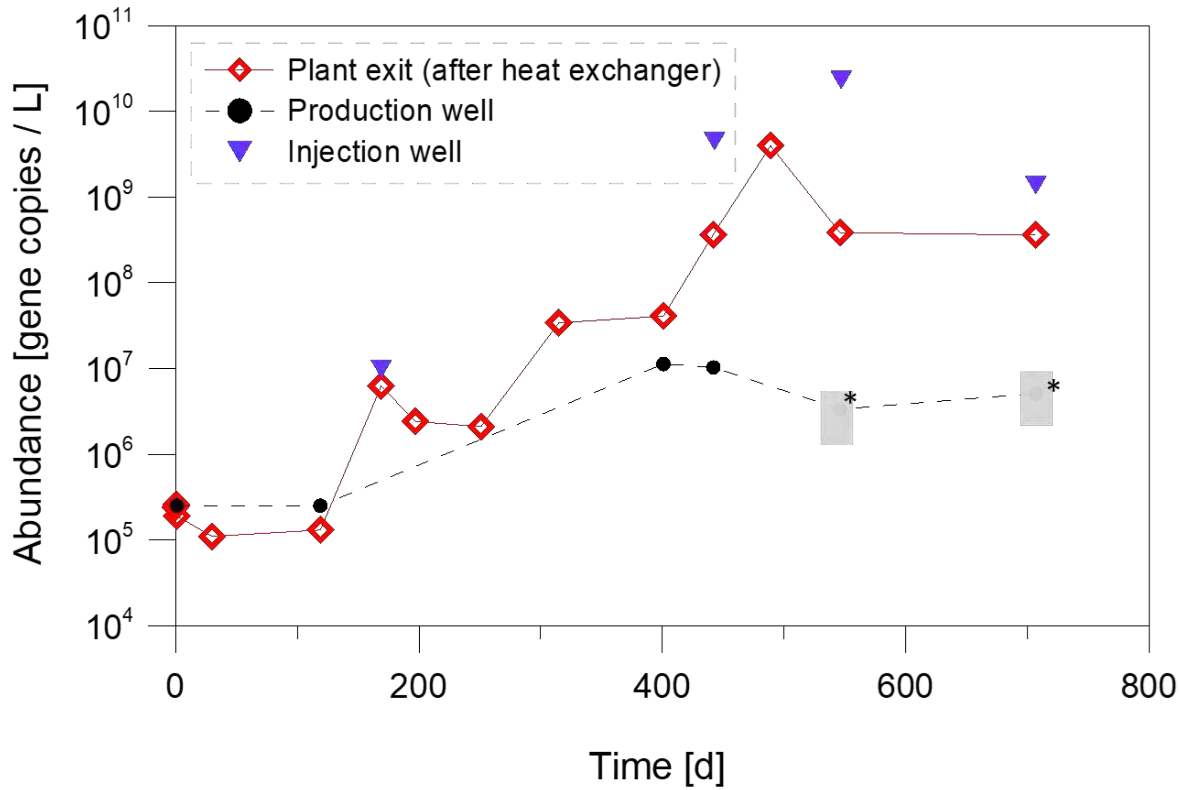
Otten *et al.* 2021

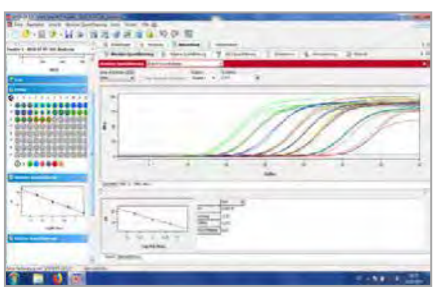
Increase of bacteria after heat extraction and inhibitor dosage

quantitative PCR (16S rRNA Bacteria)







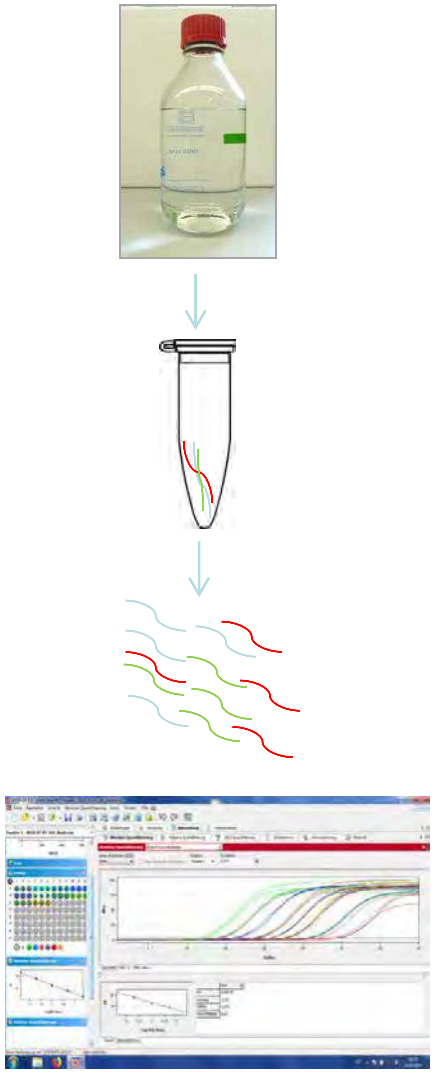


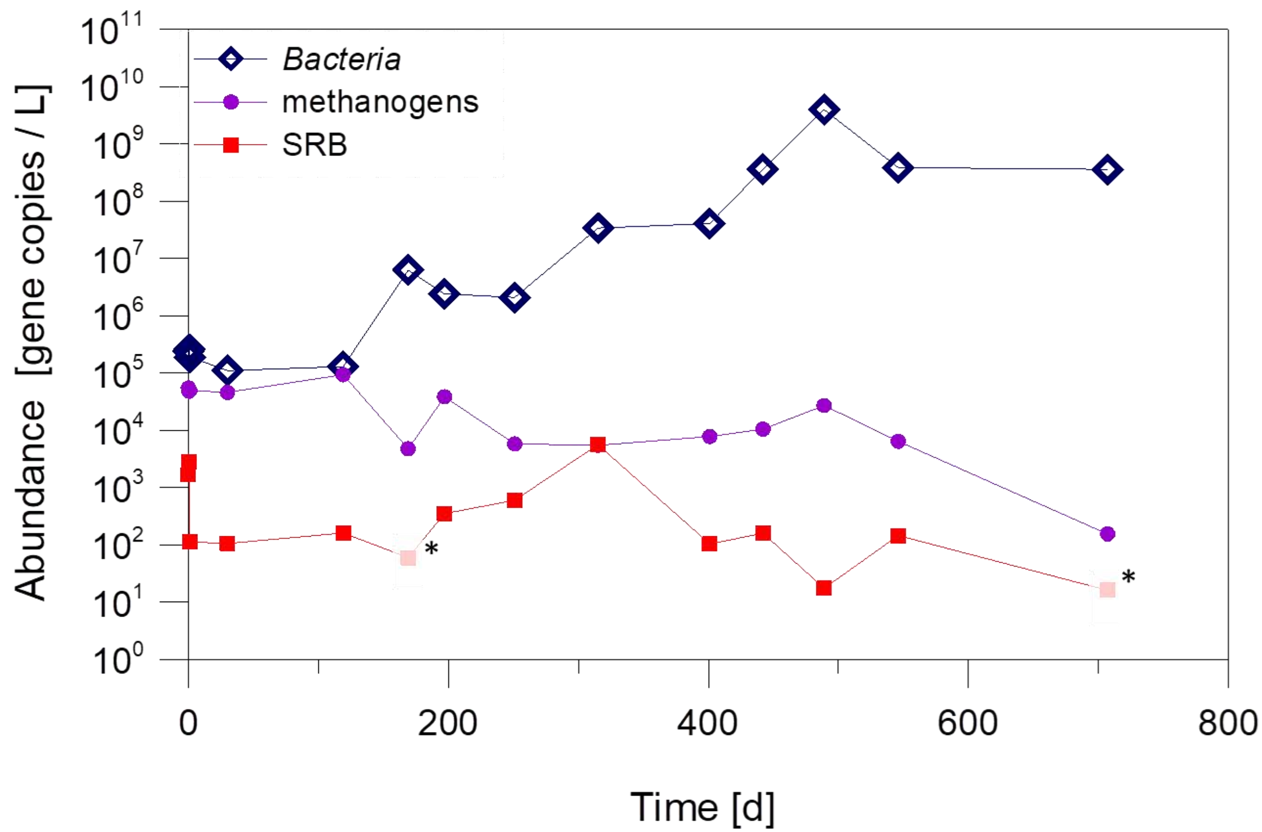
Increase of *Bacteria* due to inhibitor dosage in fluid samples from different sampling sites at the geothermal plant Unterhaching over a monitoring since 700 days of inhibitor dosage.

* below the sample specific detection limit

Otten *et al.* 2021

Increase of bacteria after heat extraction and inhibitor dosage
(qPCR of Bacteria, Sulfate-reducing bacteria and Archea)



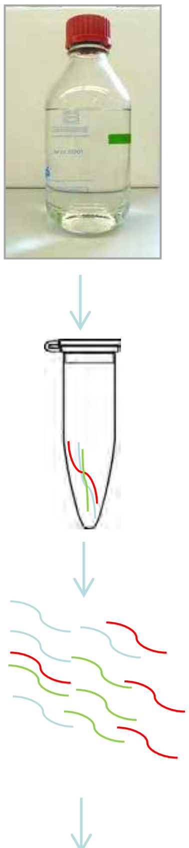


Quantification with qPCR with primers for the 16S rRNA gene (*Bacteria* and methanogenic archaea) and the *dsrA*-gene for sulfate-reducing bacteria.

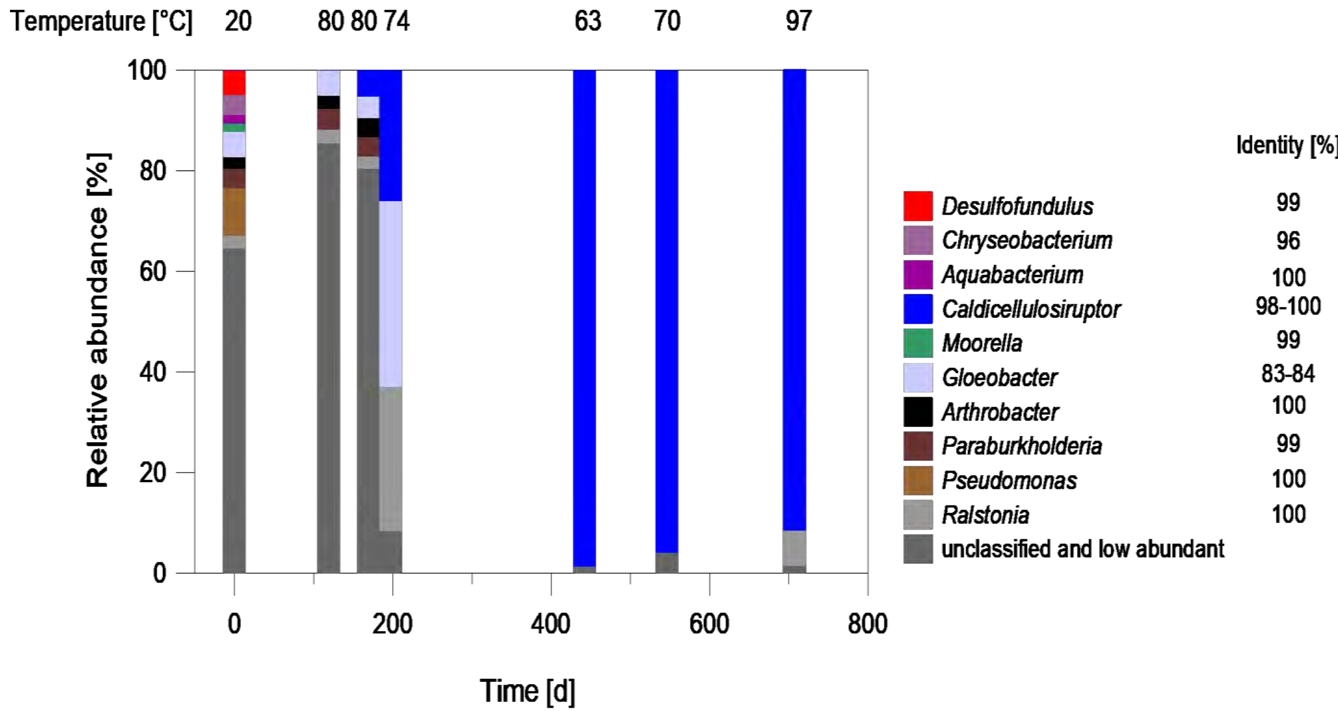
* below the sample specific detection limit

Otten *et al.* 2021

Change of the microbial community composition
(Microbiome analysis)



Microbiome analysis



Characterization of the bacterial biocenosis of fluid samples from the plant exit at the geothermal plant Unterhaching since 700 days inhibitor dosage.

Blue: fermentative bacteria,
Red sulfate-reducing bacteria

Otten *et al.* 2021

Projektträger Jülich
Forschungszentrum Jülich

Gefördert durch:
Bundesministerium für Wirtschaft und Energie
aufgrund eines Beschlusses des Deutschen Bundestages

Many thanks for your attention

GFZ Helmholtz-Zentrum Potsdam · HoMe Hochschule Merseburg · TU Berlin · SWM Stadtwerke München · GTN Ingenieure & Geologen · BWG Geochemische Beratung GmbH · neu.sw · Theisen Versorgungstechnik · KSB

Literature

Lerm, S., Westphal, A., Miethling-Graff, R., Alawi, M., Seibt, A., Wolfgramm, M., Würdemann, H. (2013). Thermal effects on microbial composition and microbiologically induced corrosion and mineral precipitation affecting operation of a geothermal plant in a deep saline aquifer. Extremophiles. Volume 17, Issue 2, Page 311-327.

Westphal et al. (2016). Effects of plant downtime on the microbial community composition in the highly saline brine of a geothermal plant in the North German Basin. Appl Microbiol Biotechnol 100(7):3277-3290.

Würdemann, H., Westphal, A., Kleyböcker, A., Miethling-Graff, R., Teitz, S., Kasina, M., · Andrea Seibt, A., Wolfgramm, M., Eichinger, F., Lerm, S. (2016). Störungen des Betriebs geothermischer Anlagen durch mikrobielle Stoffwechselprozesse und Erfolg von Gegenmaßnahmen. Grundwasser 21 (2): 93-106. dOI 10.1007/s00767-016-0324-1.

Kleyböcker, A., Lienen, T., Kasina, M., Westphal, A., Teitz, S., Eichinger, F., Seibt, A., Wolfgramm, M., Würdemann, H. (2017). Effects of heat shocks on biofilm formation and the influence on corrosion and scaling in a geothermal plant in the North German Basin Energy Procedia, Energy Procedia 125 (2017) 268–272. 10.1016/j.egypro.2017.08.173.

Otten *et al.* (2021). Interactions between the calcium scaling inhibitor NC47.1 B, geothermal fluids, and microorganisms – Results of in situ monitoring in the Bavarian Molasse Basin (Germany) and accompanying laboratory experiments. Adv. Geoscience in print.

Annex 5: Presentations – Nutrient recovery

The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

Online seminar
Nutrient recovery

F. Fatone, A. Kleyböcker, S. Casas, C. Bruni, S. Radini

December, 17th 2020.

Ultimate (June 2020 – May 2024)

Industry water-utility symbiosis for a smarter water society

- Promotion, establishment and extension of **Water Smart Industrial Symbioses**
- Development and demonstration of **innovative technologies** for symbioses
- **Assessment** of the technologies and development of **digital «support tools»**
- Development of **new business models** towards marketability

9 Symbioses between:

Industrial sectors

- Agro-food
- Beverage
- (Petro)chemical
- Biotech

Service providers

- Municipal utility
- Multi-industry utility
- Specialized SME
- Water services provider

Coordinator: KWR

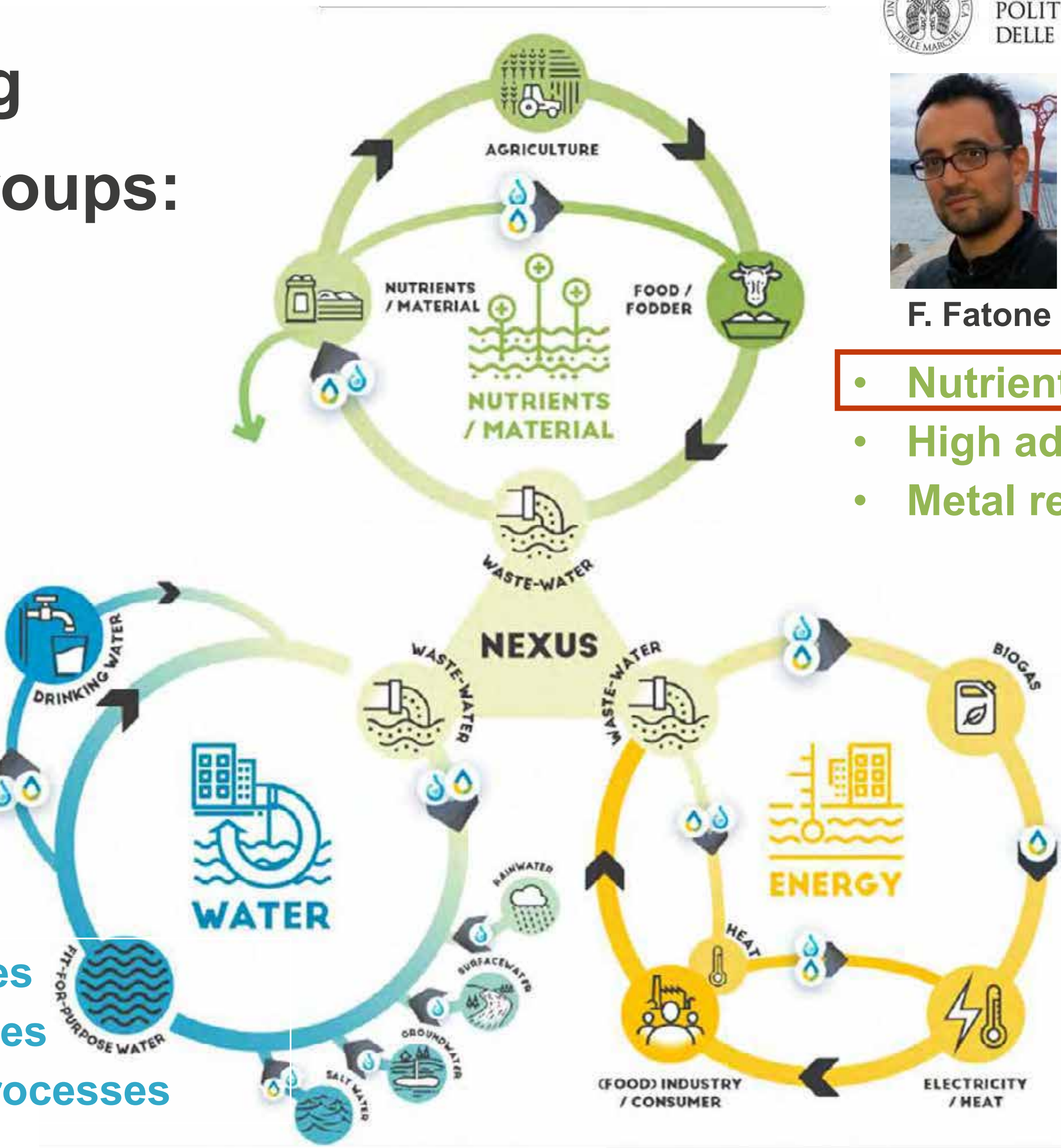
9 Case Studies

27 Partners

37 Technologies

The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

3 Cross-cutting Technology Groups: 9 Topics



UNIVERSITÀ POLITECNICA DELLE MARCHE


F. Fatone C. Bruni S. Radini

- Nutrient recovery
- High added value products
- Metal recovery

eurecat
Centre Tecnològic de Catalunya

S. Casas

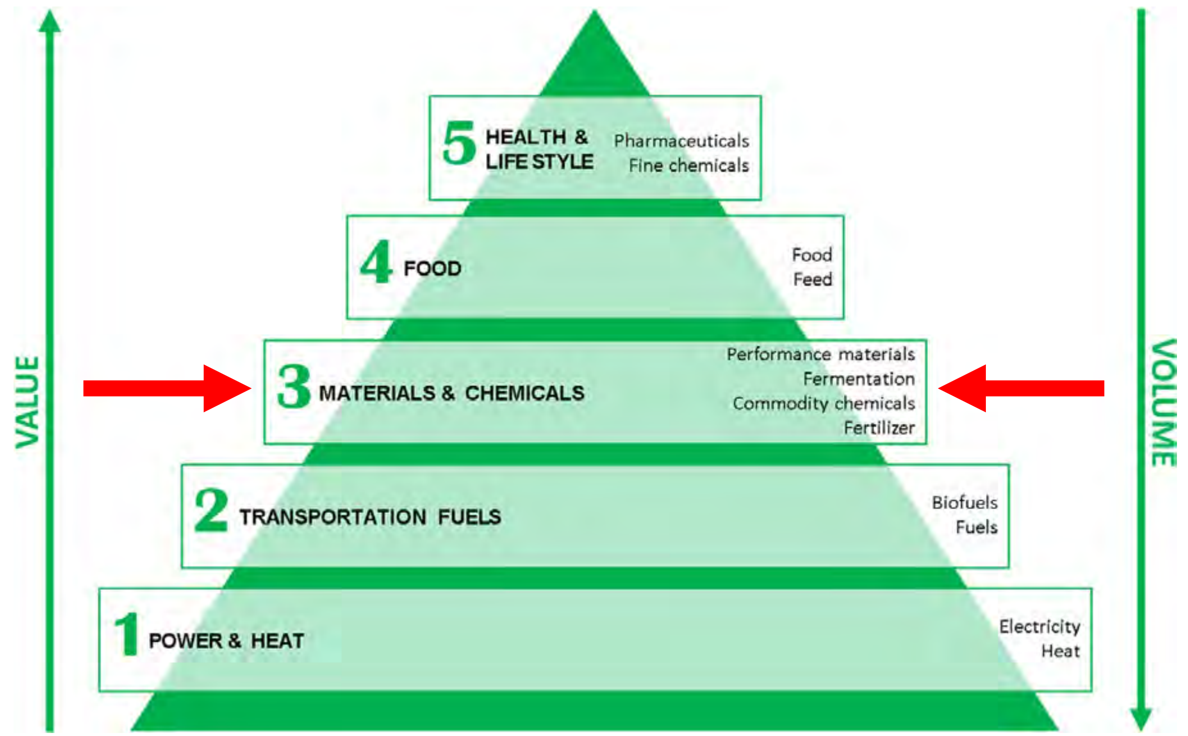
- Membrane technologies
- Adsorption technologies
- Advances oxidation processes

KOMPETENZZENTRUM Wasser Berlin

A. Kleyböcker

- Biogas technologies
- Heat Recovery
- Digitalization

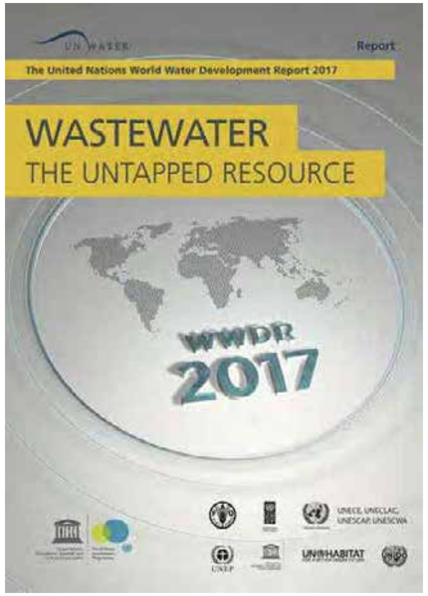
Water Resource Recovery Facilities must recognize the value of the materials they recover



The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

Water in the CEAP: still untapped resource?

*"Furthermore, the Commission will develop an **Integrated Nutrient Management Plan**, with a view to ensuring more sustainable application of nutrients and stimulating the markets for recovered nutrients. The Commission will also consider **reviewing directives on wastewater treatment and sewage sludge** and will assess **natural means of nutrient removal such as algae**"*



The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

6

Policy and barriers

European policies, regulations and directives

Circular Economy Package

Proposed new Common Agricultural Policies (CAP)

New Fertilising Products Regulation (FPR)

Remaining barriers

No (apparent) willingness of customers to accept a premium for sustainability

Possible customer reluctance if sewage-originated raw materials are declared

Public procurement focusing on low cost instead of closed loops

Except for Fertilising Products Regulation, harmonized European regulatory framework missing

Source: IWA Resource Recovery Conference and SMART-Plant final event – Venice (Italy) 2019

The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

More direct Support Needed

Governance of Water-Energy-Food-Carbon nexus by quantified evidence and metrics

Targeted Circular Economy Directives with **clear targets** comparable to energy directives (REDII)

Simplification and harmonization of End-of-Waste

More **harmonisation of regulation** in the EU

Free trade of secondary resources for recycling with tracing and tracking system and obligatory, proven recycling

Cross-sector collaboration and industrial symbiosis encouraged by ad-hoc regulatory framework that supports **long-term binding agreements** with industry and stable **public-private partnerships**

Adapted from IWA Resource Recovery Conference and SMART-Plant final event – Venice (Italy) 2019

The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

Coordinator: KWR

9 Case Studies

27 Partners

37 Technologies

The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

Agenda

15:15 **Nutrient recovery in CS2**: KWR expertise in Nutrient recovery and conceptual presentation of Nutrient recovery in CS2
Tavishi Guleria and Nienke Koeman (KWR)

15: 30 **Nutrient recovery in CS7 Tain**: Recovery of ammonia from distillery wastewater by IEX/packed columns after AnMBR
Mark Pidou (Cranfield University)

15:45 **Smart Plant:** bio-based fertilizer recovery from wastewater and sewage sludge
Sergio Ponsa (Beta/UVIC)

16:05 **Next Gen:** Full-scale nutrient recovery via struvite and ammonium sulfate production at a municipal wastewater treatment plant
Jonas Schneider (NextGen)

16:25 **Run4Life:** current results and exploitation pathways
Nicolas Morales (AQUALIA)

16:45 **Conclusions** and future interactions with ULTIMATE
Francesco Fatone (UNIVPM)

17:00 **End**

ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

CS2 – Nutrient Recovery

Tavishi Guleria (KWR) and Nienke Koeman-Stein (KWR)

17th December 2020

ULTIMATE Project

REUSE WATER
Recover, refine & reuse wastewater from industries & municipalities

EXPLOIT ENERGY
Extract & exploit energy, combined water-energy management, water-enabled heat transfer, storage & recovery

RECOVER MATERIALS
Nutrient mining & reuse, extraction & reuse of high-added value exploitable compounds

"Water Smart Industrial Symbiosis"

9 DEMOSITES

ULTIMATE will implement Water Smart Industrial Symbiosis in nine large-scale business cases from the international agro-food, petrochemical and biotech sector.

- 1- Tarragona (ES)
- 2- Nieuw Prinsenland (NL)
- 3- Rosignano (IT)
- 4- Nafplio (EL)
- 5- Lleida (ES), Ostrava (CZ)
- 6- Karmiel, Shafdan (IL)
- 7- Tain (UK)
- 8- Saint-Maurice l'Exil (FR)
- 9- Kalundborg (DK)

The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

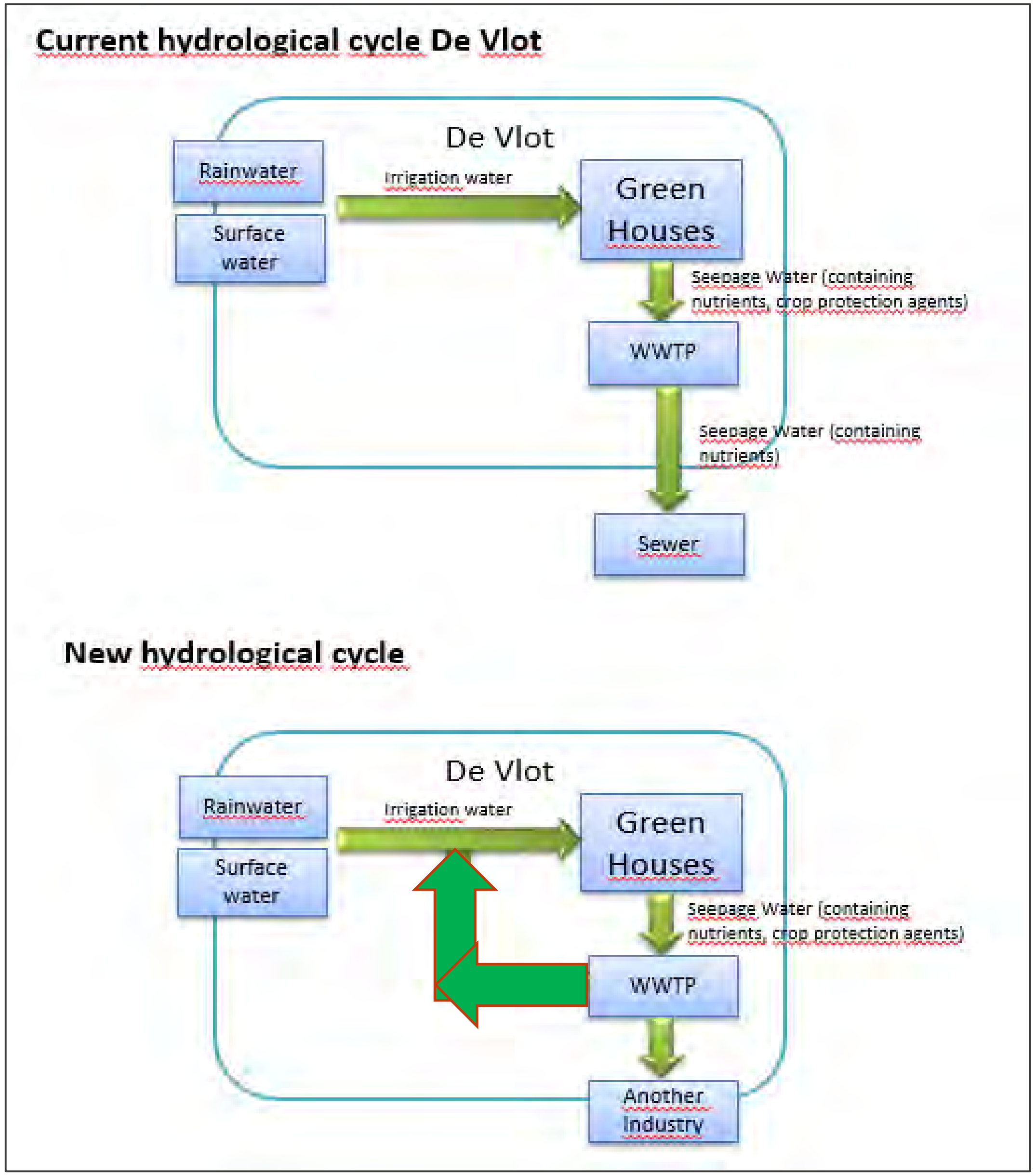
Horticulture – Industry symbiosis

- Greenhouse development in the Netherlands
- Builds upon existing symbiosis and collaborations
- Project partners involved

The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

Fate of Nutrients

- Pesticides and pathogens removed with advanced treatment - reclaimed greenhouse wastewater will contain valuable nutrients
- Effects of nutrient composition in the reused water on plant growth and health (e.g. Na/K ratio) will be assessed in the demo-greenhouse.
- Optimum nutrient balance and prevent the accumulation of specific minerals (B, Cu, etc.)
- Economic analysis of potential cost savings by using recovered nutrients



The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

Timeline

S.no.	Case Study 2		2020							2021												2022						
			6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
1	Defining the case study and demonstration site	KWR																										
2	Detailed literature review of technologies for greenhouse drainwater reuse	KWR																										
3	Proposed pilot site baseline (data collection)	KWR																										
4	*Definition of workplan (MS5)*	KWR																										
5	Designing an experimental plan and setting up laboratory equipment	KWR																										
6	Bench scale experiments and system optimization	KWR																										
7	Assessment of achieved reuse safety (water quality and microbiological)	KWR																										
8	*Selection and scaling up the technology to pilot scale and site adaptation (MS9)*	KWR																										
9	Designing prototype for construction	KWR																										
10	Prototype installation at the pilot site	KWR																										
11	*Operating the prototype technology at the pilot site, data collection, data analysis and*	KWR																										
12	*Pilot monitoring, results, follow-up and scenario comparison (MS19)*	KWR																										

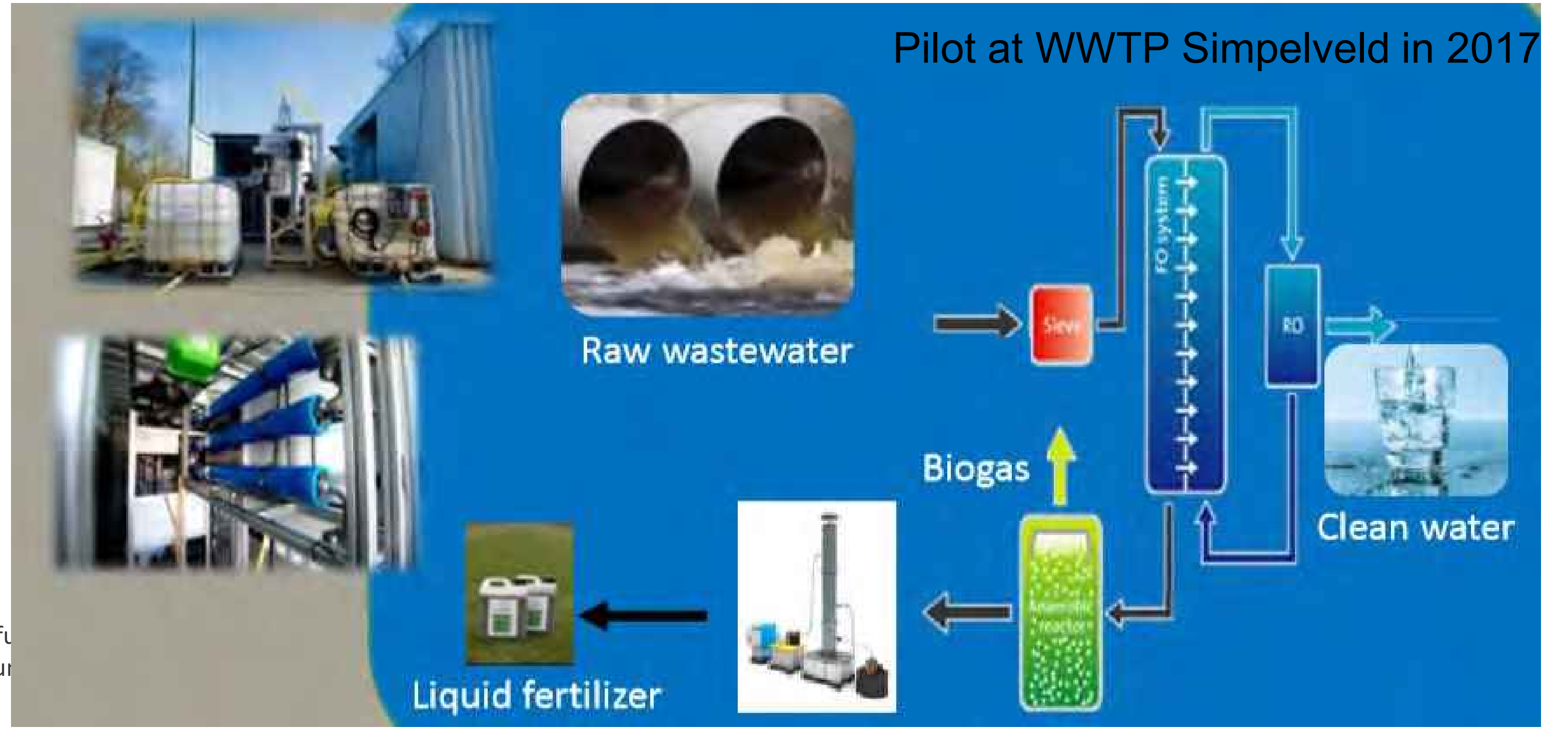
KWR and Nutrient Recovery

- Nutrient recovery as part of resource recovery
- Resource recovery from **drinking water production**
- In cooperation with Aqua Minerals → company that sells resources from water and wasewater
- Calcite in face scrub
- Ferric (hydr)oxide pellets for removal of sulphur from (bio)gas, phosphorus from (surface) water and arsenic from (ground)water

The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

KWR and Nutrient Recovery

- Nutrients from wastewater
- Metals: heavy metals are rare earth metals from fly ash
- Biogas from slaughterhouse wastewater



- Core project:

Liquid fertilizer production

The project leading to this application has received fu
Horizon 2020 research and innovation programme u

KWR and Nutrient Recovery

Resources from drinking water production and industry for application in wastewater treatment

- Spent powdered activated carbon from industrial use for OMP removal from WWTP effluent

Reuse of greenhouse drain in greenhouses: project in Nieuw Prinsenland to determine theoretical safety of reuse: microbiological and pesticides

Reuse of municipal effluent for greenhouses: treatment for upcycling, regulations, risk analysis and monitoring throughout the whole chain for responsible reuse: from WWTP to greenhouse to table

The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

Thank You!

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The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

CS7 – Tain (Glenmorangie distillery)

Cranfield University

Aquabio

Meeting: December, 17th 2020

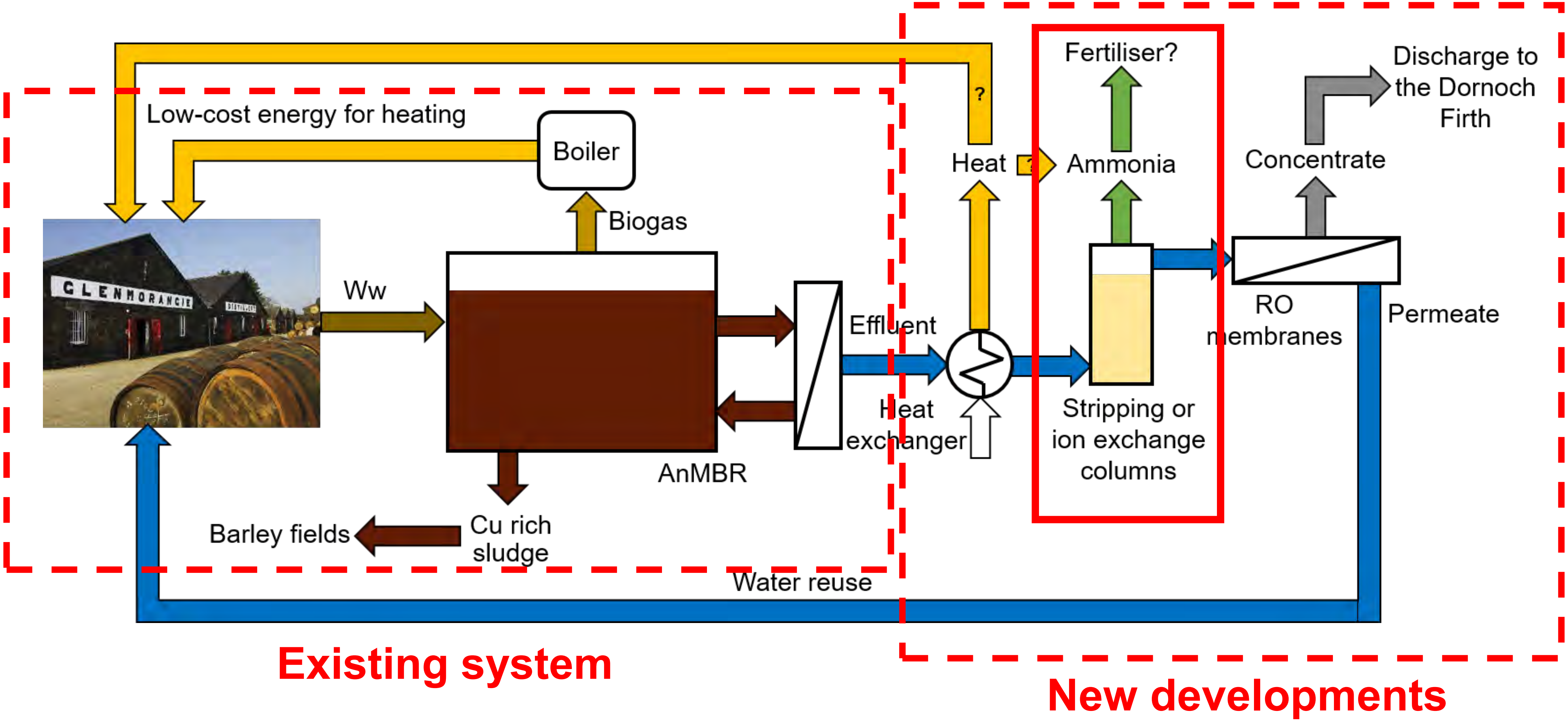
CS7

7 TAIN
9 KALUNDBORG
2 NIEUW PRINSENLAND
5 OSTRAVA
SAINT-MAURICE L'EXIL 8
3 ROSIGNANO
LLEIDA 5
1 TARRAGONA
NAFPLIO 4
KARMIEL, SHAFDAN 6

GLENMORANGIE

GLENMORANGIE
THE ORIGINAL

Treatment systems

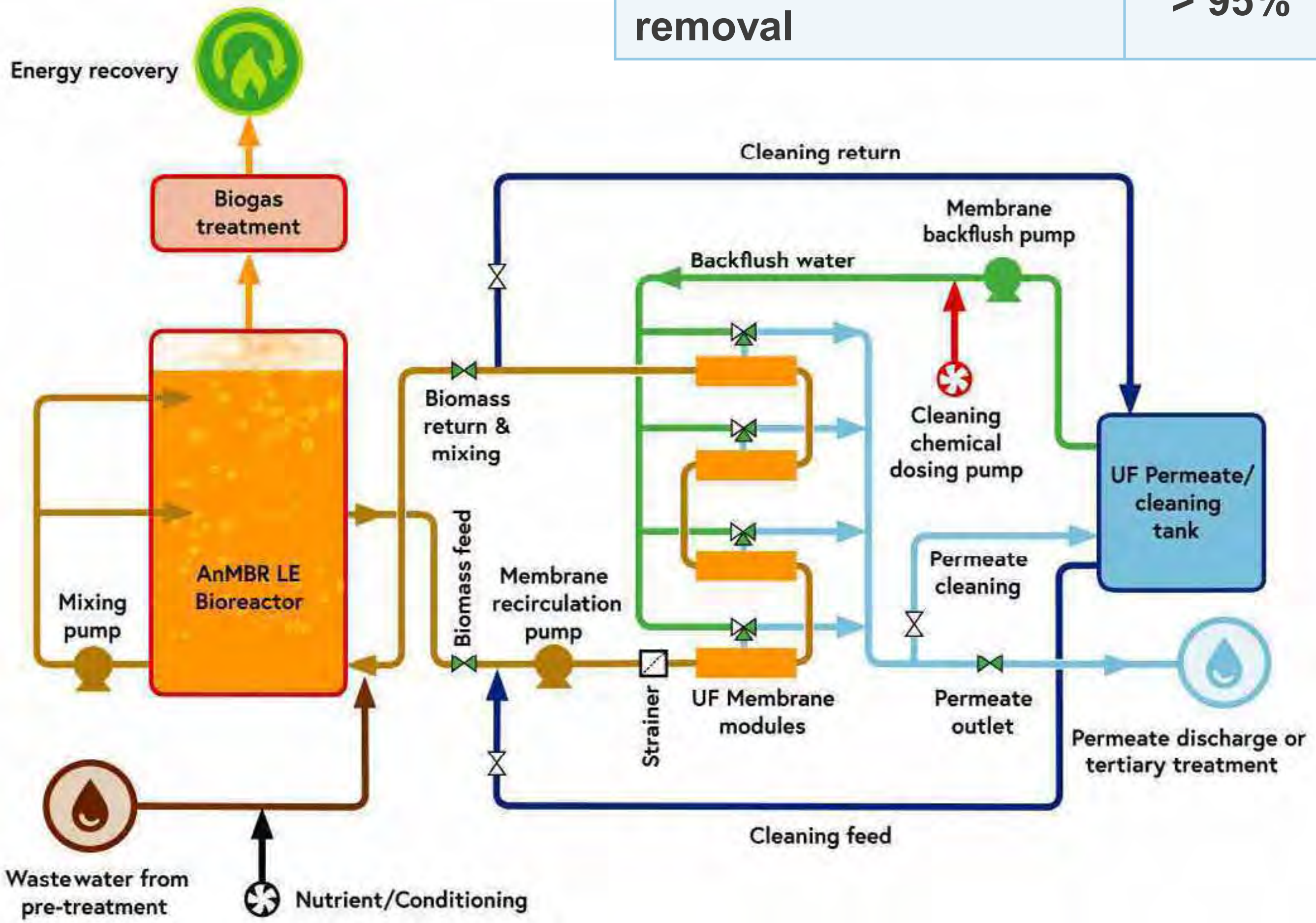


The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

AnMBR LE™

Aquabio

Peak/average AnMBR Feed flow rate (m^3/d)	467/377
Design COD load (kg/d)	14,527
Average total COD removal	> 95%



COD (mg/L)	656 (316 – 1454)
SS (mg/L)	3 (0 – 18)
NH_4-N (mg/L)	797 (329 – 1349)
NO_3-N (mg/L)	5 (4 – 8)
PO_4-P (mg/L)	252 (152 – 343)
pH	7.2 (6.4 – 8.0)

Ammonia removal and recovery:

- Stripping
- Precipitation
- Ion exchange

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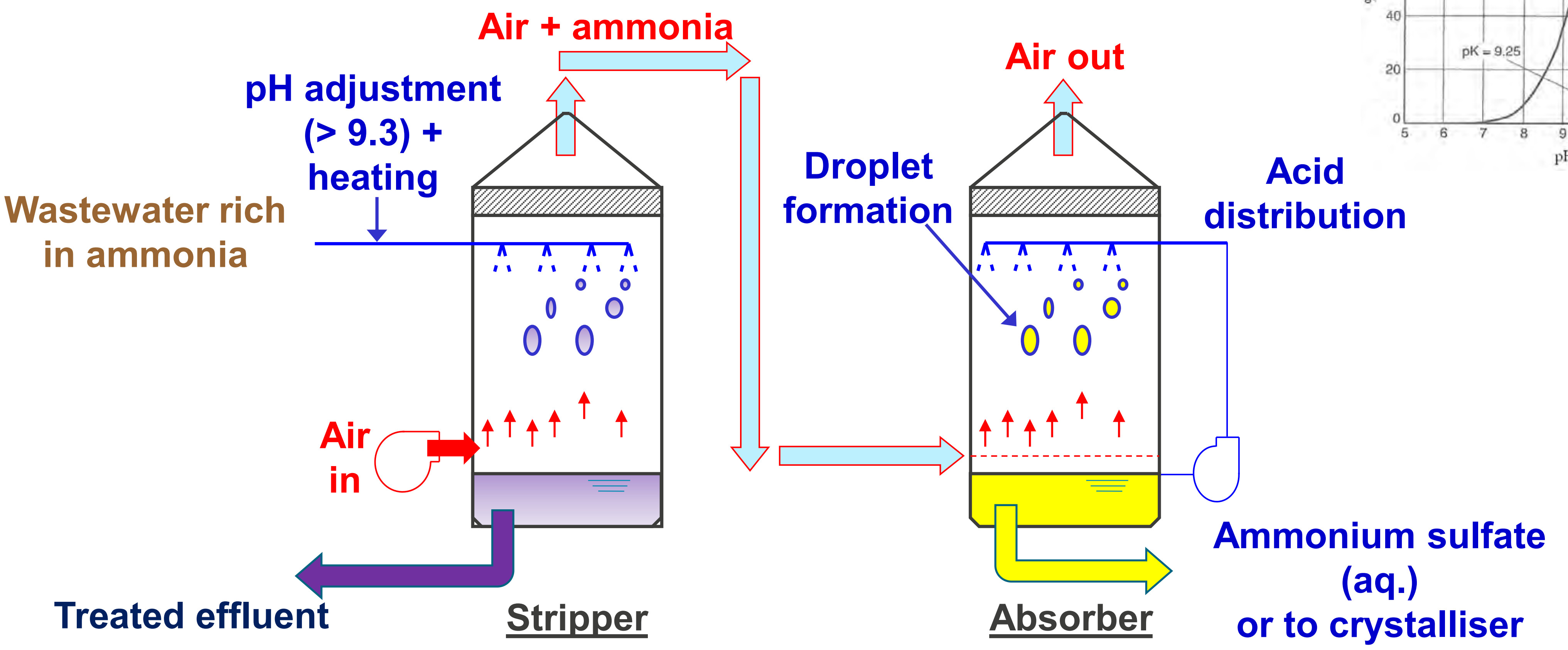
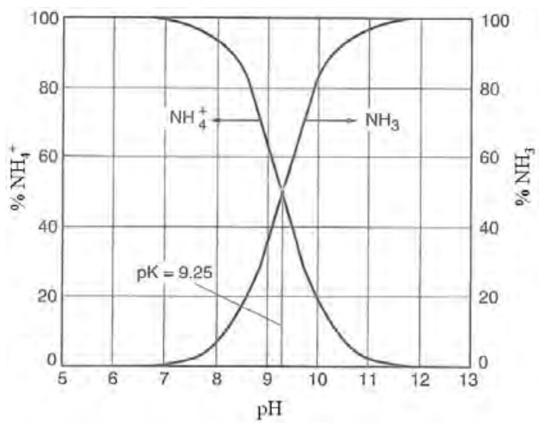
Stripping columns





Key attributes:

- Established technology
- Large footprint
- Energy intensive

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Precipitation - Struvite

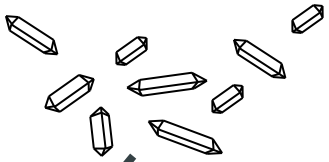
Wastewater

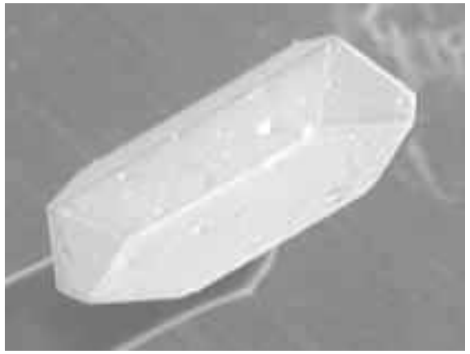
pH adjustment (8.5 – 9.0) + magnesium and phosphate addition

magnesium
ammonium
phosphate

$$Mg^{2+} + NH_4^+ + H_nPO_4^{3-n} + 6H_2O \leftrightarrow MgNH_4PO_4 \cdot 6H_2O + nH^+$$

Struvite (Magnesium ammonium phosphate - $NH_4MgPO_4{\cdot}6H_2O$)





Key attributes:

- **Established technology**
- **Simpler configuration**
- **Availability of P and Mg?**

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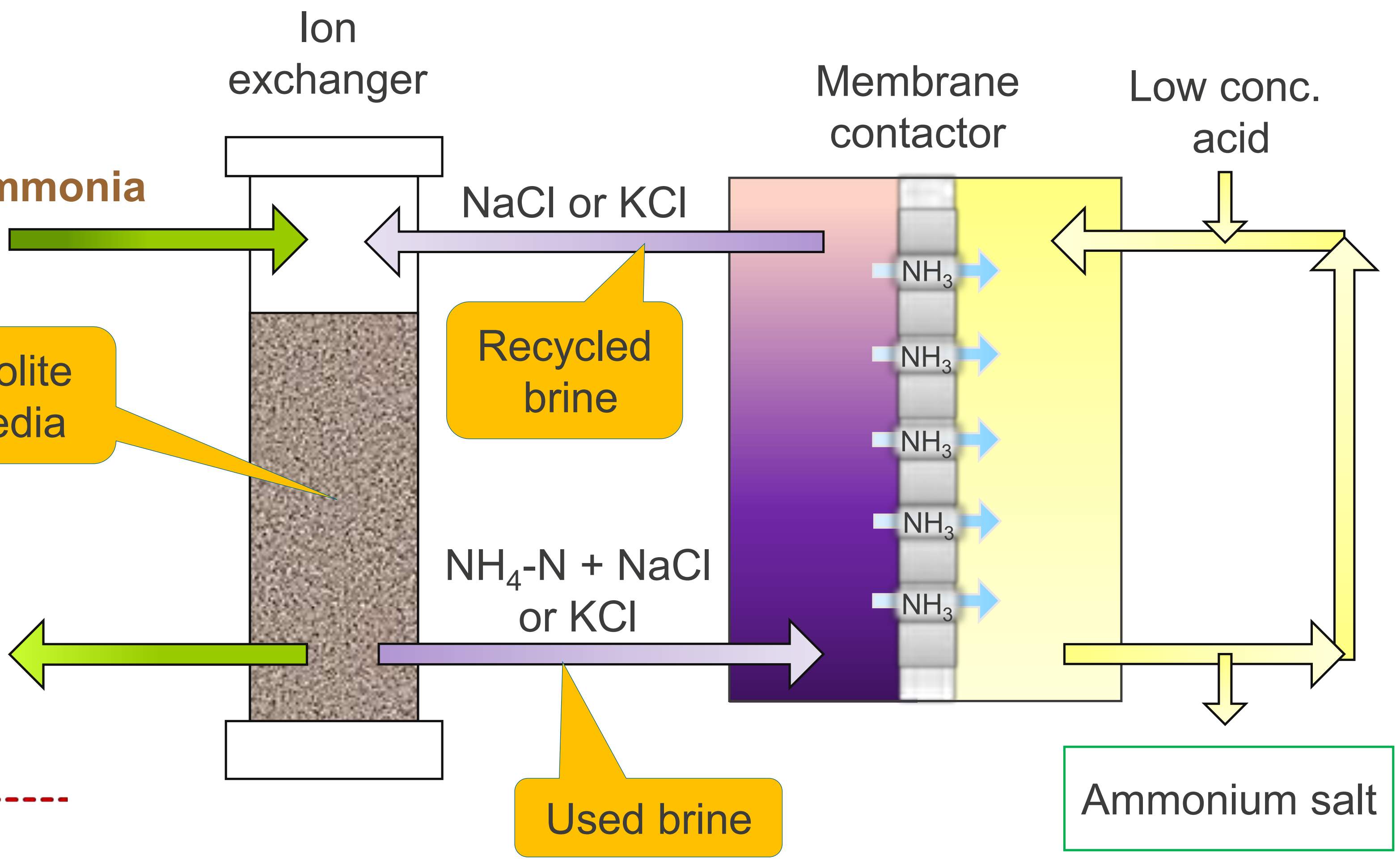
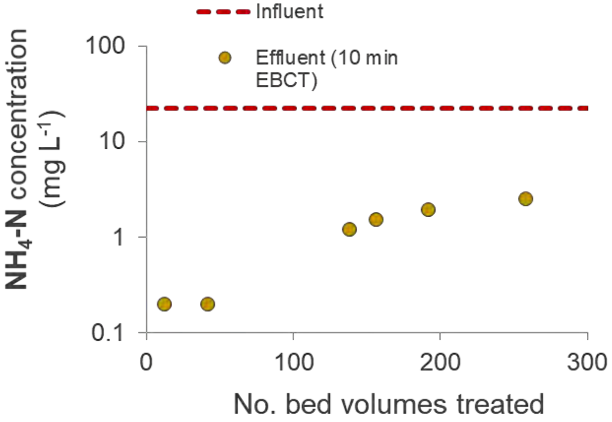
Ion exchange

Wastewater rich in ammonia



Treated effluent



Key attributes:

- **Small foot print**
- **Adsorption capacity at high ammonia concentrations?**
- **Supply chain of media**

The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

Trials

Internal milestones: water recovery	2020							2021												2022												2023												2024				
	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
Wastewater characterisation																																																
Lab to smale pilot scall trials																																																
Demo unit design																																																
Demo unit build																																																
Demo unit commisioning																																																
Demo unit peration																																																

(1) Preliminary work: determine the optimum ammonia removal and recovery technology for distillery wastewater:

- **Impact of ammonia concentration on system efficiency**
- **Impact of operational conditions (pH, temperature, foreign compounds, …)**
- **Product quality and quantity**
- **Chemical use => OPEX**

(2) Design and construction

(3) Demonstration of integrated system at the distillery

The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

Thank you!

Scale-up of low-carbon footprint material recovery techniques in existing wastewater treatment plants "SMART-Plant"

H2020 ULTIMATE seminar: Nutrient and biobased fertilizer recovery withi[redacted]

Speaker: Sergio Ponsá – BETA Tech. Centre

sergio.ponsa@uvic.cat

Proud Partner of SMART Plant project

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Biodiversitat, Ecologia, Tecnologia Ambiental i Alimentària

ULTIMATE
WATER SMART INDUSTRIAL SYMBIOSIS

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FERTIMANURE

H2020-SC2-RUR-08B-2019 BBF and TMF from animal manure (Coordinator)

SMART-Plant

H2020-SC5-Water1b-2015 BBF production

Beta

RE-FLOW

H2020-MSCA-ETN-2018 (2 ESR Fellows). P-Recovery and BBF production from dairy industries (WP Leader)

DECOST

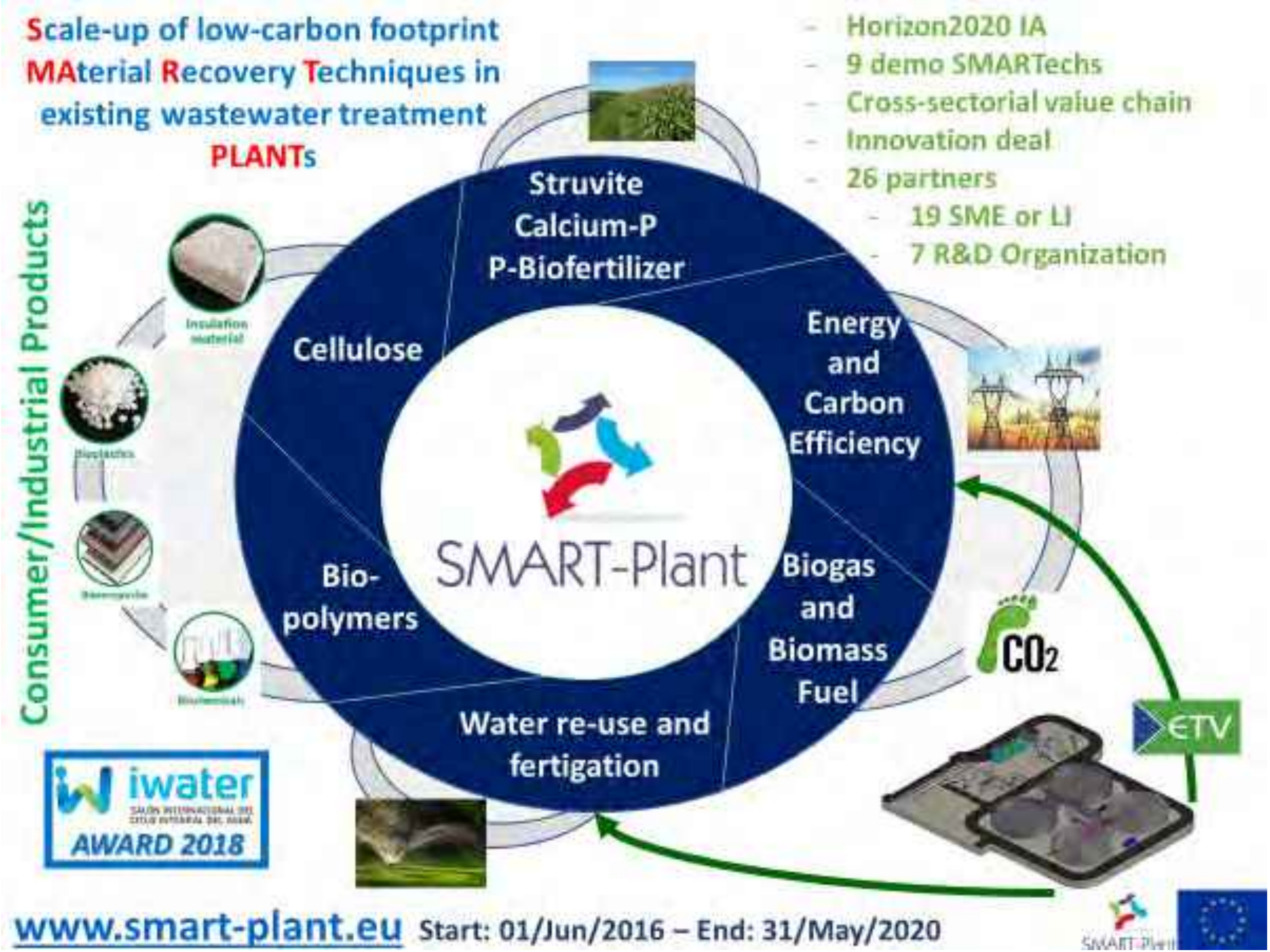
ENI-CBC-MED-2018 Community composting for OFMSW recycling (Coordinator)

AccelWater

H2020-CE-SPIRE-07-2020. Nutrient recovery and BBF and biostimulants production from food industries (WP Leader)

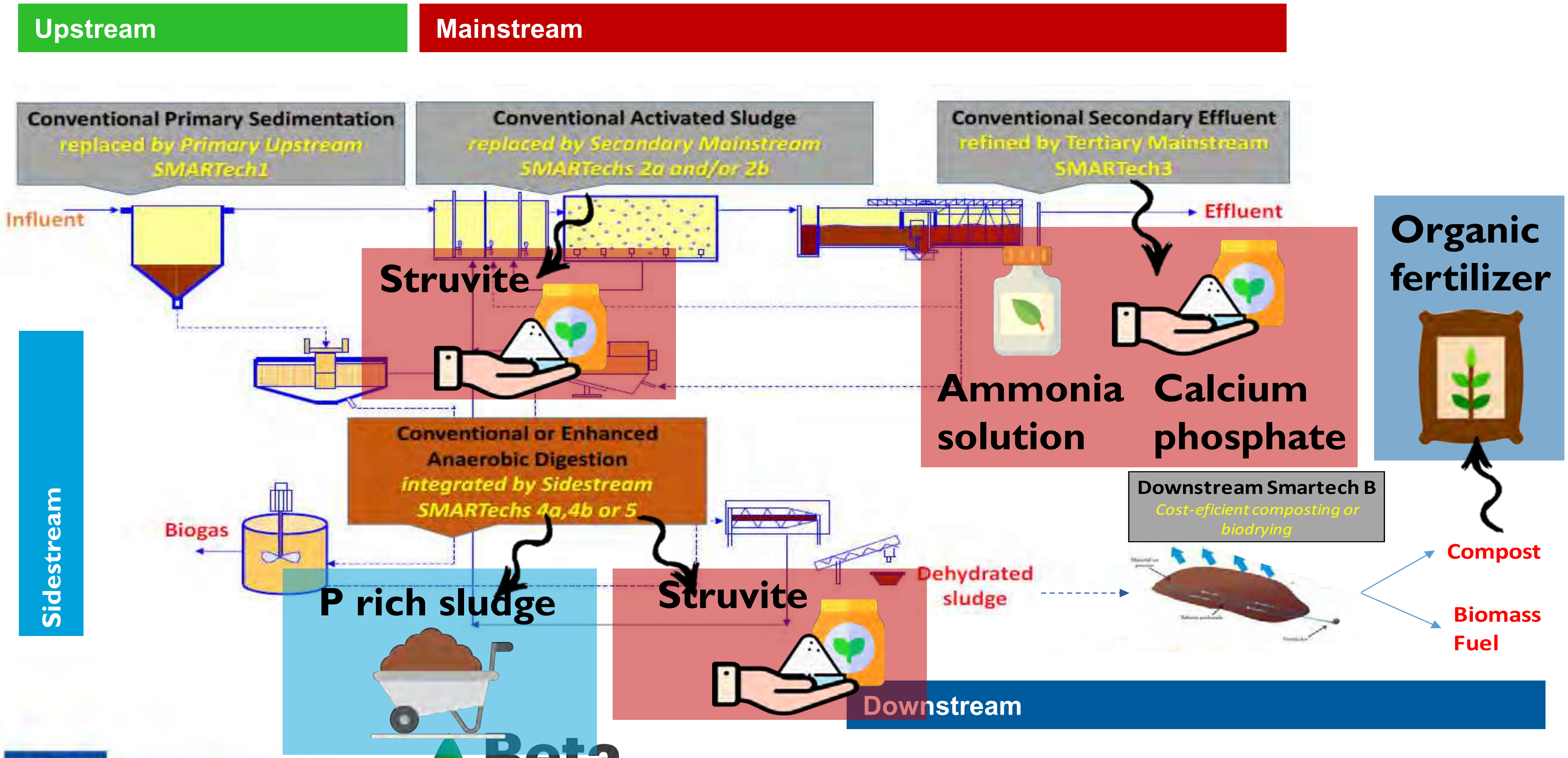
Sea2Land

H2020-SC2-RUR-08C-2020 BBF and TMF from fisheries and aquaculture. (WP Leader)

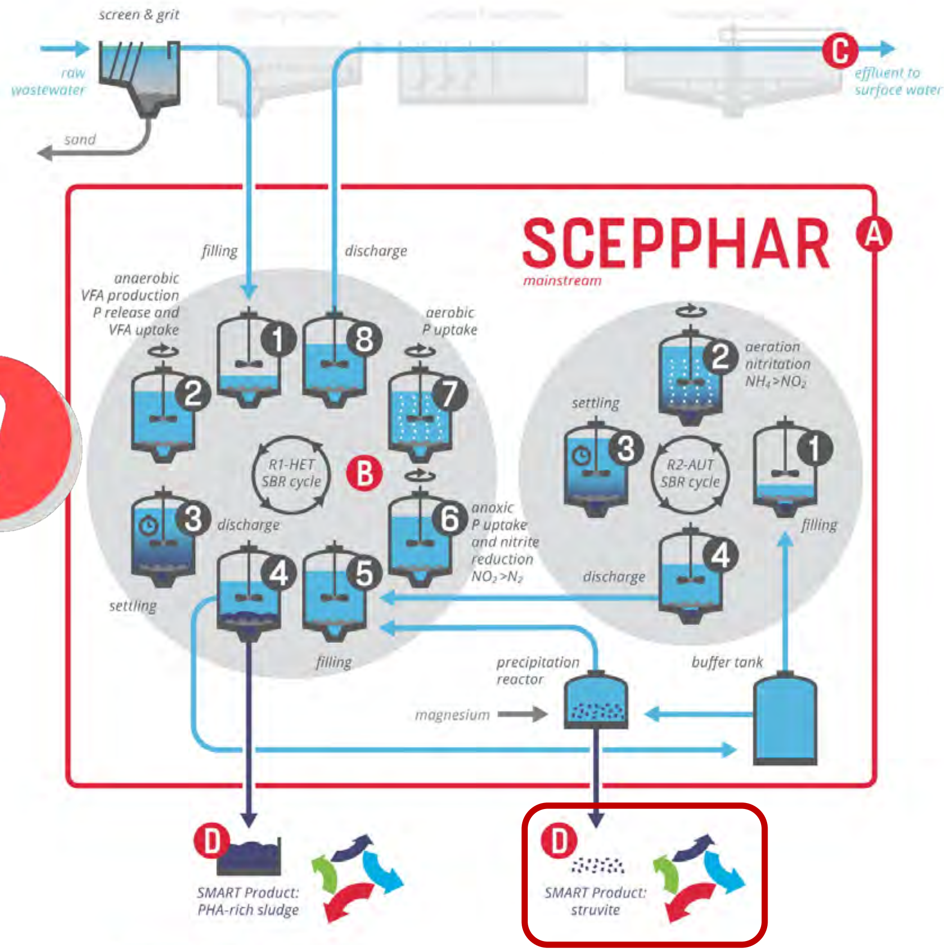


Scale-up of low-carbon footprint MAterial Recovery Techniques in existing wastewater treatment PLANTs
- Horizon2020 IA
- 9 demo SMARTechs
- Cross-sectorial value chain
- Innovation deal
- 26 partners
- 19 SME or LI
- 7 R&D Organization
Consumer/Industrial Products
Struvite
Calcium-P
P-Biofertilizer
Energy and Carbon Efficiency
Biogas and Biomass Fuel
Water re-use and fertigation
Bio-polymers
Cellulose
SMART-Plant
Insulation material
CO_2
ETV
iwater
AWARD 2018
www.smart-plant.eu
Start: 01/Jun/2016 – End: 31/May/2020

Nutrient recovery within SMART Plant



SMARTech 2b: mainstream SCEPPHAR



86% N removal
96% P removal
6.6g/m³ struvite production

Unique Selling Points

- **A** Reduced energy demand and operational costs
- **B** No external carbon source or metal salt needed
- **C** High effluent quality (P < 1 mg/L, N < 10 mg/L)
- **D** Recover 50 % of phosphorus as struvite and sludge with 30 % PHA content

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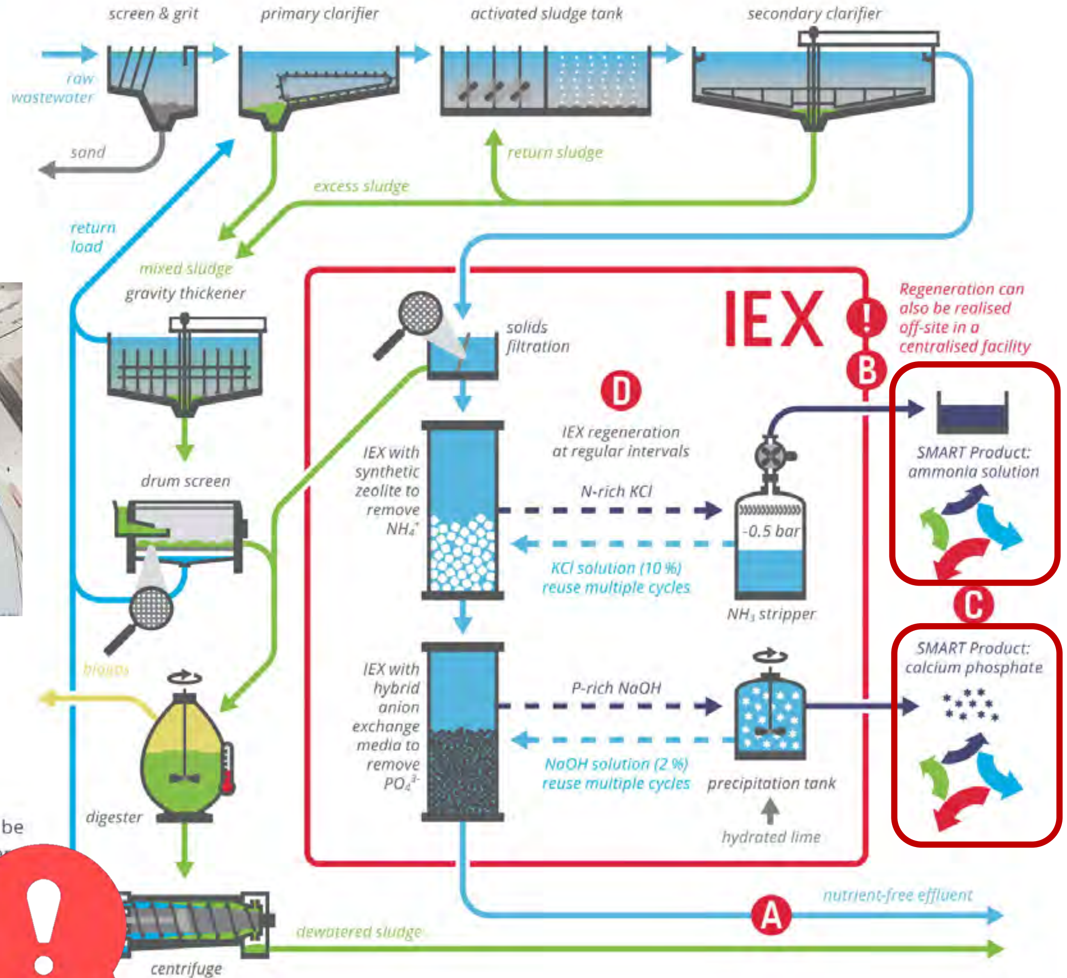
SMARTech 3: IEX



Unique Selling Points

A Achieves tight nutrient discharge limits by removing NH_4^+ and PO_4^{3-} to very low concentrations (< 5 mg N/L and < 0.5 mg P/L)

B High recovery rates: up to 97 % of ammonia and 95 % of phosphorus

C High quality products which can be used in the chemical and fertilize[...] industry

D Multiple use and recovery [...] regenerants leading to an e[...] feasibility of the IEX technolo[...] wastewater industry

92% of NH_4 recovery

95% of P recovery as CaPO4

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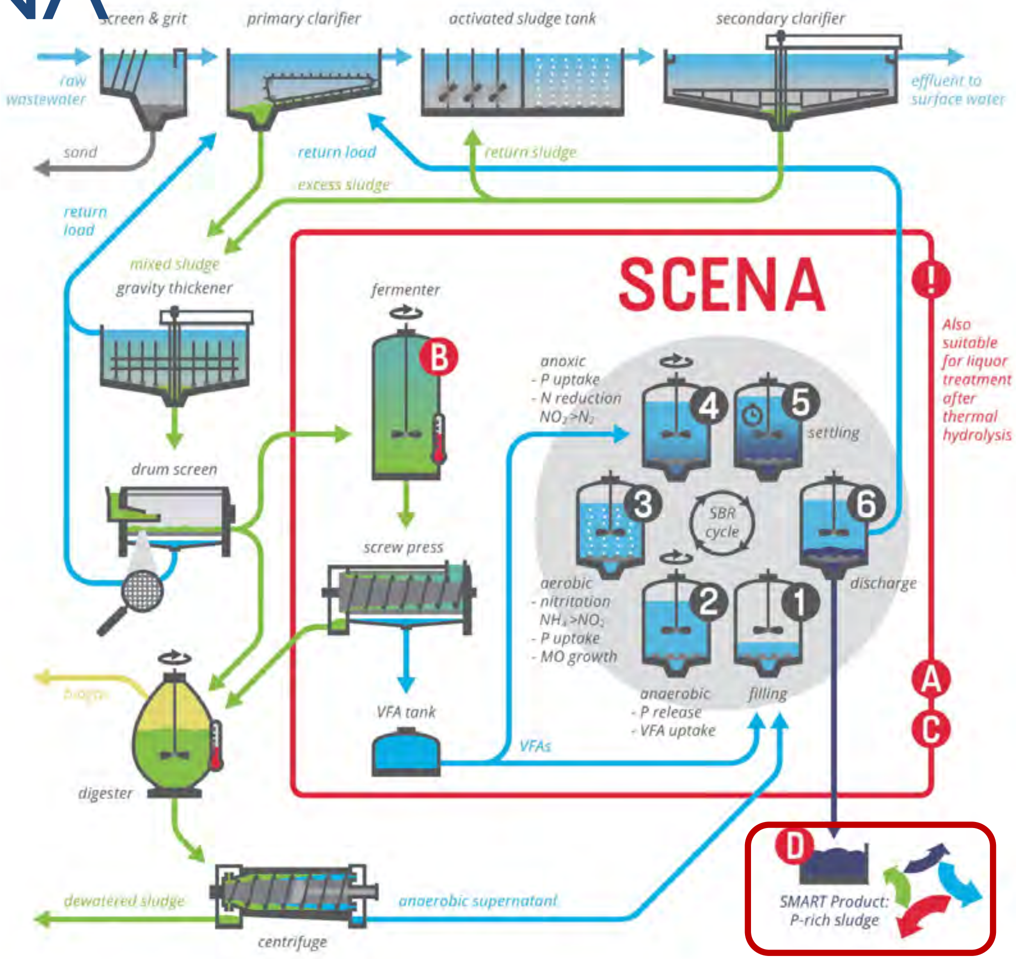
SMARTech 4a: SCENA

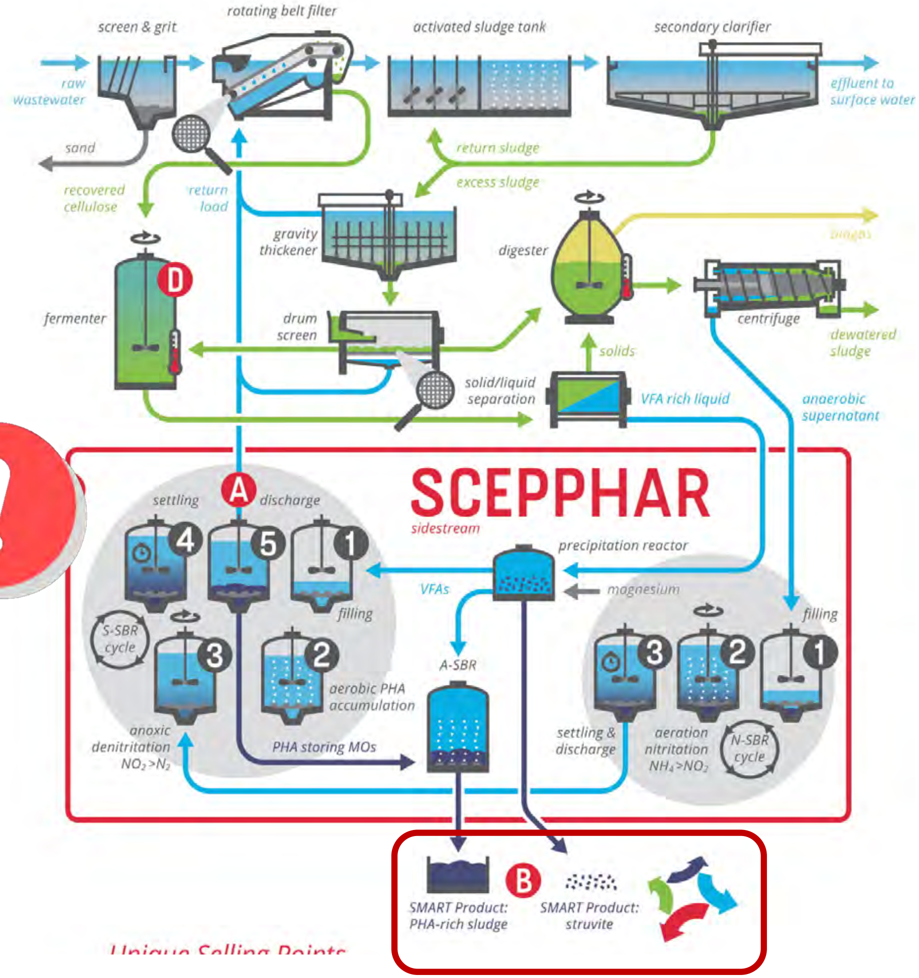
92% of P removal and recovery through P rich biomass. Dewatered SCENA sludge contains up to 5% (d.b) phosphorus

Unique Selling Points

- A Low-energy nutrient removal from sludge liquor
- B Biological N and P elimination without chemicals or external carbon source
- C Stable and robust operation compared to other biological processes
- D P-rich sludge can be valorized as organic fertilizer



SMARTech 5: sidestream SCEPPHAR



Unique Selling Points

- **A** High effluent quality due to effective N removal from sludge liquor
- **B** Recovery of valuable products (PHA, struvite)
- **C** Reduction of energy and operational costs
- **D** Carbon source (VFA) for PHA production is gained in the process

85% P removal
225 g/d struvite production

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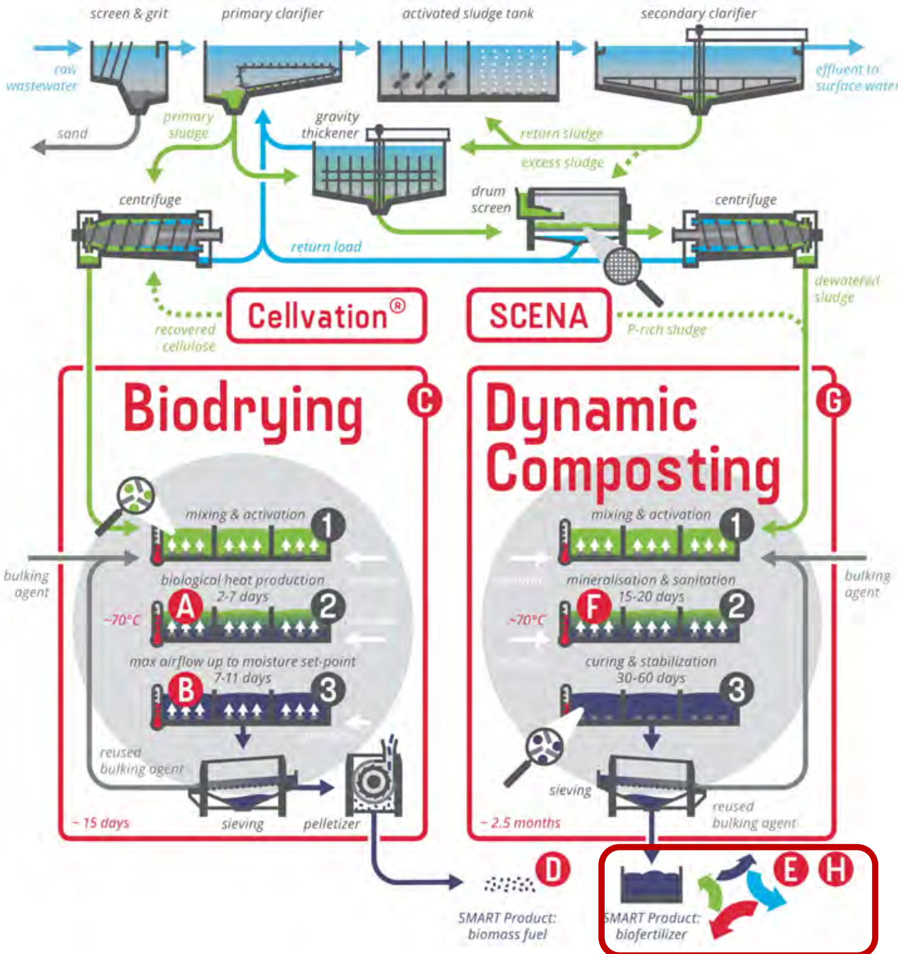
Downstream SMARTechB



Unique Selling Points

Satisfactory agricultural performance demonstrated

- **E** Production of a biofertilizer with high stability + N and P content up to 5 % DM
- **F** Advanced aeration control for an optimal organic carbon mineralization by maximizing the biological activity
- **G** Reduction of GHG emissions and energy consumption for aeration
- **H** Opportunity for tailor made fertilizers

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Quality of SMART BBF/fertilising products

- In terms of:
  - [redacted]gronomic test in pot
    [redacted]
- Safety of products:
  - Heavy metals
  - Polycyclic aromatic hydrocarbons [redacted]
  - [redacted]
  - [redacted] polluting molecules)
  - [redacted]ding antibiotics, pesticides, and [redacted]s) (15 substances included in 2018 EU watch-list).

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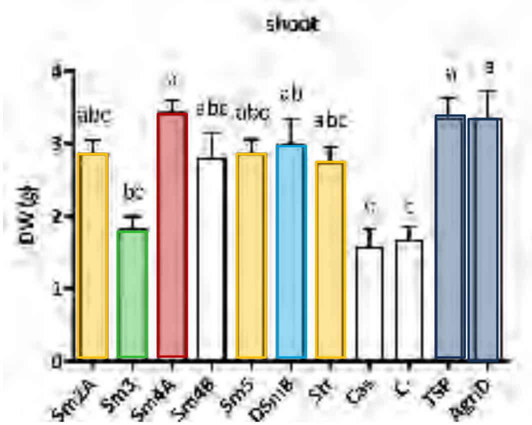
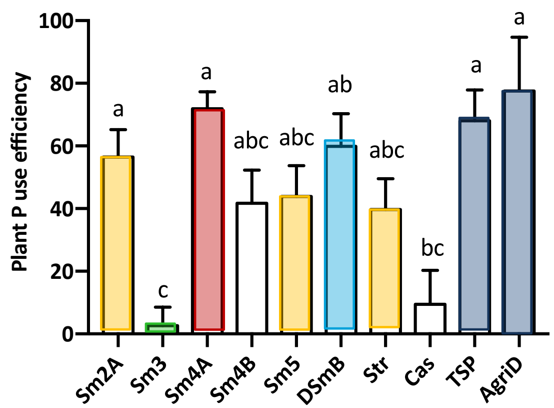
Agronomic value: agronomic test in pot



Shoot biomass (dry) achieved with **P rich sludge and P rich compost** equal to positive control. **Effective for plant growth.**

- + Control (TSP + agricultural digestate)
- Struvite (from different SMARTechs + commercial)
- $CaPO_4$ (SMARTech 3, IEX)
- P-rich sludge (SMARTech 4A, SCENA)
- P rich compost (Downstream SMARTech B)



Plant phosphorus efficiency achieved with **P rich sludge and P rich compost** equal to positive control. **Efficient source of P.**

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Safety of fertilising products: emerging pollutants

- Sum of 16 PAH:
  - **None** of the products **exceeds** the most stringent value established in different EU regulations (3 mg PAH/ kgTS)
- Pesticides:
  - **6 pesticides detected** out of 108, only in CaPO4 and struvite
  - Values slightly higher than the most restrictive values of the maximum residue level tolerated in food (Reg. EC 396/2005)
- PPCP:
  - **5 PPCPs quantified** out of 15: Clarithromycin, Azythromycin, Ciprofloxacin, Imidacloprid, Estrone.
  - **Lower PPCP concentrations** in **mineral** fertilisers compared to organic fertilisers
  - **Dynamic composting** is able to **reduce PPCP** concentration in sludge

Safety of fertilising products: Heavy metals Regulation 2019/1009

**86 / 278 / CEE
Use of sludge in agriculture

SMART Product	SMARTech	Fertilising product	Category
Struvite	**SMARTech 2b (SCEPPHAR) & SMARTech 5**	Solid mineral, P as sole primary macronutrient	PFC 1 (C)
Ammonia solution	**SMARTech 3 (IEX)**	Liquid mineral, N as sole primary macronutrient	
Calcium phosphate	**SMARTech 3 (IEX)**	Solid mineral, P as sole primary macronutrient	PFC 1 (C)
P rich sludge	**SMARTech 4A (SCENA)**	Solid organic, NP as primary macronutrients	**
P rich compost	**Downstream SMARTechB**	Solid organic, NP as primary macronutrients	PFC 1 or PFC 3

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Regulatory barriers for SMART recovered nutrients

- Sewage sludge is **not included as input material** for compost in **fertilising products European regulation** (2019/1009 and previous 2003/2003)
- Although, its **inclusion** was **proposed** in the **end-of-waste criteria** for biodegradable waste subjected to biological treatment

CMC 3: COMPOST

1. An EU fertilising product may contain compost obtained through aerobic composting of exclusively one or more of the following input materials:

(a) bio-waste within the meaning of Directive 2008/98/EC resulting from separate bio-waste collection at source;

(b) derived products referred to in Article 32 of Regulation (EC) No 1069/2009 for which the end point in the manufacturing chain has been determined in accordance with the third subparagraph of Article 5(2) of that Regulation;

(c) living or dead organisms or parts thereof, which are unprocessed or processed only by manual, mechanical or gravitational means, by dissolution in water, by flotation, by extraction with water, by steam distillation or by heating solely to remove water, or which are extracted from air by any means, except:

— the organic fraction of mixed municipal household waste separated through mechanical, physicochemical, biological and/or manual treatment,

— sewage sludge, industrial sludge or dredging sludge, and

— animal by-products or derived products falling within the scope of Regulation (EC) No 1069/2009 for which no end point in the manufacturing chain has been determined in accordance with the third subparagraph of Article 5(2) of that Regulation;

(d) composting additives which are necessary to improve the process performance or the environmental performance of the composting process provided that:

(i) the additive is registered pursuant to Regulation (EC) No 1907/2006 ([1]), with a dossier containing:

— the information provided for by Annexes VI, VII and VIII to Regulation (EC) No 1907/2006, and

European fertilising products regulation 2019/1009

Barriers for SMART recovered BBF

- **Market competition**:
  - Fossil fertilising products
  - Cost of current mineral fertilisers
  - Manure based fertilising products

Opportunities for SMART recovered BBF

- **Opportunity for decentralised production (near of the end-users)**
- **WWTP turning into biorefineries → added value production/crossing value chains**
- **Renewable and sustainable**
- **Job opportunities**
- **Upgrading to tailor made fertilisers (reducing heterogeneity, improving delivery, etc)**

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Comparative economic study

Supported by the Framework Programme Horizon2020 under the grant agreement nº690323

	SMART biofertilizer	Compost from conventional sludge	Compost from MSW	Manure compost
NPK	>5%N >5% P >1%K	1.4-2.7%N 0.4-0.9% P	1.5- 2.1%N 0.6-0.9%P	2- 2.5%N 2-2.5%P 2-2.5%K
consumption	100- 160 kwh/t_{sludge}		160-250 kwh/t_{OFMSW}	
price	30-40€/tn	11-23 €/tn	20-35 €/tn	19-28 €/tn

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SMART-Plant

Scale-up of low-carbon footprint material recovery techniques in existing wastewater treatment plants "SMART-Plant"

H2020 ULTIMATE seminar:
Nutrient [redacted] recovery withi[redacted] H2020 SMAF [redacted] Plant project

AN[redacted] QUESTIONS?

Speaker: Sergio Ponsá – BETA Tech. Center

sergio.ponsa@uvic.cat

Proud Partner of SMART Plant project

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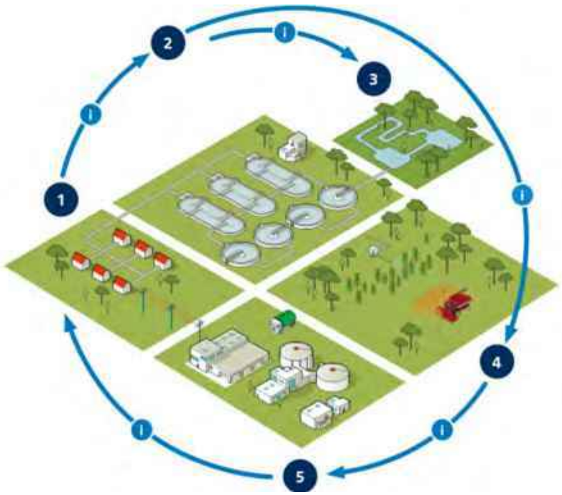
ULTIMATE
WATER SMART INDUSTRIAL SYMBIOSIS

Co-funded by the Horizon 2020 programme of the European Union

#1. Braunschweig

Germany



Circular solutions for

Materials

Energy

Relevant data

WWTP (actual load: 350,000 PE)

Relevant sectors

Water treatment

Horticulture

Energy

Lead partner:

Abwasserverband Braunschweig

Other partner:

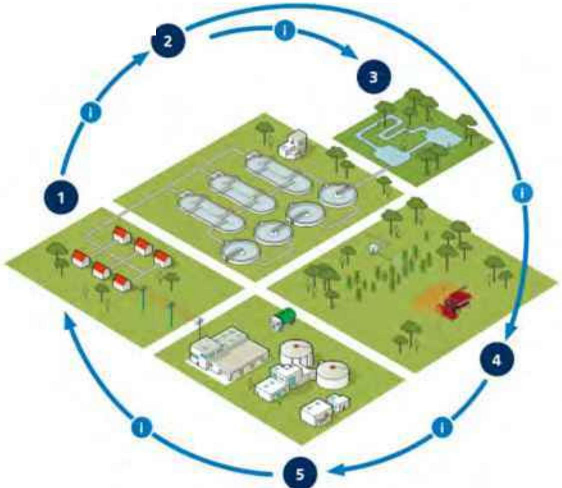
KOMPETENZZENTRUM Wasser Berlin

1. Objectives of the NextGen solutions

Starting status of sludge treatment at the WWTP:
three full-scale one-stage digesters

NextGen solution implemented in the sludge treatment:
1. Two-stage digestion system
2. Thermal pressure hydrolysis (TPH) between the two stages
3. System for struvite precipitation
4. System for ammonium sulfate production

Benefits of thermal pressure hydrolysis:
- Higher methane yield in second digestion stage
- Improved dewatering process of digested sludge
- Increase in dissolved phosphate and ammonium concentration

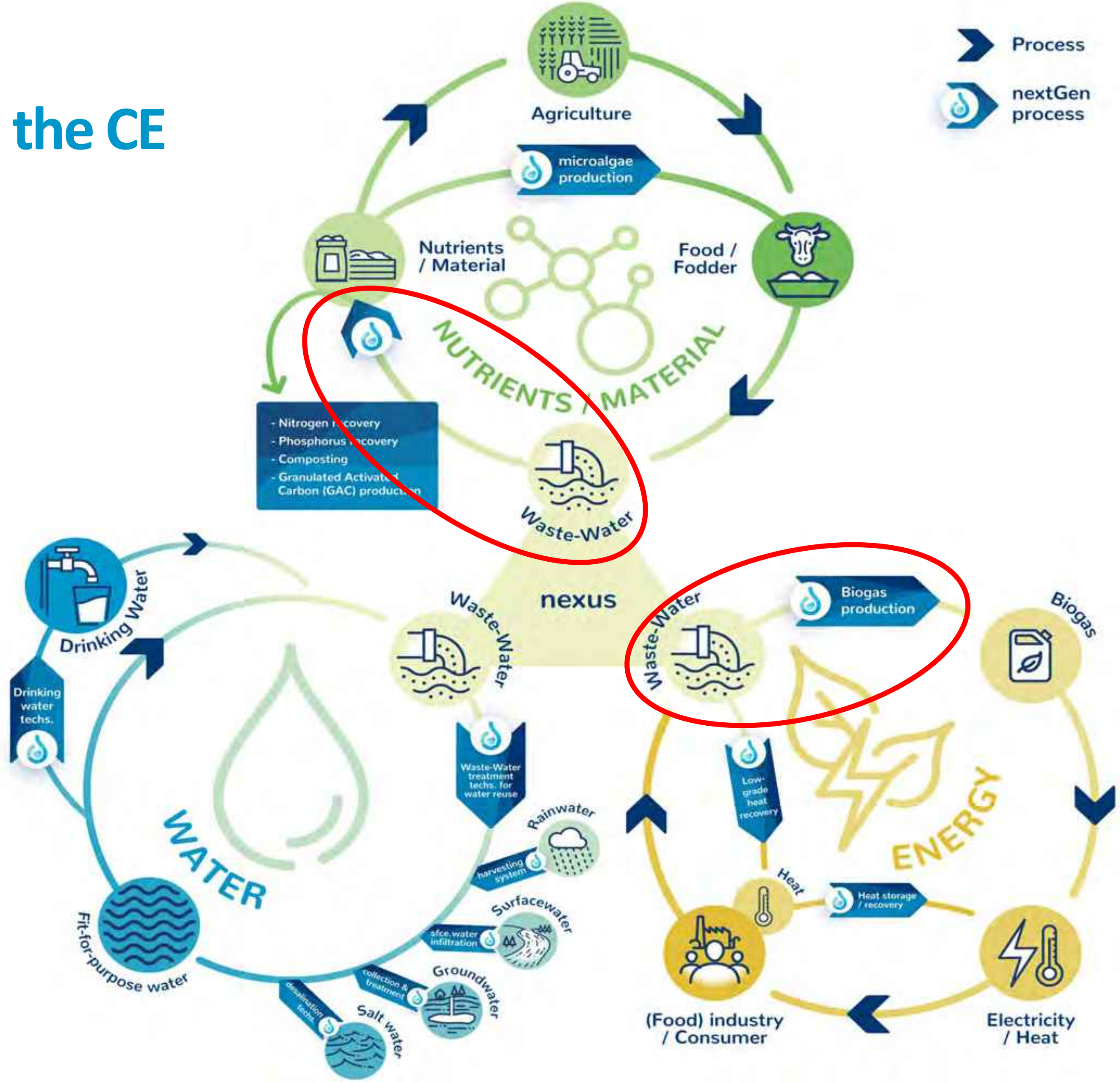


1. Objectives of the NextGen solutions

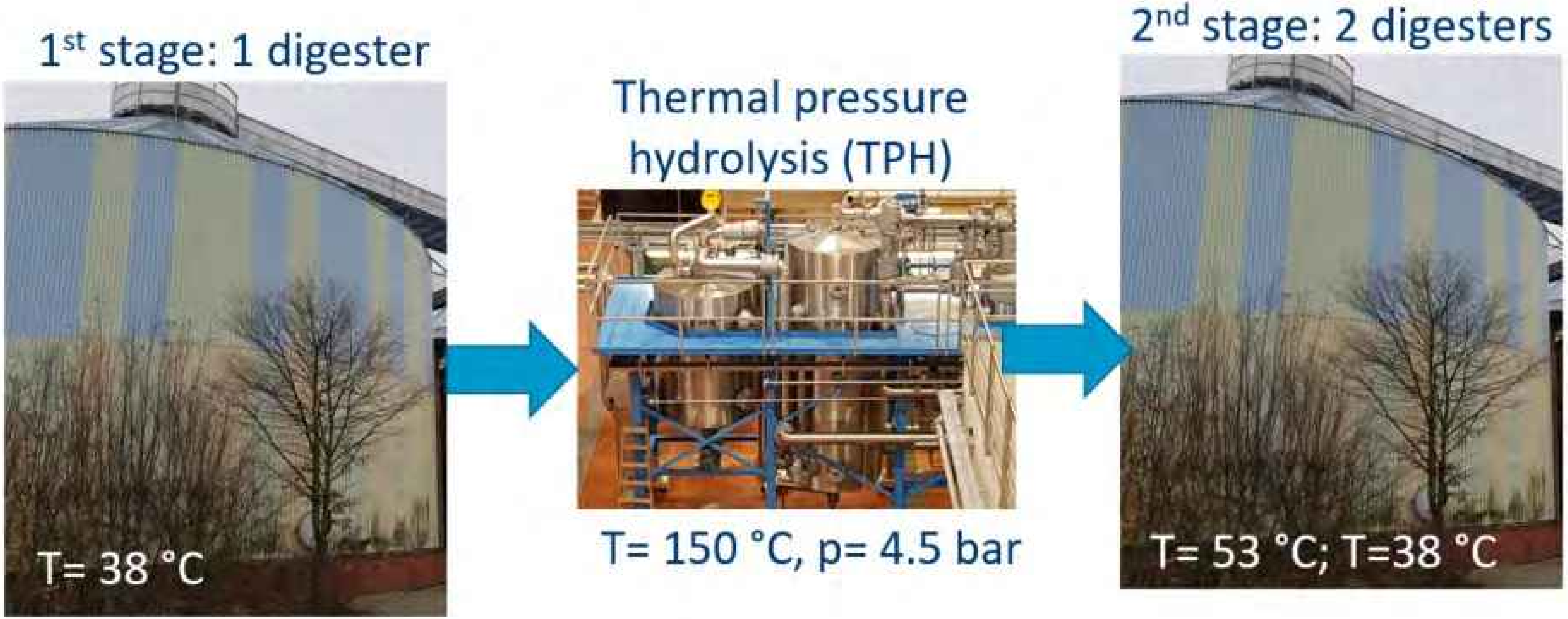
Positioning of demo case within the CE

Technology Evidence Base (TEB).

Braunschweig



2. New NextGen solutions: Two-stage digestion system and TPH



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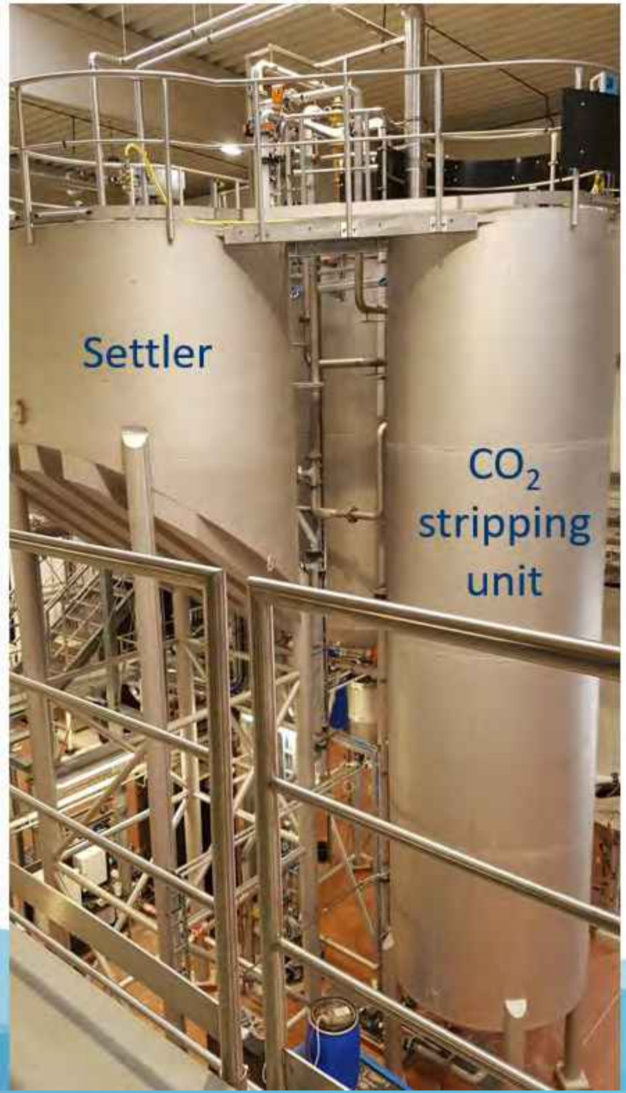
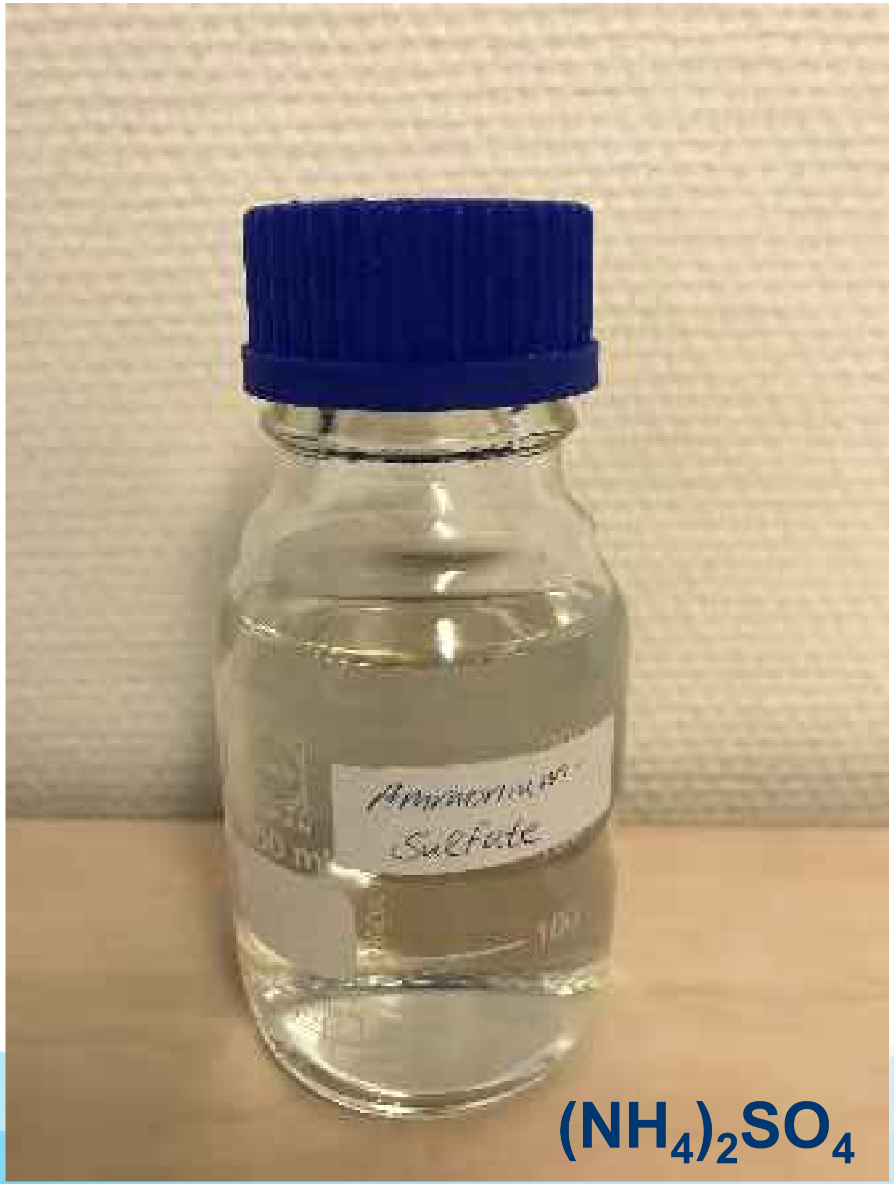
2. New NextGen solutions: struvite production

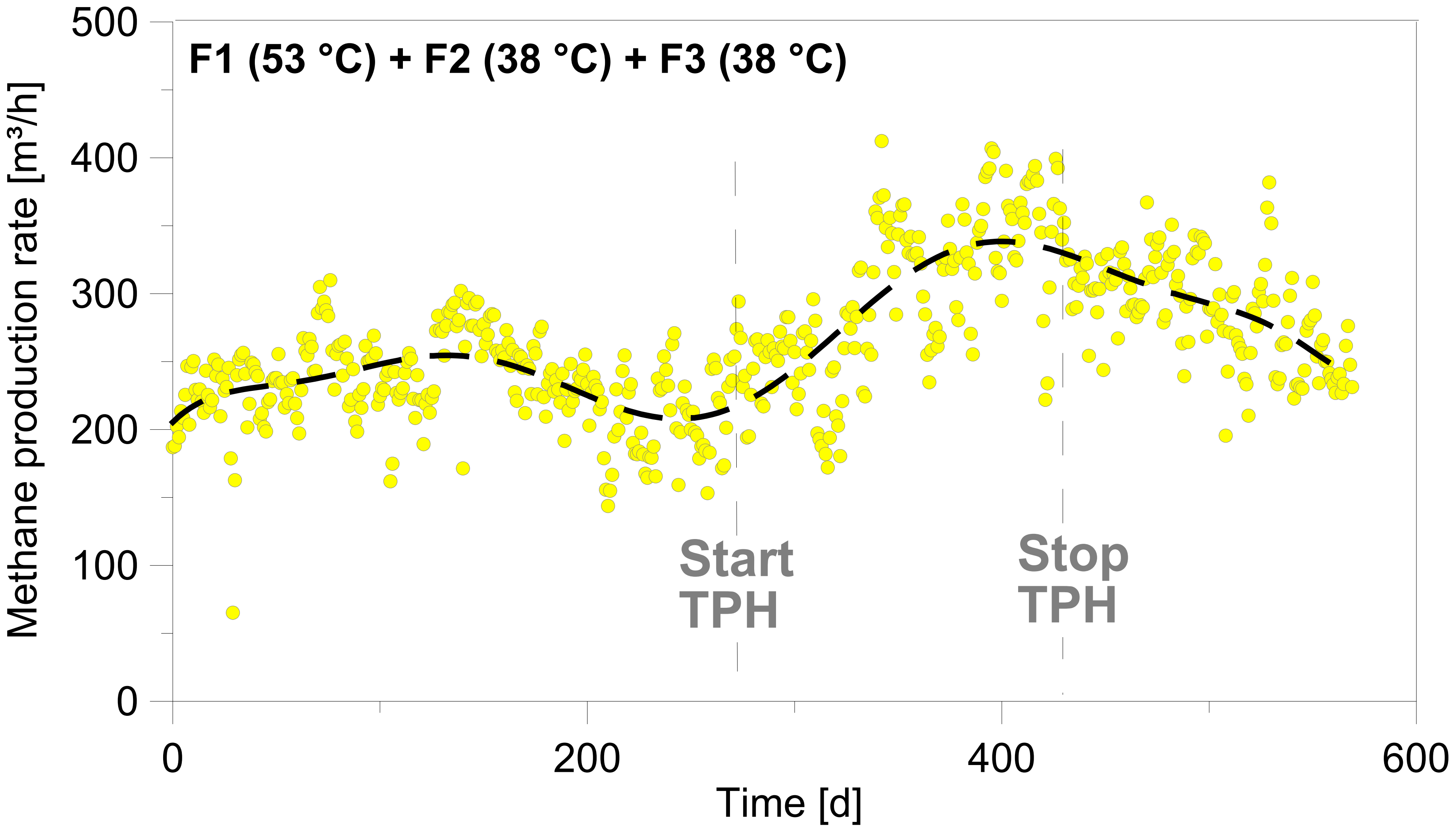


2. New NextGen solution: Ammonium sulphate production



3. Results and key performance indicators (KPIs)

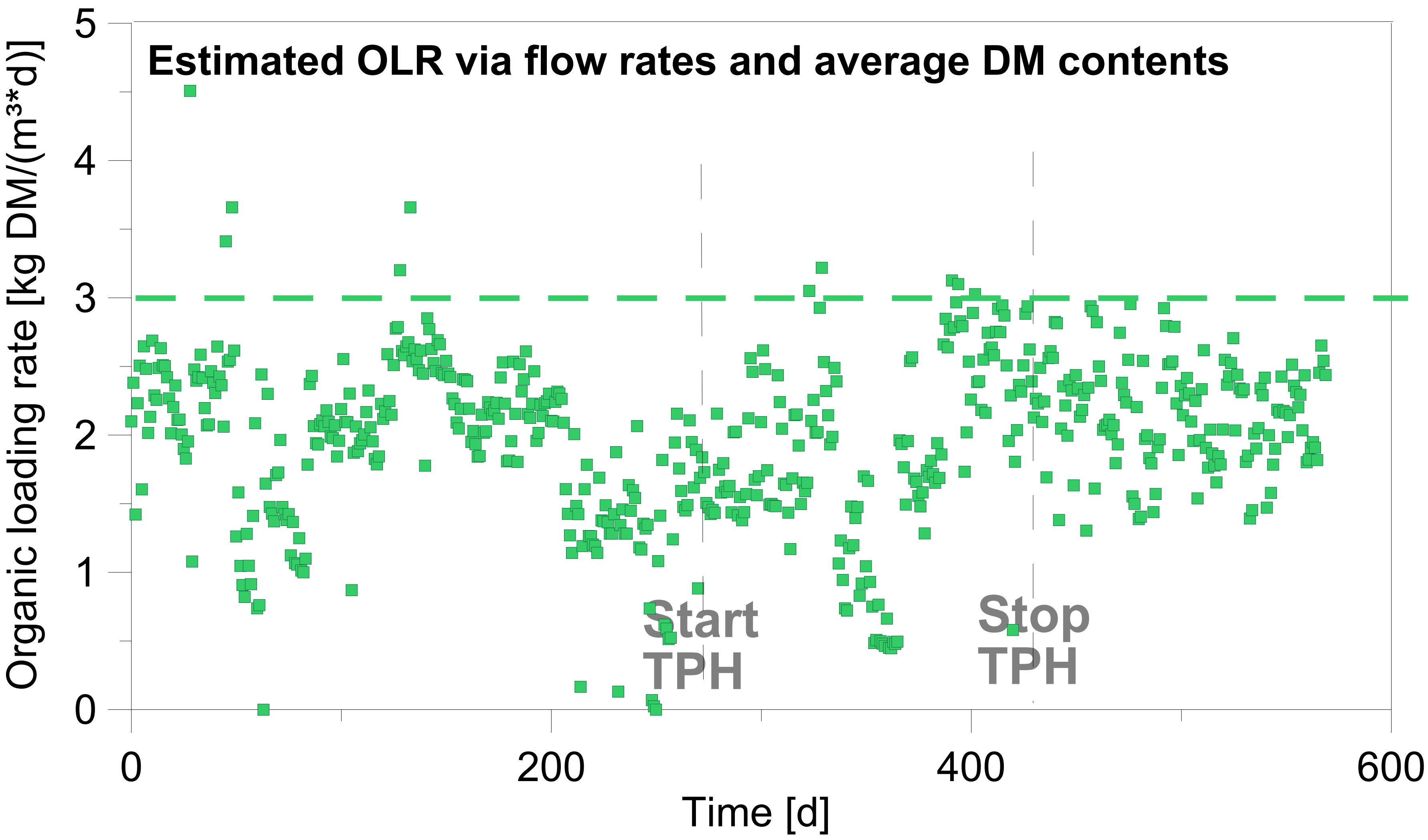
Up to 25% increase in methane production rate during TPH operation



3. Results and key performance indicators (KPIs)

Organic loading rate ranges mainly between 1 and 3 kg DM/(m³*d)

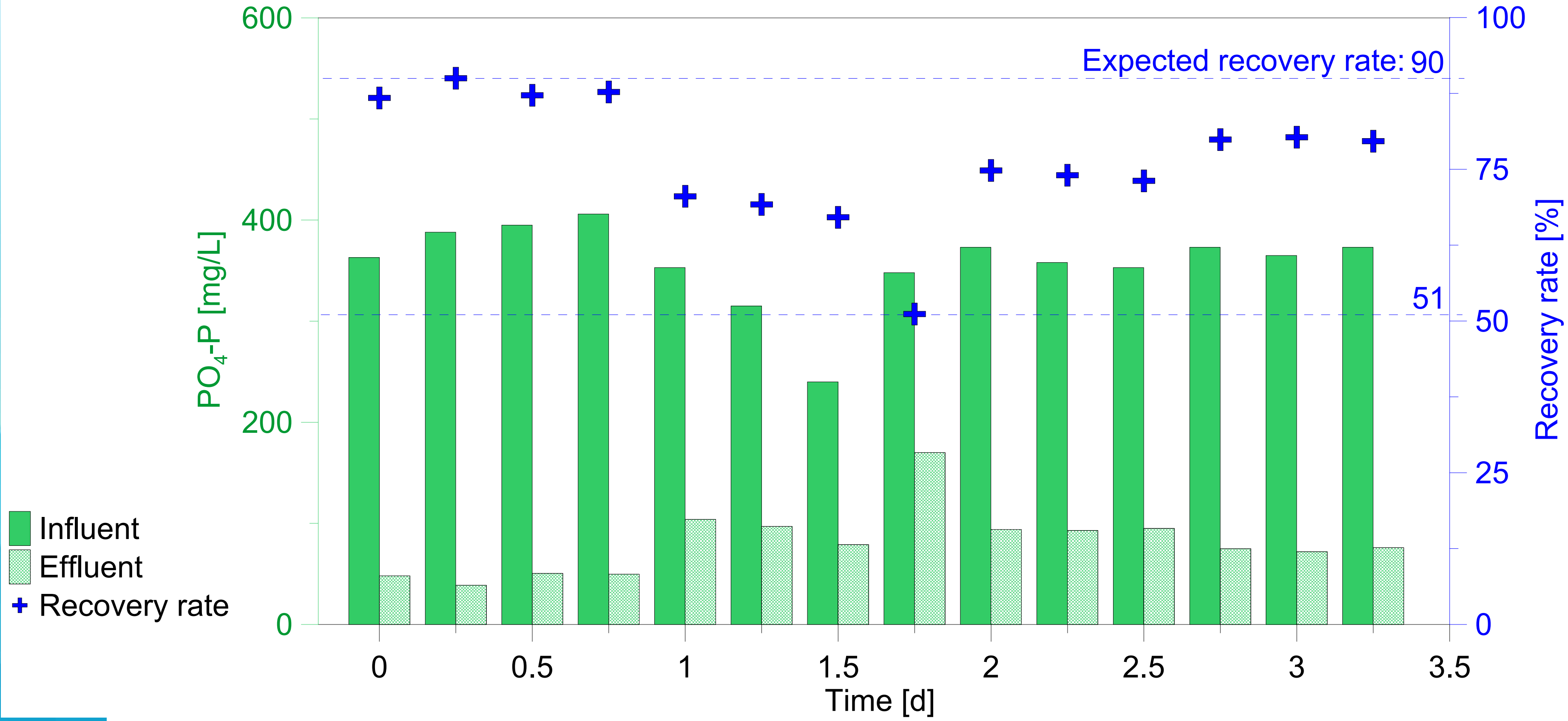
→ Increase in methane production rate due to TPH



3. Results and key performance indicators (KPIs)

Full-scale nutrient recovery

GOAL: Phosphorus recovery

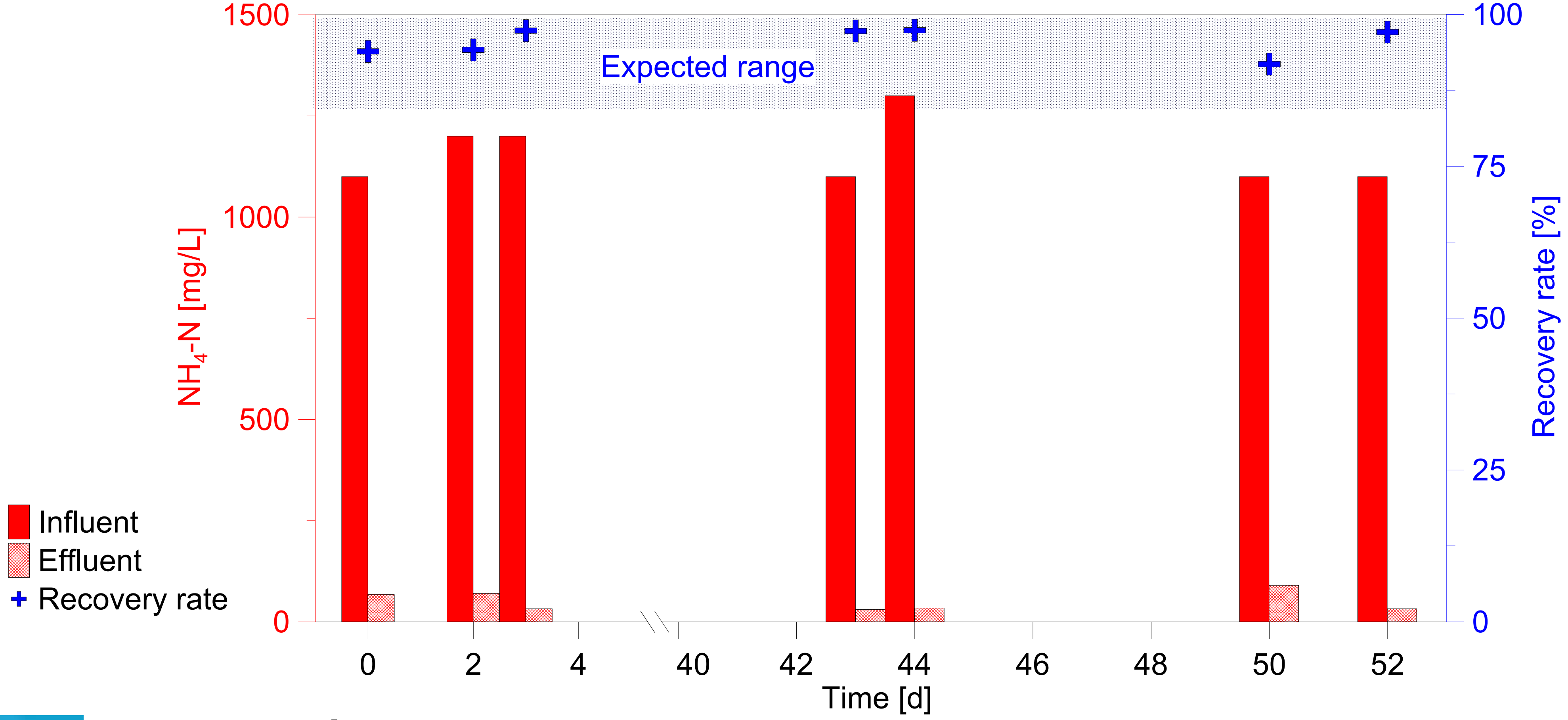


→ **Recovery rate is still too low: crystal size is too small**

3. Results and key performance indicators (KPIs)

Full-scale nutrient recovery

GOAL: Nitrogen recovery



→ **Recovery rate is higher than required**

→ **Optimization in order to save energy and chemicals**

4. Lessons learned so far

- **Thermal pressure hydrolysis:**
  - High-maintenance product
  - Constant high gas quality for steam generator -> avoiding higher fluctuations of system pressure **(< 20 – 30 mbar**)
- **Struvite precipitation**
  - Very low concentration of suspended solids in process water needed (**TSS < 600 mg/L**)
  - Long commissioning time for increasing particle size **> 3 mm**
- **Ammonium sulfate production**
  - Well-established + fail-safe technique
  - Very high recovery rates possible: **up to 98%**
- **System control**
  - Interaction of single technical units complex -> to be considered in system design

5. Outlook

Struvite production:
Optimization of production process aiming at the increase in grain size and a high P recovery rate via changes in hydrozyclone geometry, different $MgCl_2$ dosages, varying HRT

Ammonium sulfate solution production:
Optimization of production process aiming at a high N recovery rate and low energy and chemicals consumption (→ varying temperature & NaOH addition)

Heat management:
Analysis of internal heat management for TPH & two stage digestion system

Thank you!

Run4Life project.
Current results and exploitation pathways

Nicolás Morales Pereira
Run4Life Project Manager
aqualia

17th December 2020,
ULTIMATE Meeting on Nutrient Recovery

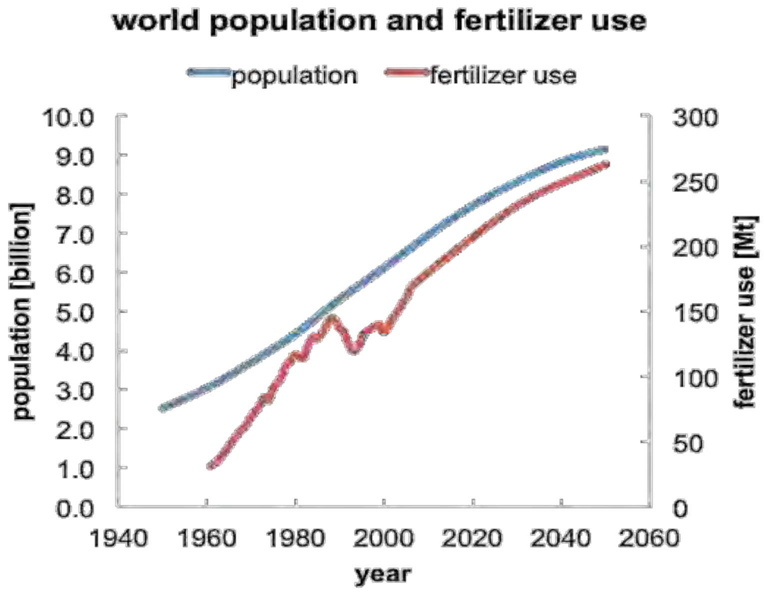
ULTIMATE
WATER SMART INDUSTRIAL SYMBIOSIS

The Run4Life project receives funding from the EU Horizon 2020
Research and Innovation programme, under G.A. No 730285.

Nutrients in wastewater

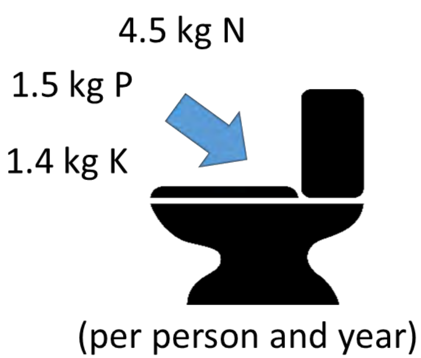
Context

- Global demand for food ↑
- Global demand for fertilisers ↑
- Phosphorus: not renewable, localised reserves
- Nitrogen: "Fertilizer from air" but highly energy demanding



Nutrients in wastewater (WW)

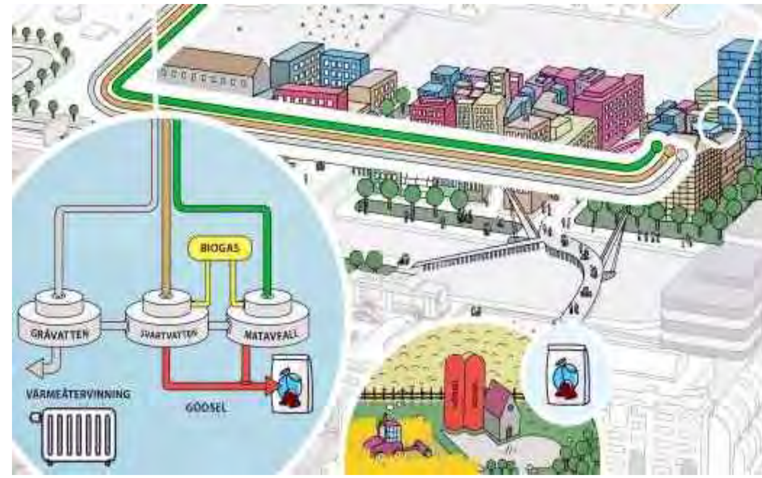
A potential pollutant – and important **resource -** currently not exploited in the conventional, centralised and linear approach based in the **old concept of Cloaca Maxima**

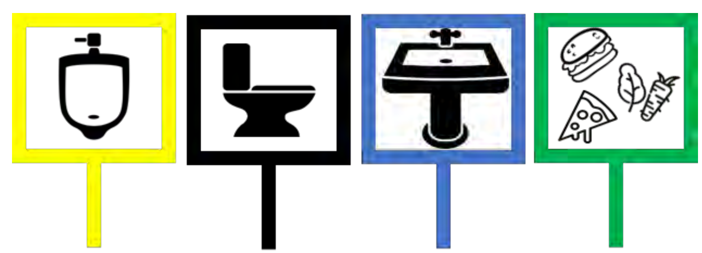


Run4Life change of concept

Run4Life: decentralised resource recovery at the source

1. **Separation** at source
   - Black water (BW), kitchen waste (KW) and grey water (GW)
2. Technological **innovations** and **new business models.**
3. Break barriers to implementation: **market** uptake, and **social and legal** acceptance

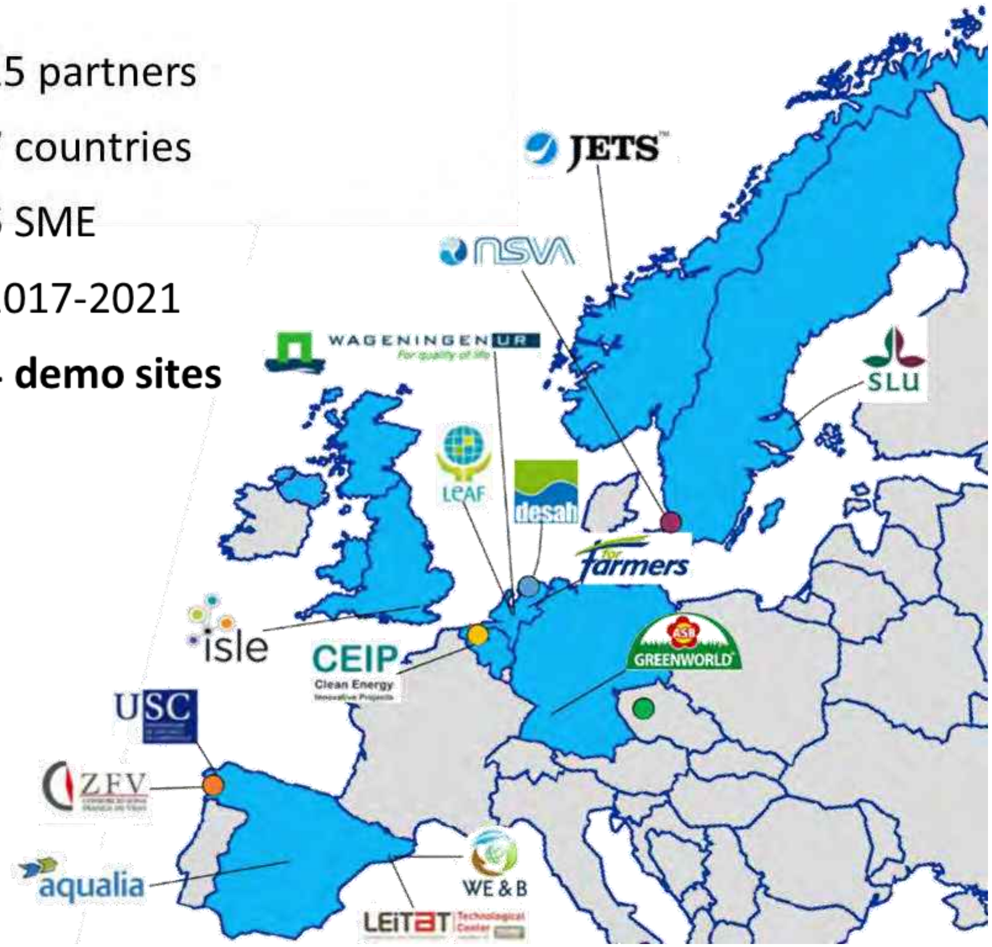




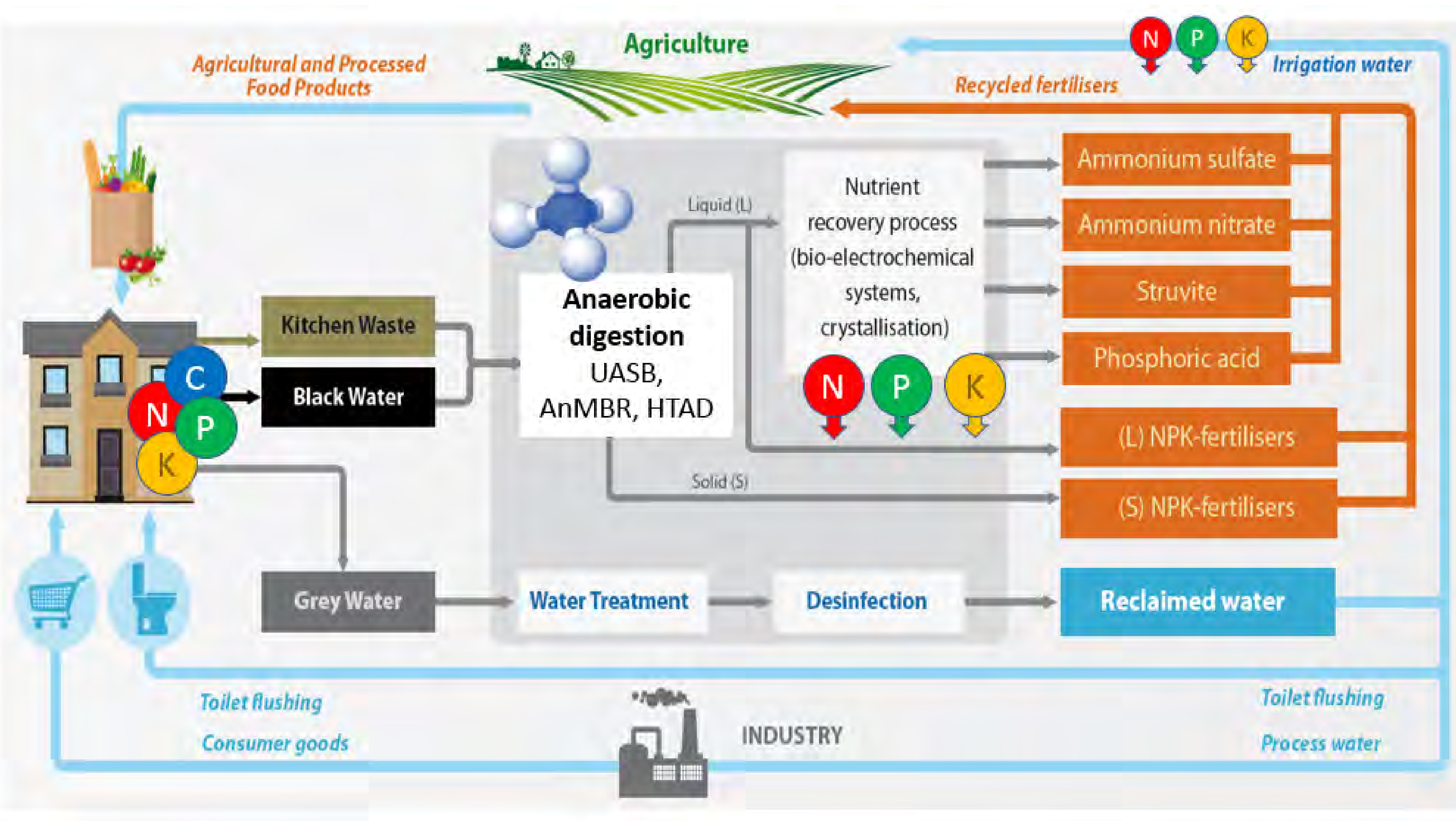
Horizon 2020, GA 730285.

Run4Life project. General data and demo sites

- 15 partners
- 7 countries
- 6 SME
- 2017-2021
- **4 demo sites**



Run4Life General flowchart



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Demo sites and technologies

Nieuwe Dokken - Ghent, Belgium (1200 p.e.)

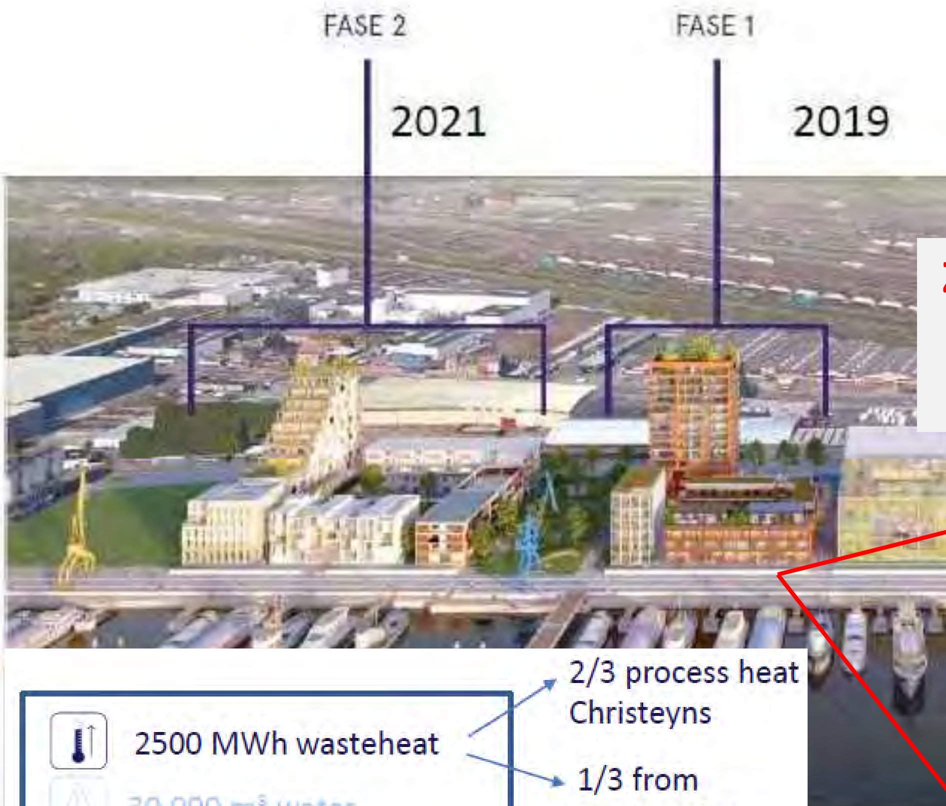
CEIP Clean Energy Innovative Projects

DuCoop

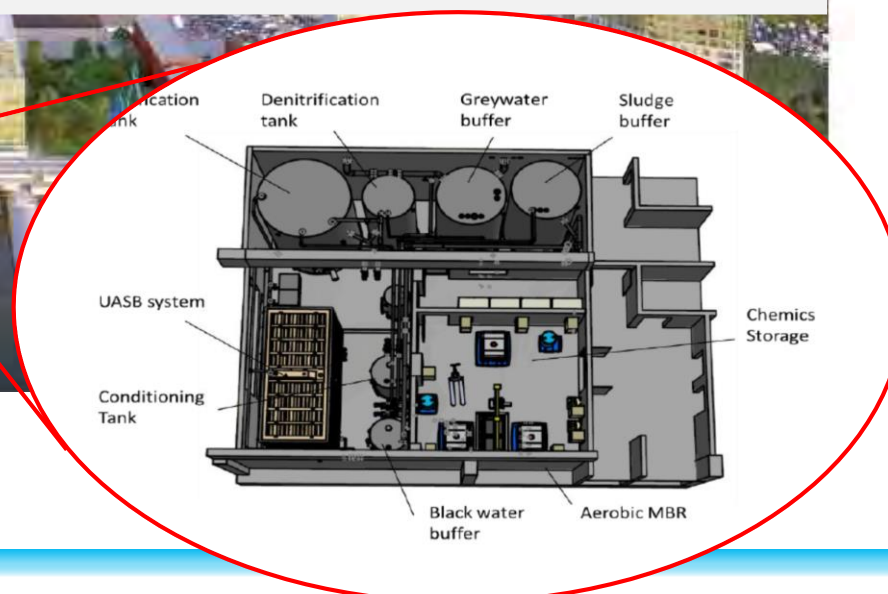
>400 Housing units+ City complex (schools, sports infrastructure etc.)

Demo sites and technologies

Nieuwe Dokken - Ghent, Belgium (1200 p.e.)



ZERO WASTEWATER WITH RECOVERY OF ENERGY & NUTRIENTS (ZAWENT)
Basement of FASE 1

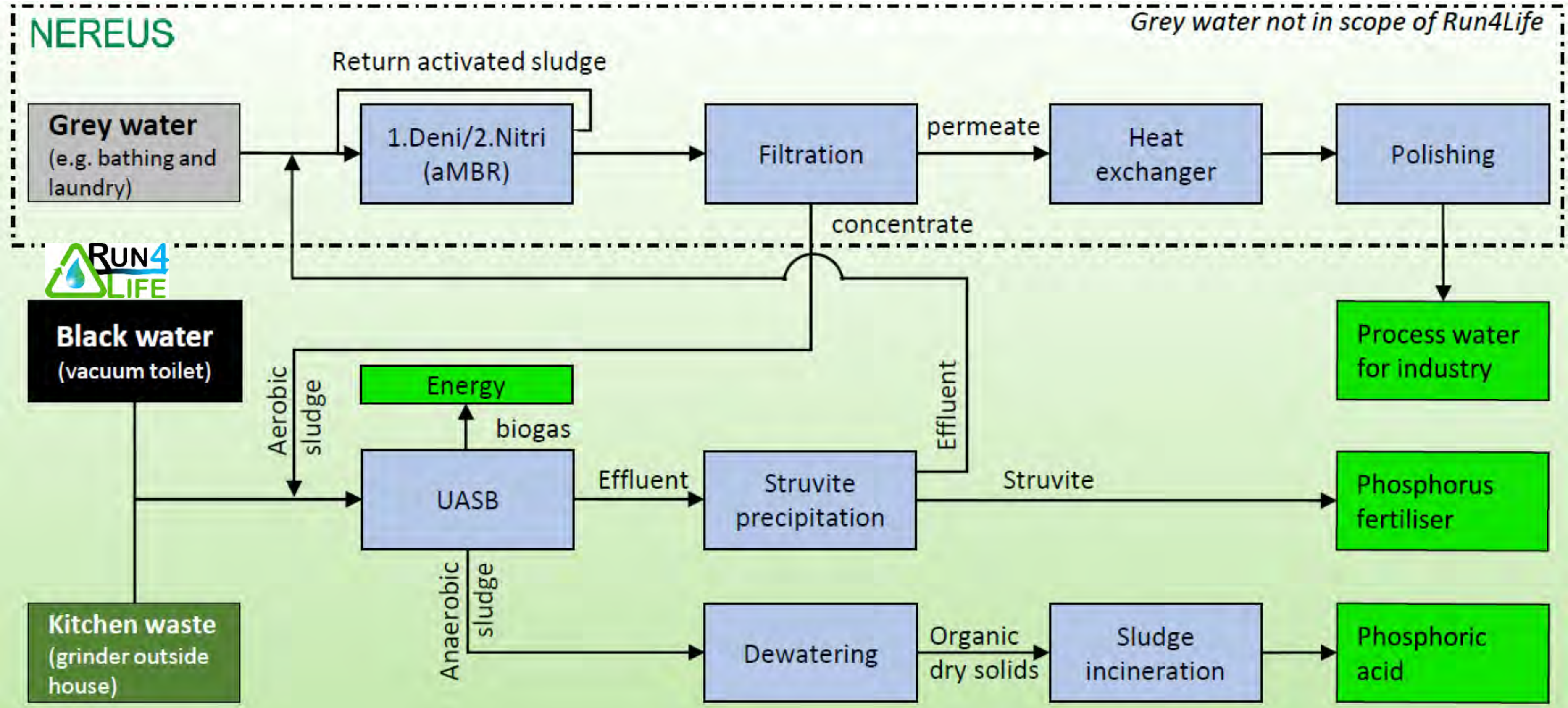


- 2500 MWh wasteheat
  - 2/3 process heat Christeyns
  - 1/3 from wastewater
- 30.000 m³ water
- 1.500kg green fertilizer

Horizon 2020, GA 730285.

Demo sites and technologies

Nieuwe Dokken - Ghent, Belgium (1200 p.e.)



Exploitation: Cooperative business model

Nieuwe Dokken - Ghent, Belgium (1200 p.e.)

Founding partners

CEIP Clean Energy Innovative Projects, FARYS, Triyidend, Energent, Oya cvba, Schipperskaai

residents

Private equity

Interreg 2 Seas Mers Zeeën NEREUS, Vlaanderen is energie, European Commission

Subsidies

Triodos Bank

Bank loans

Energy
4de gen. Heat network (waste heat Christeyns)
rooftop PV
Smart Grid appliances

Water
Local sanitation
Reuse as process water (Christeyns)

Waste
Source separation
e.g. vacuum systems
Waste collection
Water treatment
Nutrient recovery

Mobility
Electric bikes
Electric sharing cars
& charging stations

How & why a cooperative legal entity?

- **Cooperation** with citizen participation allow for:
  - Flexible capital
  - Legal limit of 6% IRR
  - Securing **fair price** setting

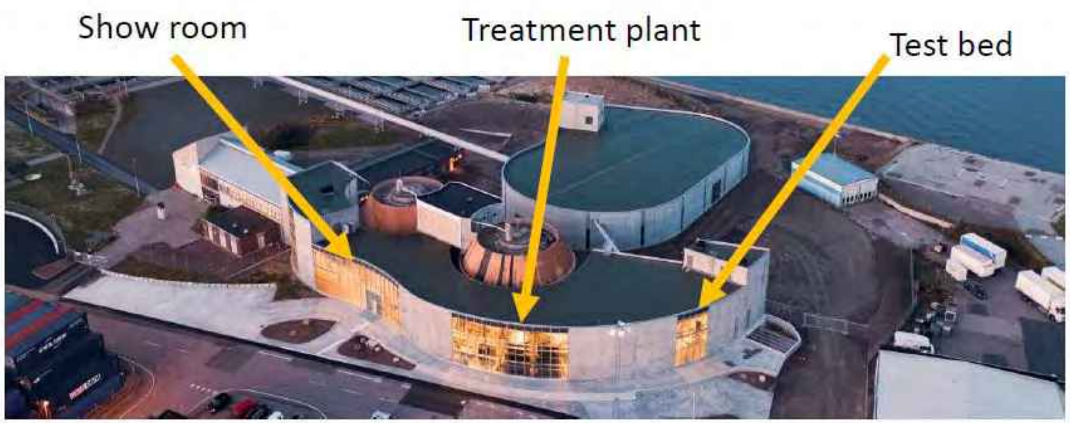
DuCoop

- **Financial stimulus** for end users (correct use of the systems)
- Governance **participation** by **inhabitants**
  - Representation in Board and General Assembly
  - Voting right in General Assembly
  - Strong involvement / ambassadors

RUN4LIFE

Oceanhamnen (H+) - Helsingborg, Sweden (1800 p.e.)

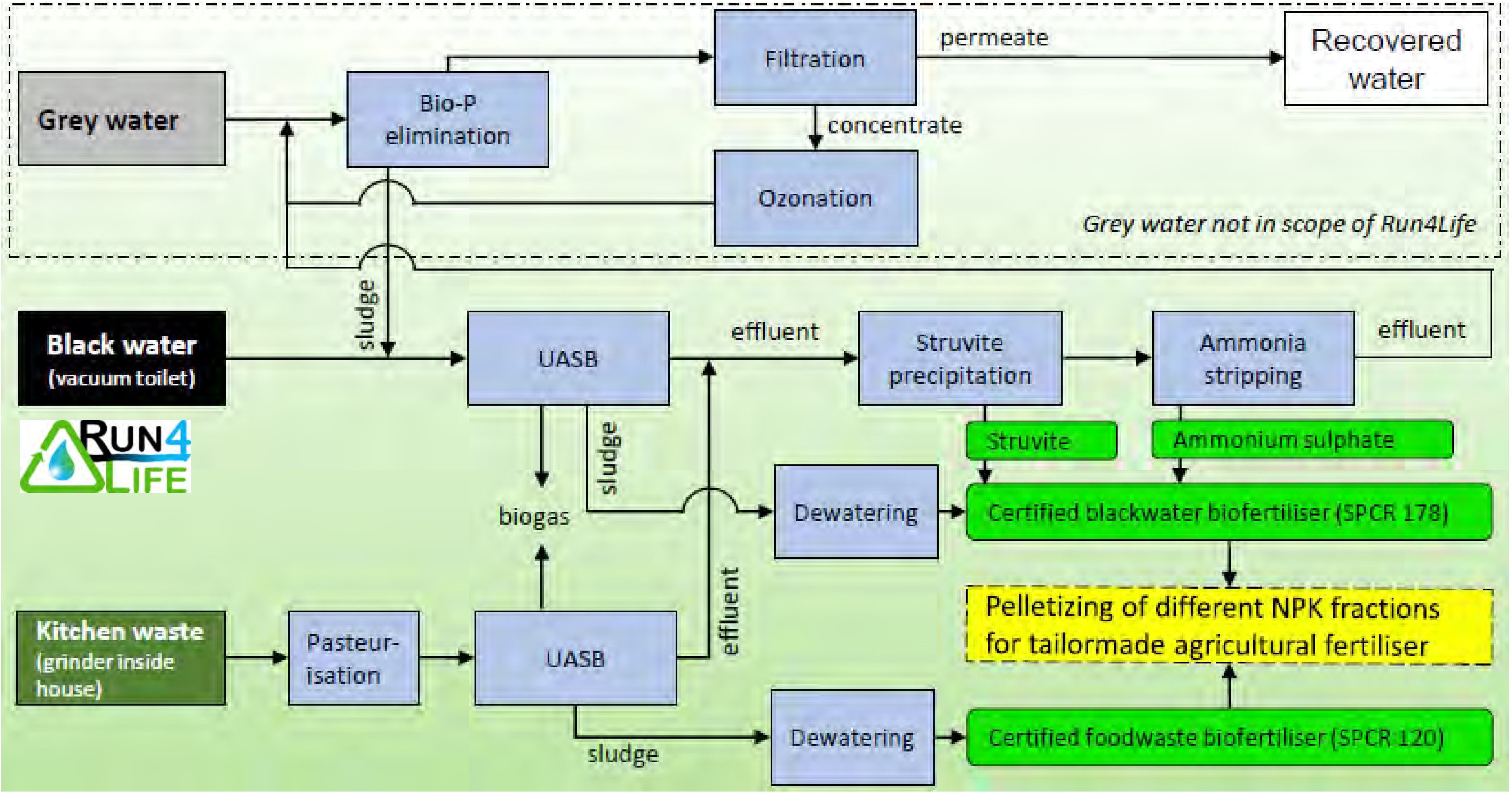
- Innovative waste and wastewater management system.
- Around 320 apartments and several office buildings



- Local treatment system
- Reco Lab: Recovery laboratory, test-bed facility
- Educational showroom

Demo sites and technologies

Oceanhamnen (H+) - Helsingborg, Sweden (1800 p.e.)



Exploitation: Tailor made fertilizer

Oceanhamnen (H+) - Helsingborg, Sweden (1800 p.e.)

NSVA

NPK pellet

- **Dewatered food waste sludge** from anaerobic digester (certified as biofertilizer using national certification system)
- **Struvite** (EU end of waste classified as a product)
- **Ammonium sulphate** (EU end of waste classified as a product)
- Commercial **potassium chloride**

Accepted by farmers in Sweden:

- **The products are clean** (free from heavy metals and organic pollutants)
- **Concentrated** (at least 5% of nitrogen, but preferably up to 20%)
- Spread using **conventional equipment**

Horizon 2020, GA 730285.

Run4Life

Demo sites and technologies

Lemmerweg - Sneek, the Netherlands (32 houses)

Lemmerweg - Sneek, the Netherlands (32 houses)

Innovations: ULF Toilets

•Normal (gravity sewer) toilets: 4-9 L/flush
•Conventional vacuum toilets: 0.8-1.5 L/flush
•**ULF vacuum toilets: 0.4-0.7 L/Flush**

Benefits
-notable water savings
-smaller piping dimensions
-**highly concentrated blackwater**

> 40 g COD/L

Horizon 2020, GA 730285.

Lemmerweg - Sneek, the Netherlands (32 houses)

Innovations: (H)TAD

One step for 3 processes (innovation)

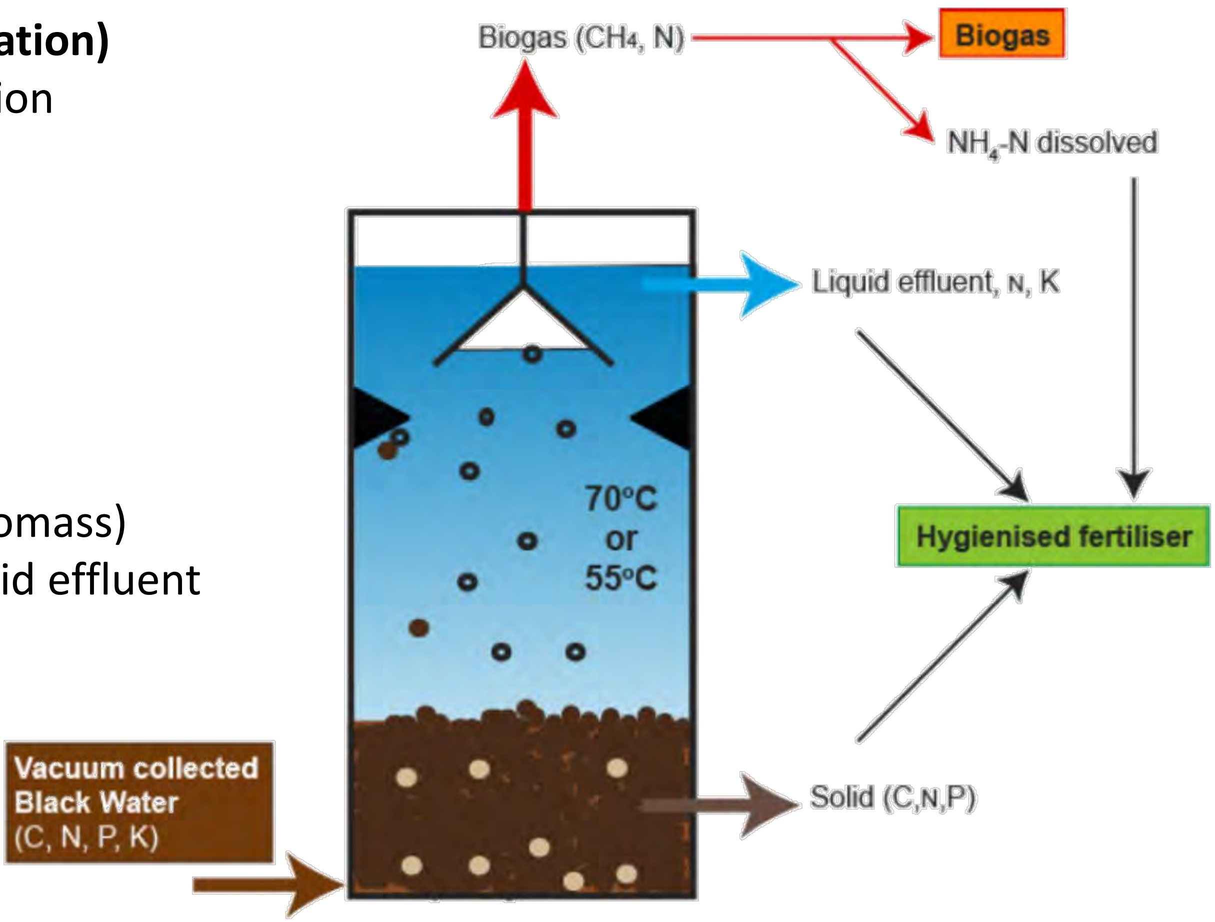
- Treatment and biogas production
- Fertiliser production
- Hygienisation

2 main fertiliser streams:

- liquid effluent
- sludge

Most P ends up in the sludge (biomass)

Most N and K ends up in the liquid effluent



Demo sites and technologies

Lemmerweg - Sneek, the Netherlands (32 houses)

(H)TAD reactor performance:

Parameter	Unit	Reference 35 °C	Desah 70 °C	Desah 60 °C	Desah 55 °C (ongoing)
HRT	d	11 ± 1.0	14.9 ± 5.0	10.9 ± 1.0	Ongoing
OLR	gCOD/L/d	0.7 ± 0.1	1.72 ± 0.39	3.5 ± 1.1	
COD in	gCOD/L	10.1 ± 1.8	23.7 ± 2.0	41.7 ± 9.3	
COD_T Removal	**%**	**79.1 ± 4.9**	**42.2 ± 14.8**	**56.5 ± 17.9**	
Methanization	**% of COD_{rem}**	**87.3 ± 16.4**	**41.4 ± 12.3**	**51.9 ± 17.6**	

- COD removal and methanization increase with decreasing T
- The balance between hygenisation and methane production seems to be around 55ºC. (up to 80 % methanization at lab scale).

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Lemmerweg - Sneek, the Netherlands (32 houses)

(H)TAD reactor performance:

Fertiliser Production

	Reference		Run4Life	
	Influent (35°C)	Effluent (35°C)	Influent (60°C)	Effluent (60°C)
Total N (g/L)	1.4	1.3	3.8	2.9
NH4-N (g/L)	0.8	1.1	1.5	1.8
Total P (mg/L)	120	96	960	340
PO4-P (mg/L)	101	89	420	164
CARBA (CFU)	0.9	0.03	Not Detected	Not Detected
TBX E.coli (CFU)	5.9	3.6	5.5	Not Detected
ESBL (CFU)	3.9	1.2	3.9	Not Detected

Exploitation: (H)TAD and ULF toilets

Lemmerweg - Sneek, the Netherlands (32 houses)

Full scale installations for decentralised sanitation and resource recovery

Niche market cases:

- New build districts
- High rise buildings
- Sustainable resorts
- Areas with no sewer connection / no capacity for increased sewage flow

- ULF Toilet useful if technology downstream take profit from the ultra concentration of blackwater → Recovery of energy/nutrients

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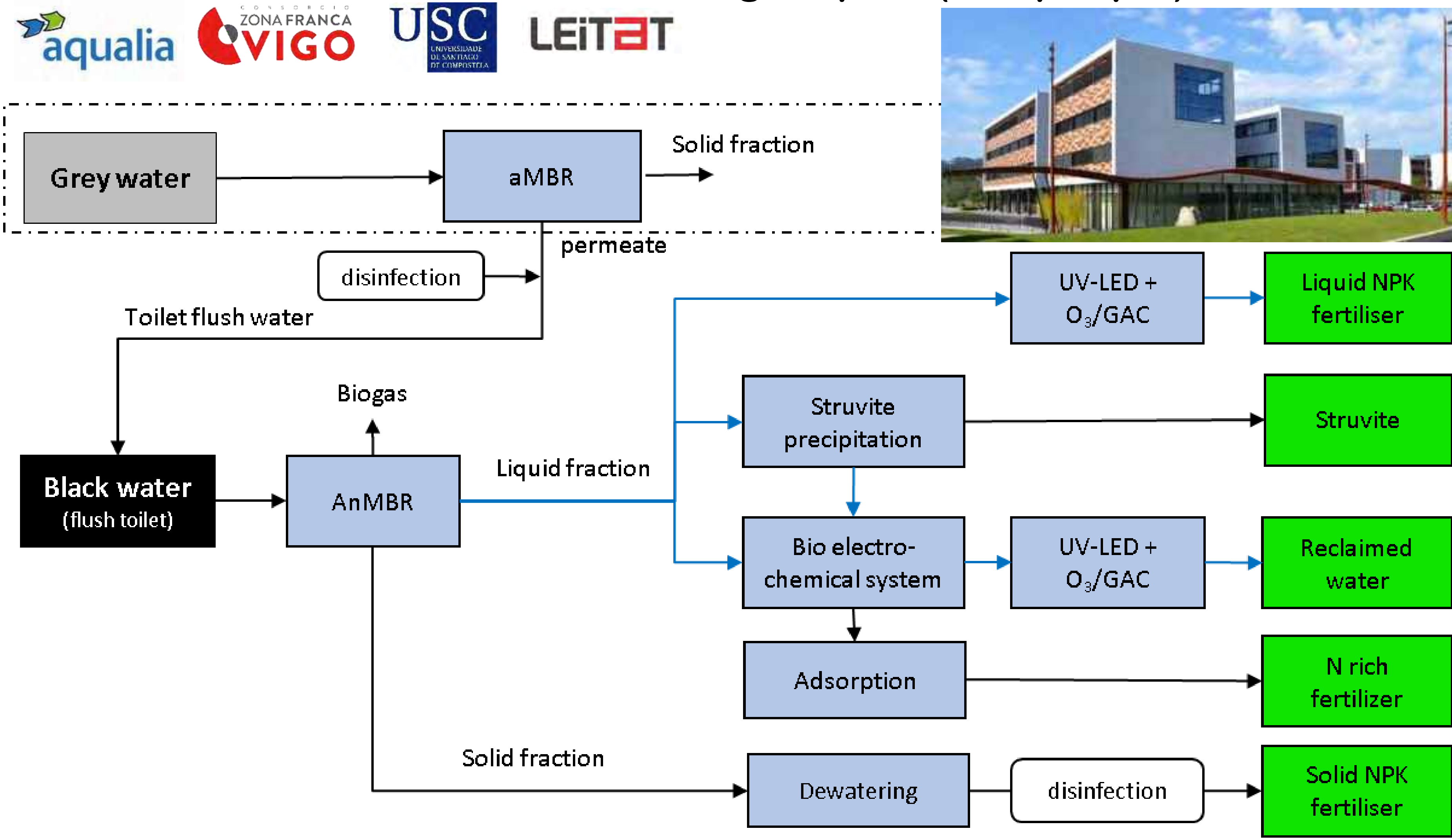
Demo sites and technologies

Porto do Molle Business Centre - Vigo, Spain (250 people)



Horizon 2020, GA 730285.

Porto do Molle Business Centre - Vigo, Spain (250 people)

aqualia ZONA FRANCA VIGO USC LEITAT

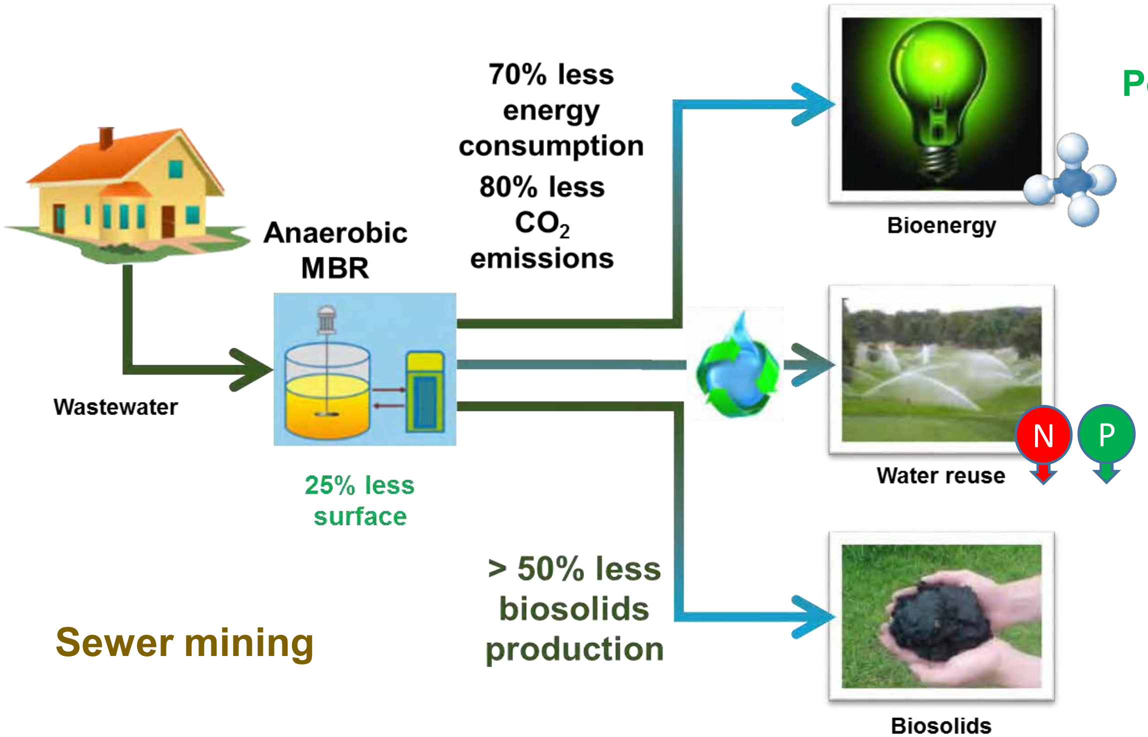
AnMBR treating BW at room temperatura (25 ºC).
Flow: 0.8-1.5 m^3/d
Stable operation: 8-10 LMH
COD BW inlet: 1425 ± 823 mg/L
COD removal: 94 %

Steady state biogas production ≈ 0.25 m^3/d
Methane ≈ 73%.

Parameter	Blackwater	Treated water
Total P (mg/L)	20 ± 10	17 ± 5
N-NH_4^+ (mg/L)	115 ± 40	130 ± 45
Total N (mg/L)	190 ± 70	195 ± 90
Potassium (mg/L)	120 ± 30	110 ± 30
pH	7.3 ± 0.3	7.15 ± 0.15
Alcalinity (mg IC/L)	133 ± 47	117 ± 30

Horizon 2020, GA 730285.

Anaerobic Membrane Bioreactor AnMBR

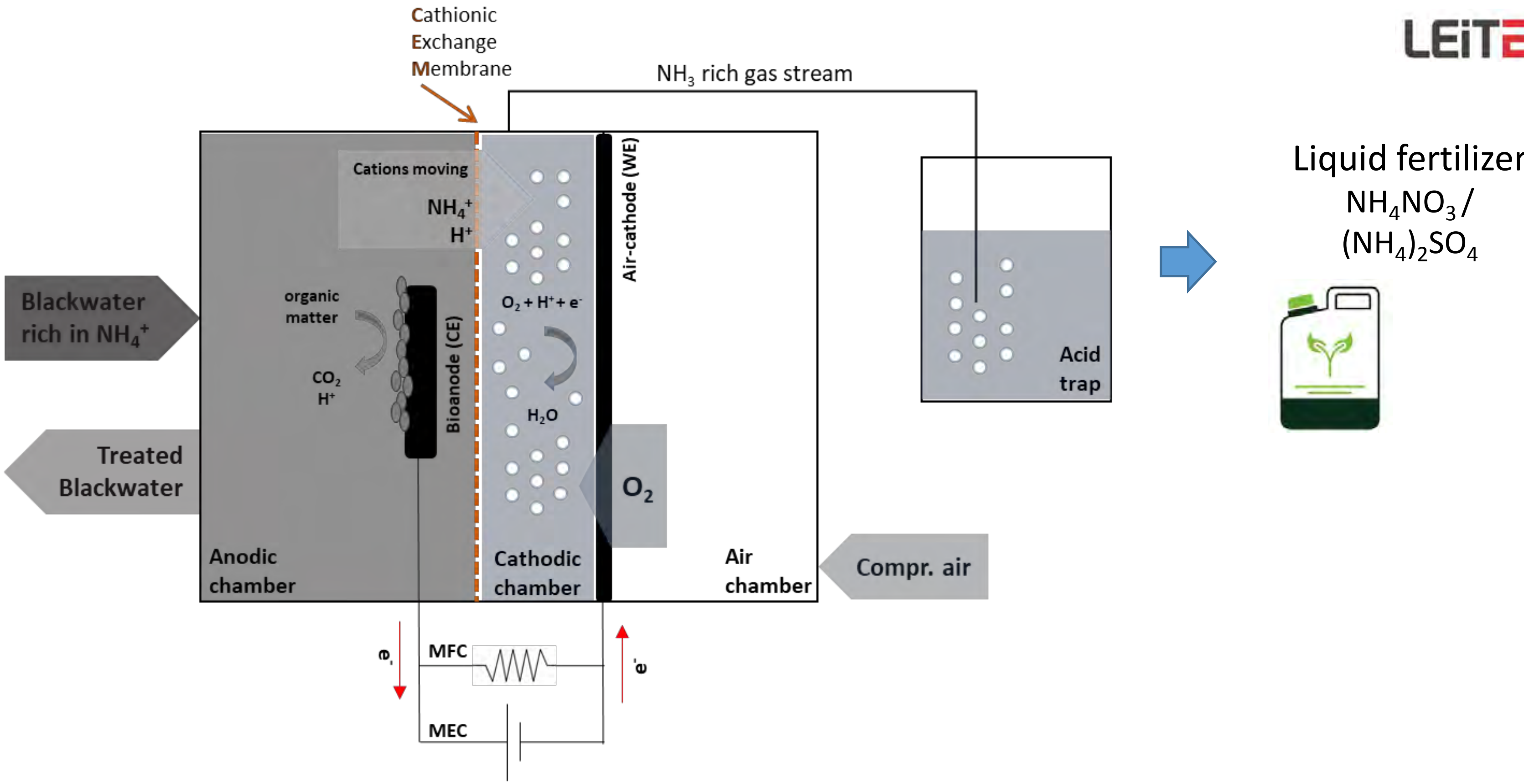


Potential Net Energy production of > 0.1 kWh/m^3

Disinfected Nutrient Rich Water for Irrigation

Horizon 2020, GA 730285.

Innovations: Nitrogen recovery with BioElectrochemical Systems (BES)



Operating as MEC in a 5 d batch

- Recovering up to 61% of initial N present in BW (1 g N/L)
- Rate of 12.8 g $N/m^2/d$

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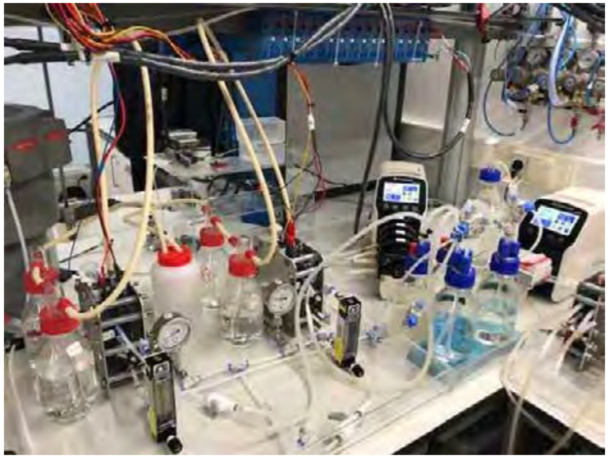
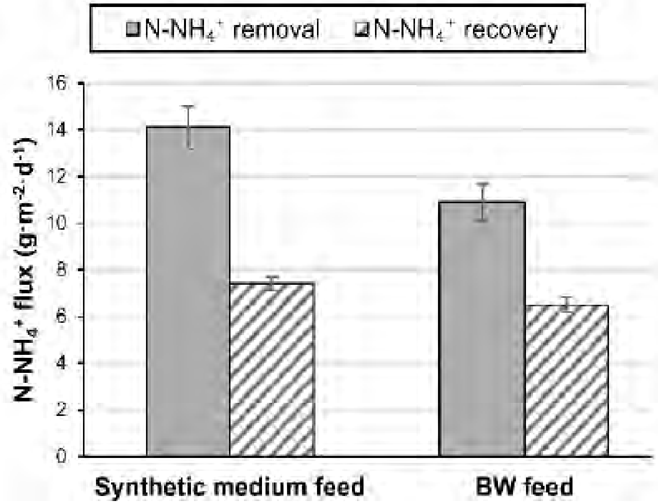
Innovations: Nitrogen recovery with BioElectrochemical Systems (BES)

LEITAT





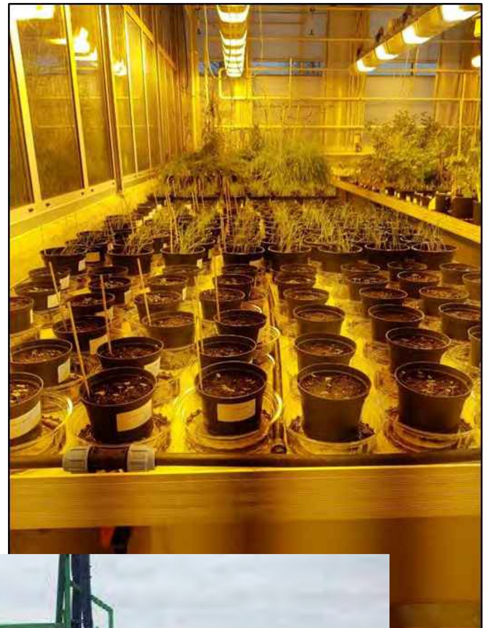
≈40-50% N recovery in the acid trap as liquid fertilizer

	Reference MEC in literature	Run4Life MEC system
Applied potential (V)	0.6-2.12[1,2]	0.2
Current density (A/m²)	1.89-30[1,2]	2.78
$N\text{-}NH_4^+$ removal efficiency (%)	34.3-51[1]	81
$N\text{-}NH_4^+$ recovery efficiency (%)	79-94[2]	60
Energy consumption	6.04-20.5 kWh per kg of nitrogen removed [3,4]	1.61 kWh per kg of nitrogen removed[4] 2.24 kWh per kg of nitrogen recovered[4]

>50% reduction respect SOA

Horizon 2020, GA 730285.

Pot and field fertilizer tests



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Horizon 2020, GA 730285.

Annex 6: Presentations – Material recovery

The project leading to this application has received funding from the European Union's
Horizon 2020 research and innovation programme under grant agreement No 869318

ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

Online seminar
Material recovery and safe reuse

F. Fatone, A. Kleyböcker, S. Casas, A. Naves, C. Bruni

June, 23rd 2021

Ultimate (June 2020 – May 2024)
Industry water-utility symbiosis for a smarter water society

- Promotion, establishment and extension of **Water Smart Industrial Symbioses**
- Development and demonstration of **innovative technologies** for symbioses
- **Assessment** of the technologies and development of **digital «support tools»**
- Development of **new business models** towards marketability

9 Symbioses between:

Industrial sectors
- Agro-food
- Beverage
- (Petro)chemical
- Biotech

Service providers
- Municipal utility
- Multi-industry utility
- Specialized SME
- Water services provider

Coordinator: KWR

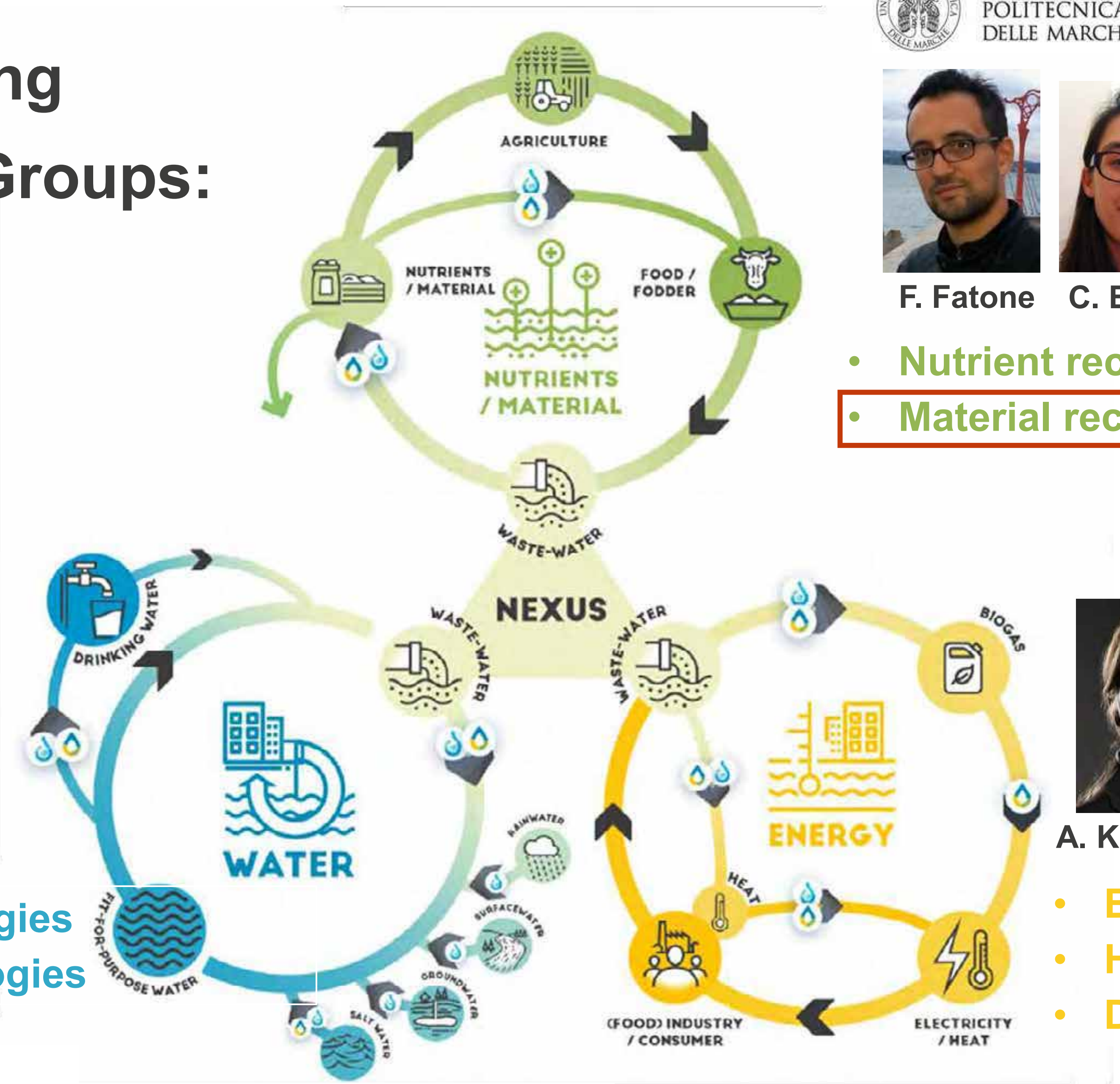
9 Case Studies

27 Partners

37 Technologies

The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

3 Cross-cutting Technology Groups: 9 Topics



UNIVERSITÀ POLITECNICA DELLE MARCHE

F. Fatone C. Bruni

- Nutrient recovery
- Material recovery

eurecat
Centre Tecnològic de Catalunya

S. Casas

- Membrane technologies
- Adsorption technologies

A. Kleyböcker

KOMPETENZZENTRUM Wasser Berlin

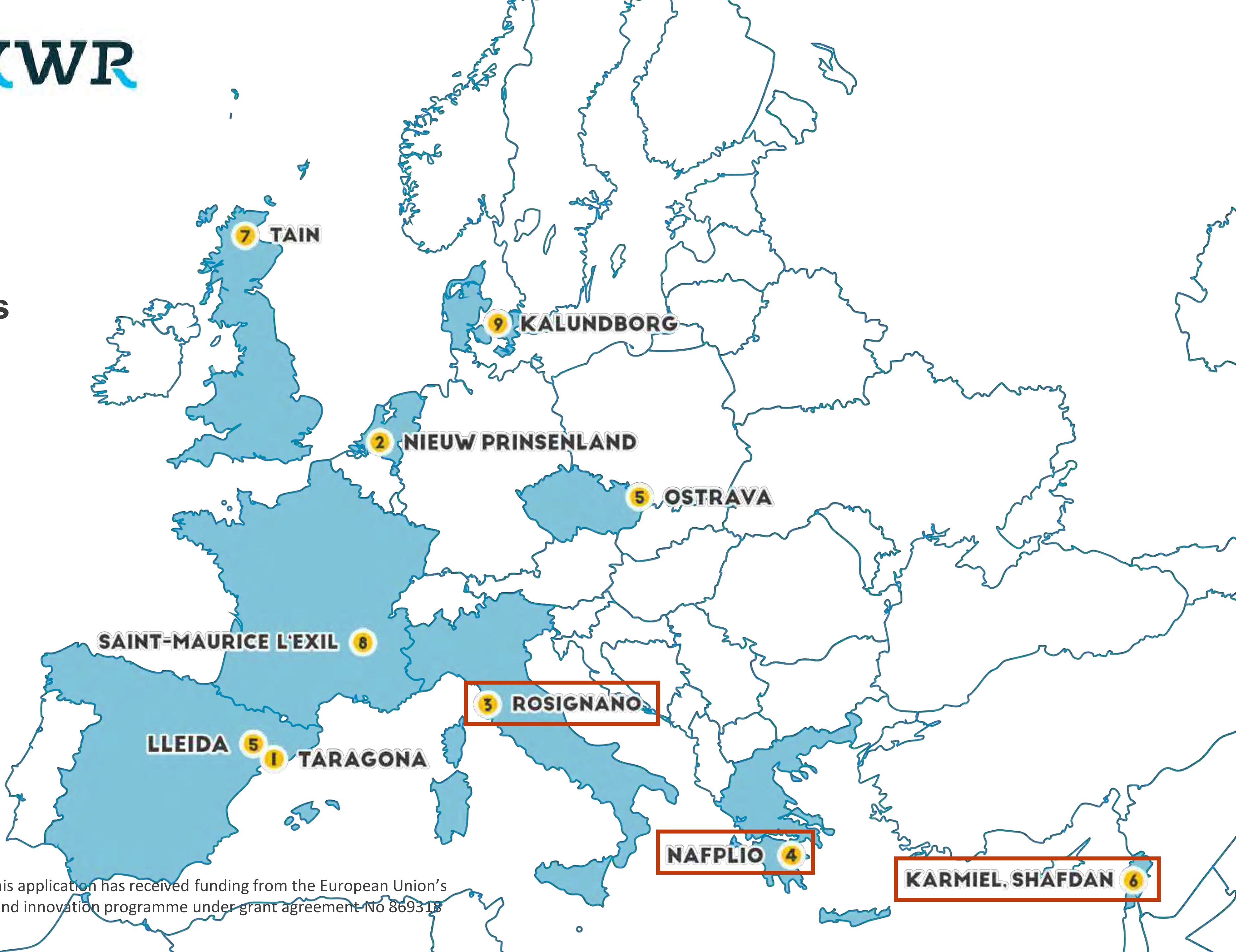
- Biogas technologies
- Heat Recovery
- Digitalization

Coordinator: KWR

9 Case Studies

27 Partners

37 Technologies



The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

Agenda

16:10 **SLUDGE 4.0:** Thermochemical treatment and down-stream strategies for materials recovery from sewage sludge
Riccardo Gori (UNIFI)

16:25 **CASE STUDY 4 & 6:** Recovery of antioxidants and polyphenols from fruit processing and olive mill wastewater
Dimitri Iossifidis (GTG)

16:45 **CASE STUDY 3:** Use of by-products of local industries for wastewater treatment in Rosignano
Francesco Fatone (UNIVPM) & Francesco Rossi (CPTM)

17:00 **SMART PLANT:** Cellulose recovery from municipal wastewater and safe reuse
Marit van Veen (CirTec)

17:20 **ROUTES; SMART-Plant; RES-URBIS:** Polyhydroxyalkanoate (PHA) recovery from sewage sludge and foodwaste
Mauro Majone (UniRoma)

17:40 **Water2REturn:** Microalgal Biomass recovery and reuse
Robert Reinhardt (ALGEN)

18:00 **End**

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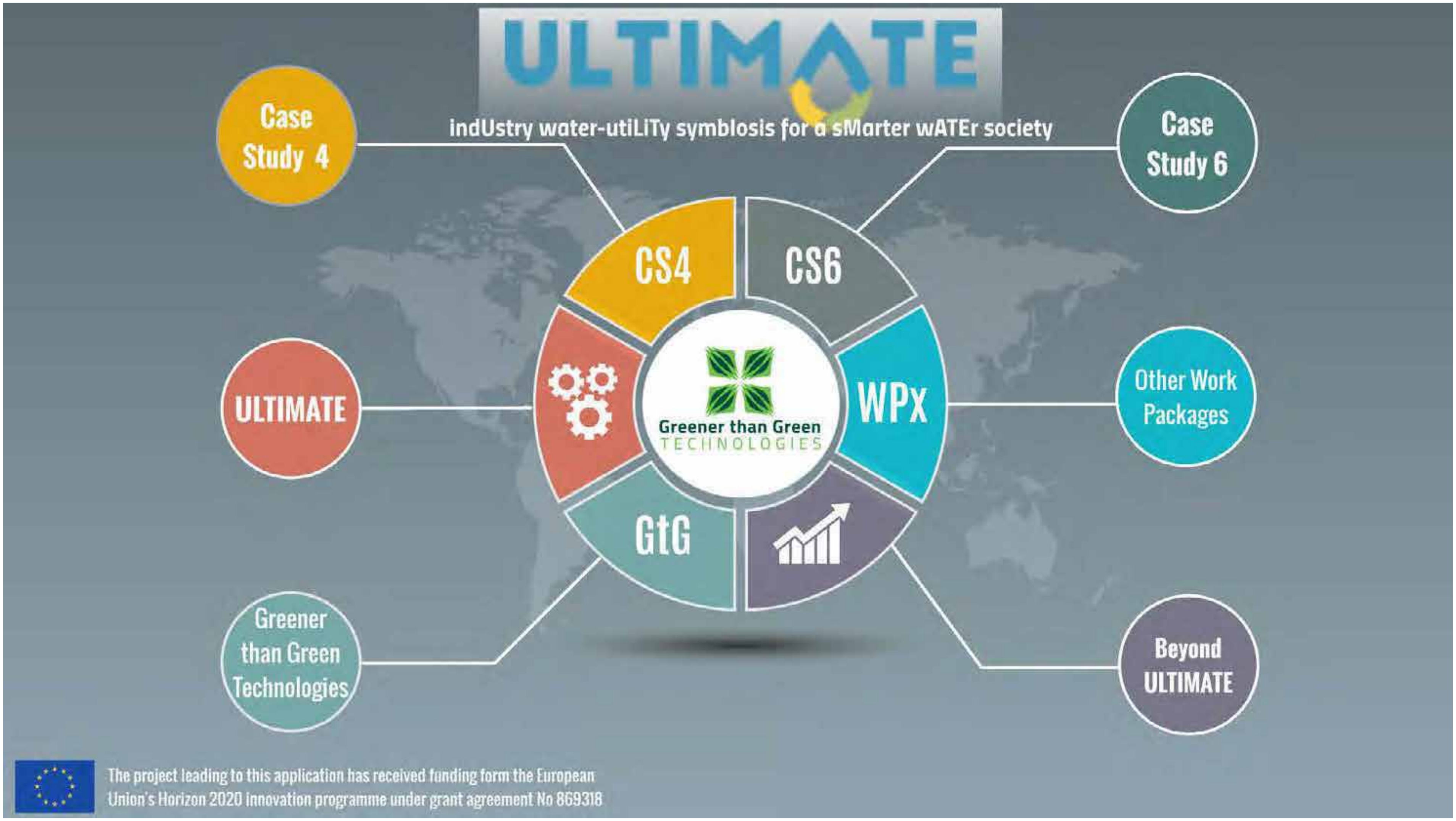
ULTIMATE
indUstry water-utiLiTy symbiosis for a sMarter wATEr society
Case Study 4
Case Study 6
CS4
CS6
ULTIMATE
Greener than Green TECHNOLOGIES
WPx
Other Work Packages
GtG
Greener than Green Technologies
Beyond ULTIMATE
The project leading to this application has received funding form the European Union's Horizon 2020 innovation programme under grant agreement No 869318

Greener than Green Technologies SA (GtG)

is active in R&D and marketing of disruptive water and wastewater remediation technologies and methodologies for the circular usage of water providing valuable tools for the transition of industries and communities towards a circular economy model, . In cases where high interest and value added compounds are present in the waste, these can be reclaimed, purified and reused, or can be commercially exploited, turning waste into a resource.

Established in 2014, we are start-up company that sprung out of pioneering university research. Our research efforts are funded by private capital as well as EU grants and we continuously seeking synergies in both the industrial and research partners. Since 2019 we are marketing and promoting in Greece and the wider southeastern European area novel and innovative environmental technologies.

The team

Greener than Green TECHNOLOGIES

info@greenerthangreen.co

The project leading to this application has received funding form the European Union's Horizon 2020 innovation programme under grant agreement No 869318

The team

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Chemist, BSc MSc PhD

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Case Study 4

- Fruit processing industry
- Nafplio, Eastern Peloponese, Greece
- High water demand puts pressure in the aquifer
- Seasonality puts strain on the local biological treatment plant
- Under-performing biological treatment plant, leads to higher waste removal cost

Goals

The Unit

Value-added compound extraction

AOP

SBP

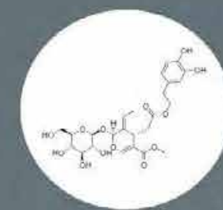
The project leading to this application has received funding form the European Union's Horizon 2020 innovation programme under grant agreement No 869318

Case Study 4 Goals

- Treat individual & final waste streams

- Isolate useful/value-added compounds compounds (properties & market price) e.g. polyphenols, flavonoids, anthocynins etc

- Treat wastewater so it can be recycled:
  - **Irrigation of nearby orchards**
  - Reused within the plant for secondary uses or reduce the organic load sufficiently so the biological treatment plant can cope



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Case Study 4

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Goals

The Unit

Value-added compound extraction

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SBP

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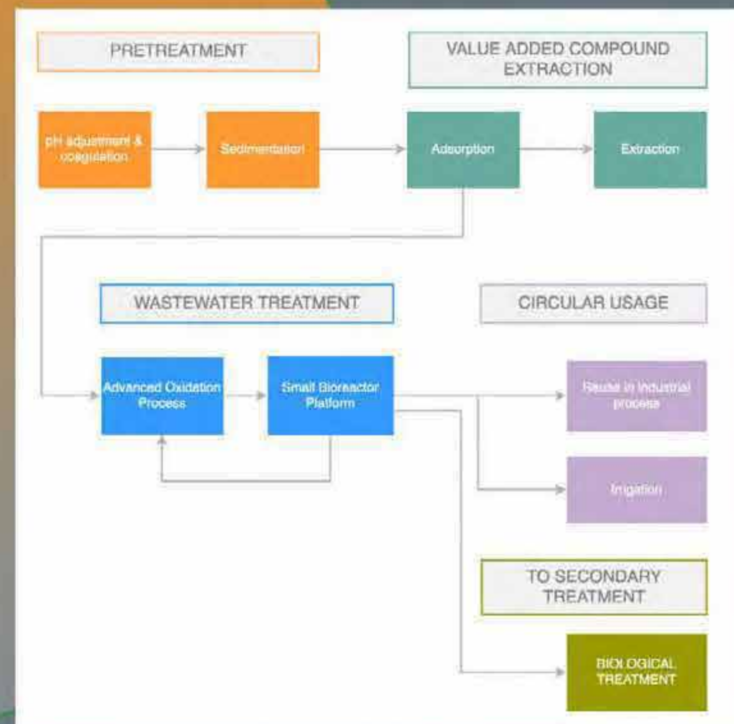
Unit Design

Cross-section

P&ID



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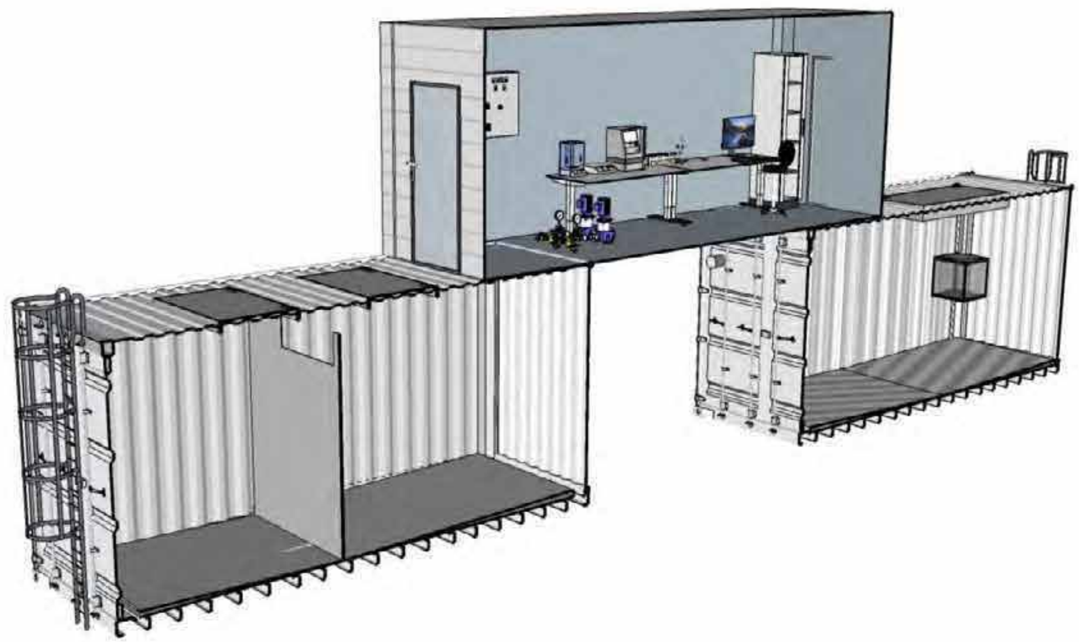
Unit Cross-section



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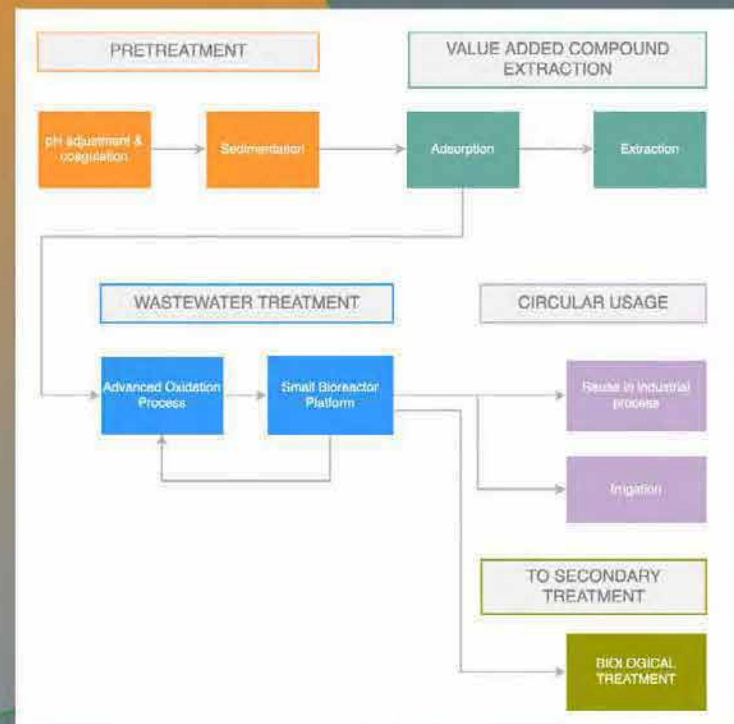
Unit Design

Cross-section

P&ID



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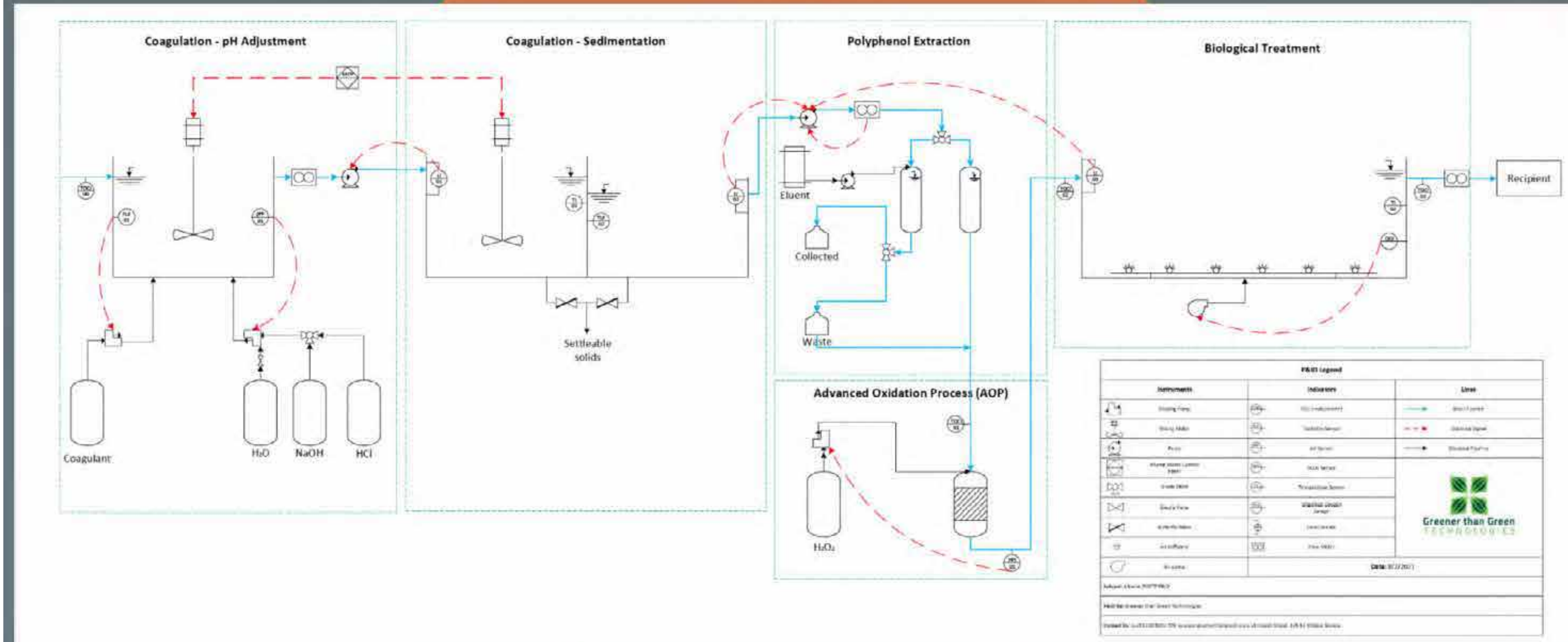
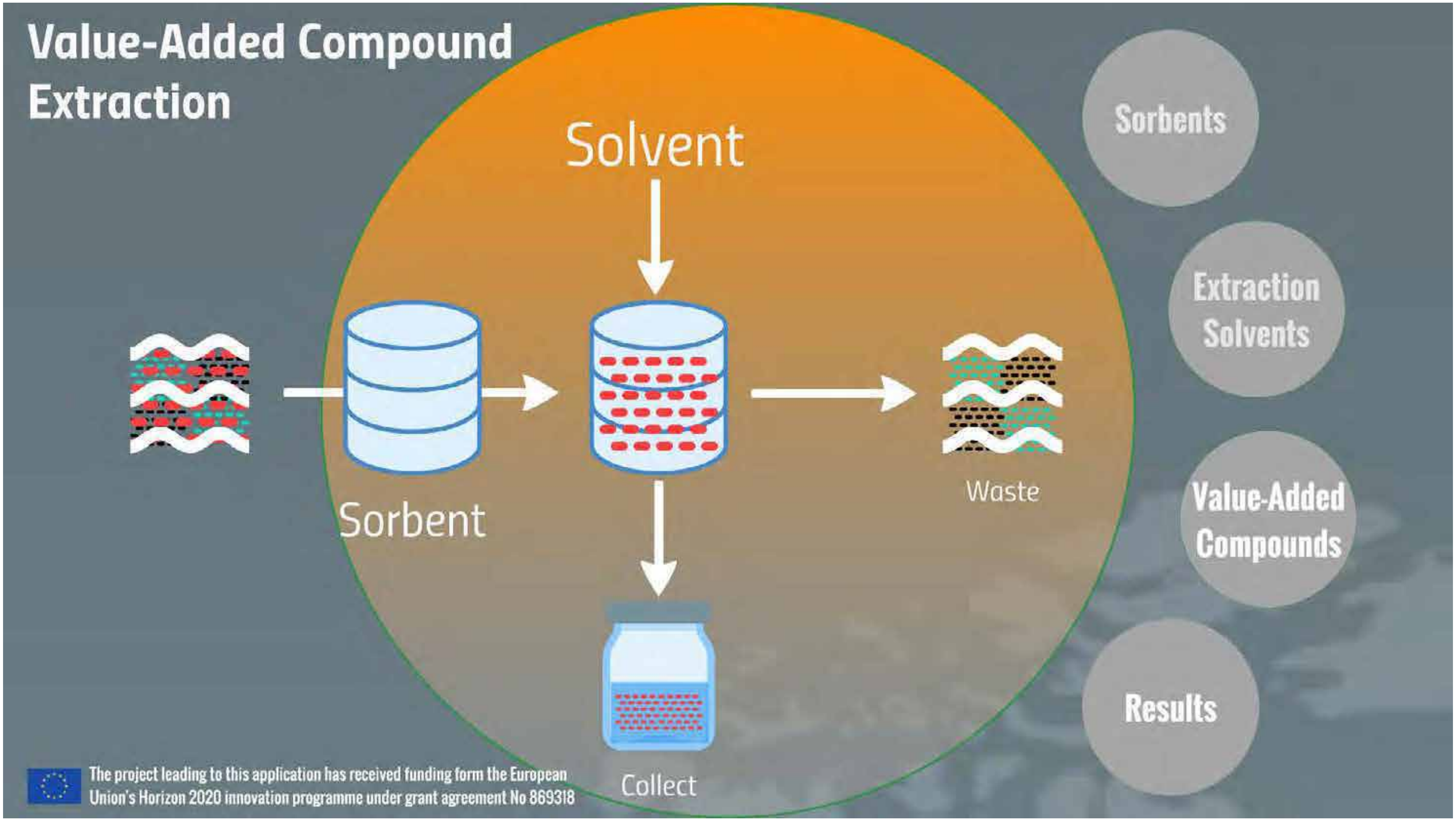
Unit P&ID

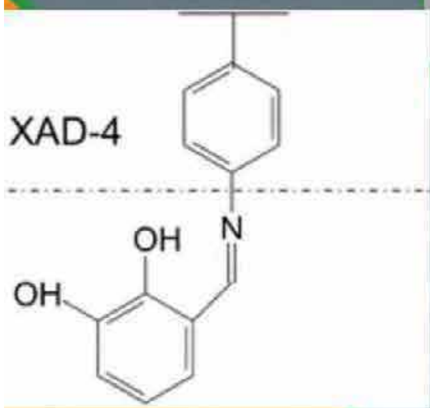


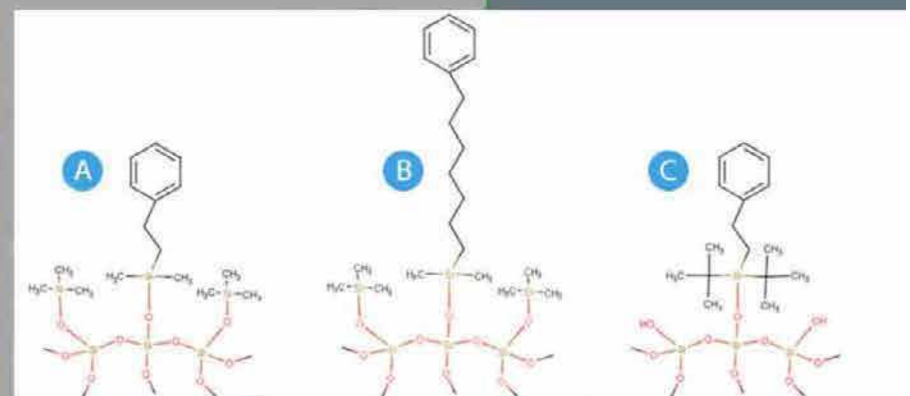
Coagulation - pH Adjustment
Coagulation - Sedimentation
Polyphenol Extraction
Biological Treatment
Advanced Oxidation Process (AOP)
Coagulant
H₂O
NaOH
HCl
Settleable solids
Eluent
Collected
Waste
H₂O₂
Recipient
P&ID Legend
Instruments
Indicators
Lines
Greener than Green
TECHNOLOGIES


Value-Added Compound Extraction
Solvent
Sorbent
Waste
Collect
Sorbents
Extraction Solvents
Value-Added Compounds
Results
The project leading to this application has received funding form the European Union's Horizon 2020 innovation programme under grant agreement No 869318

Sorbents

	Adsorbent	Material	Structure	Particle size (µm)	Surface Area (m^2/g)	Pore Size (Å)
	AmberLite™ FPX66	Resin	Aromatic	700	800	150
	AmberLite™ XAD-4	Resin	Aromatic	640	750	100
?	Phenyl-Hexyl	Silica	Aromatic	15	400	100

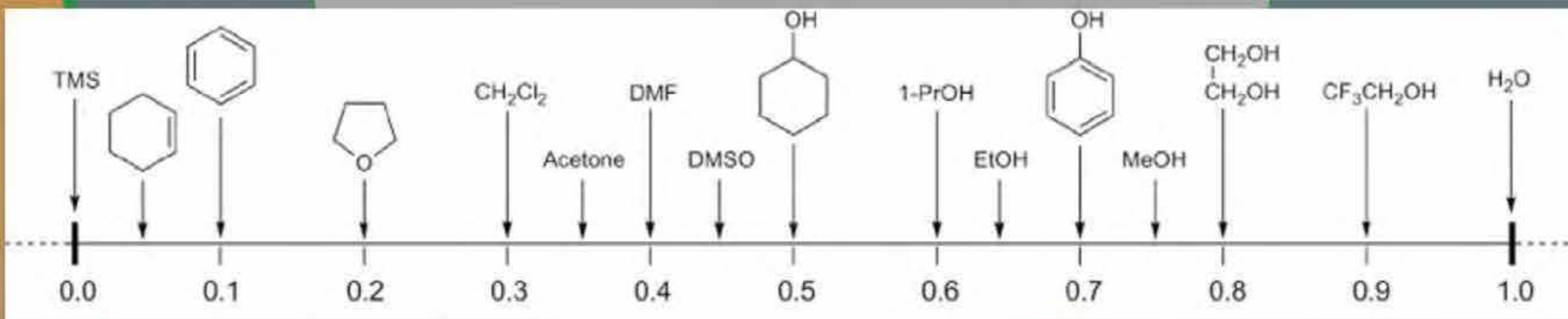




Extraction Solvents

Water - cheap, inefficient, non-toxic
Methanol - high cost, increased toxicity
Ethanol - very high cost, lower toxicity

Subcritical Water Extraction



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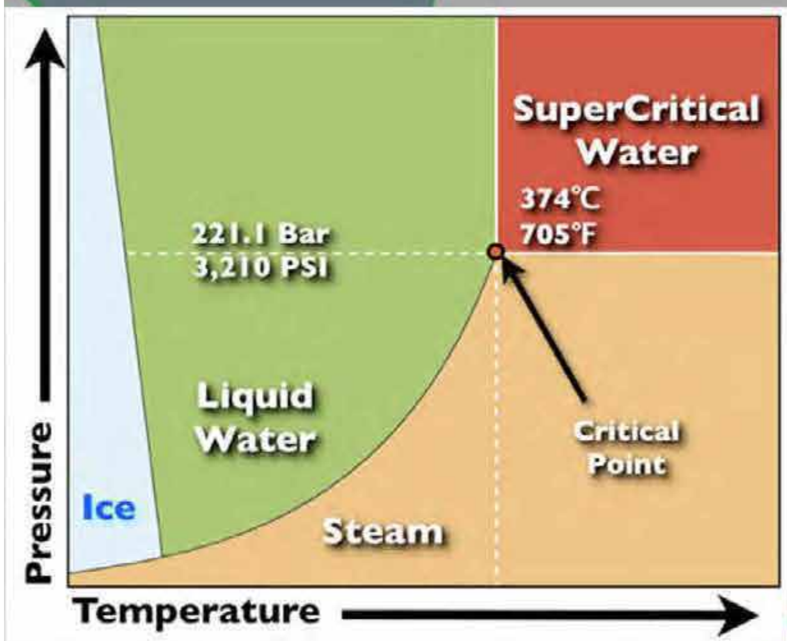
SubCritical Water Extraction (SCWE)

- Temperature: 100 - 374°C
- Pressure high enough to be in the liquid phase 10-20 bar



- Efficiency
- Low cost
- Non-hazardous - green

Value-Added Compounds

Polyphenols:

- Naturally occurring compounds
- Complex structures containing multiple phenolic rings
- Two main classes **phenolic alcohols**, **phenolic acids**
- Further classification depending on the phenolic ring strength (phenolic acids, flavonoids, stiblins, phenolic alcohols, and lignans)

Structures

Examples

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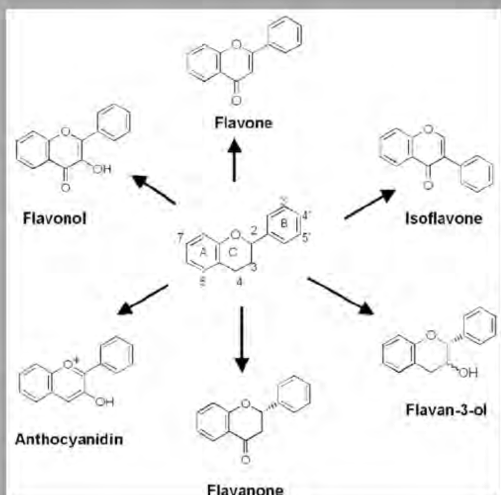
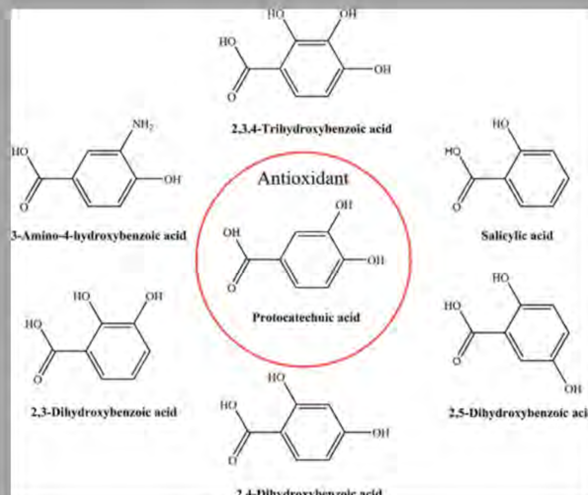
Structure of polyphenols

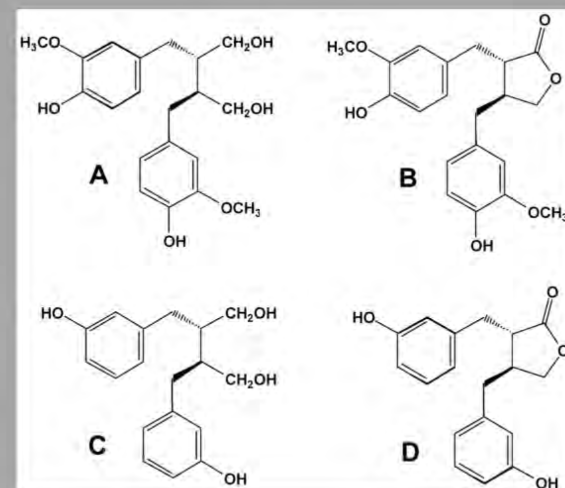
Flavonoids



Benzoic acids



Lignans

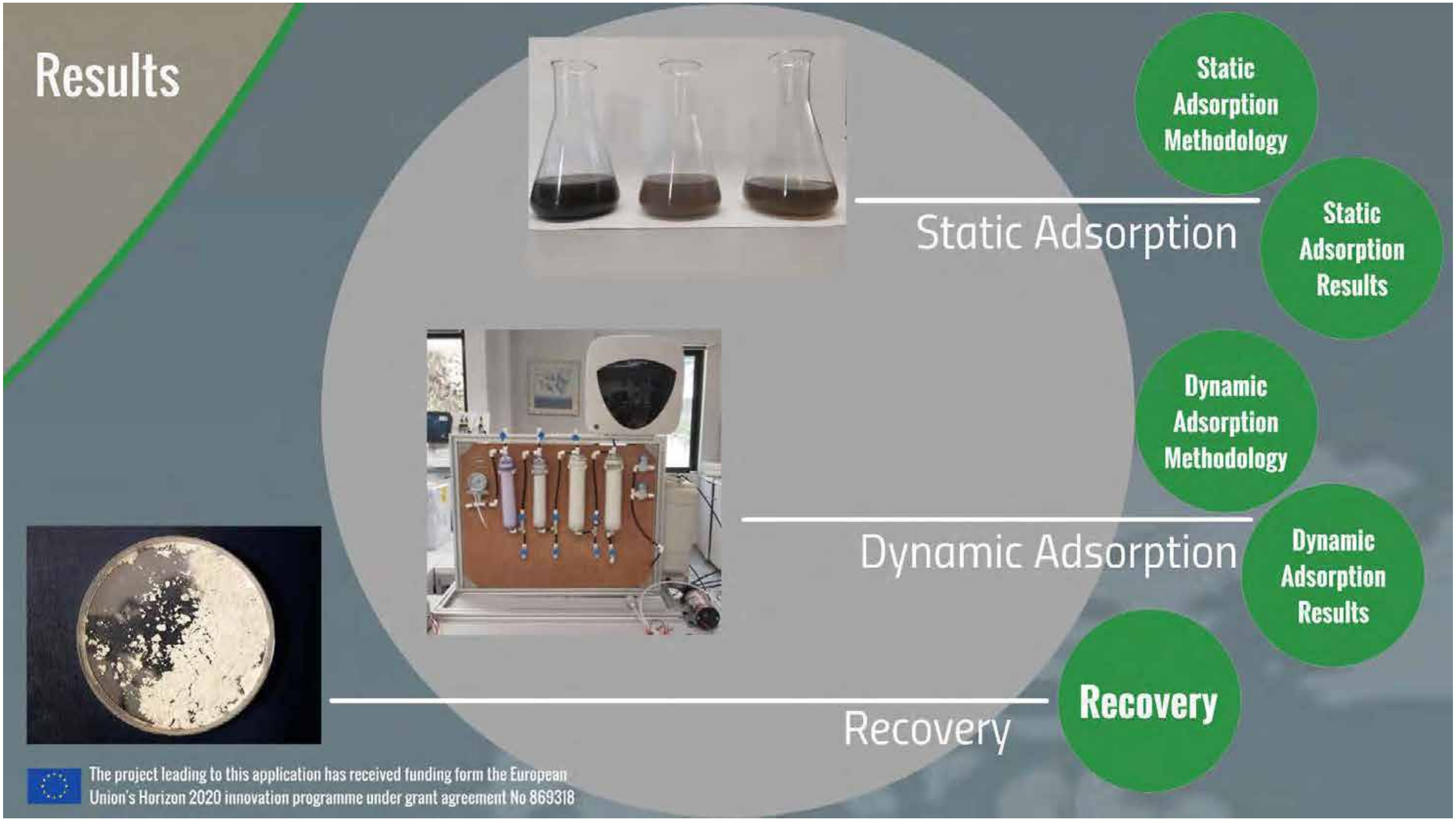


Examples of Value-Added Compounds

"Let food be thy medicine and medicine be thy food"
Hippocrates 460-377 BC

Fruit	Compound	Class	Properties & Uses	Price/g*
Orange	Hesperetin	Flavonone	Lowers cholesterols, Anticancer, Favourably favours lipids	€13
	Naringenin	Flavonone	Antioxidant	€1
	Kaempferol	Lignan	Reducing the risk of chronic diseases, especially cancer	€5.900
Redcurrant	Cyanidin 3-O-glucoside	Anthocyanin	Food colourant	€29
Beetroot	Luteolin	Flavone	Potentials for cancer prevention and therapy	€18.100
	Quercetine	Flavonoid	Anticancer activity	€9.600
Black Chokeberries	Cyanidin 3-O-arabinoside	Anthocyanin	Used as natural colorant	€84.000
Pomegranate	(+)-Catechin	Flavonol	Used in green tea extracts	€22.499
	(+)-Gallocatechin	Flavonol	Antibacterial, Antifungal, Antimalarial, Diuretic, Antiulcer, Xanthine oxidase inhibitor, Antiplasmodic…	€150.000
Carot	3,4-Dicaffeoylquinic acid	Phenolic acid	Antioxidant, anti-inflammatory, anti-cancer, DNA protective, Neuroprotective, Hepatoprotective, Anti-influenza viral activity	€374.000

*Price of analytics standards normalised to 1g


Results
Static Adsorption
Static Adsorption Methodology
Static Adsorption Results
Dynamic Adsorption
Dynamic Adsorption Methodology
Dynamic Adsorption Results
Recovery
Recovery
The project leading to this application has received funding form the European Union's Horizon 2020 innovation programme under grant agreement No 869318

Static Adsorption Methodology

Determine most suitable material depending

- Batch experiment
- Constant volume of wastewater
- Different quantities of adsorbing material
- Sampling at regular intervals

- Maximum adsorption capacity of each material
- Adsorption kinetics - how fast
- Modelling of adsorption dynamics

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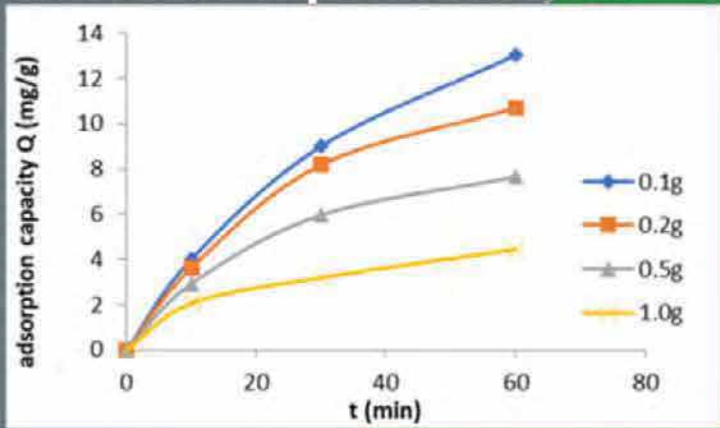
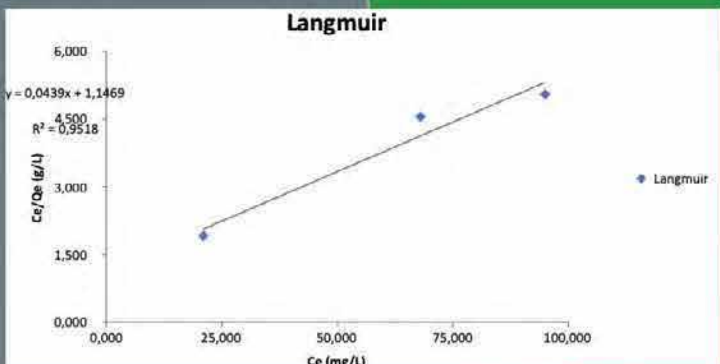
Static Adsorption Results





Maximum capacity 22,78 g/kg
(g of polyphenol per kg of resin)

Contact time vs Adsorption %

60 min	95%
30 min	60%

Yield = 130 g/m3
(mg of polyphenol per L of wastewater)

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Dynamic Adsorption Methodology

Determine conditions for optimal recovery

- Lab simulation of real process
- Continuous process
- Wastewater flows though a packed bed

- Breakthrough curve
- Relationship between contact time and flow rate
- Optimise flow conditions & packed bed design

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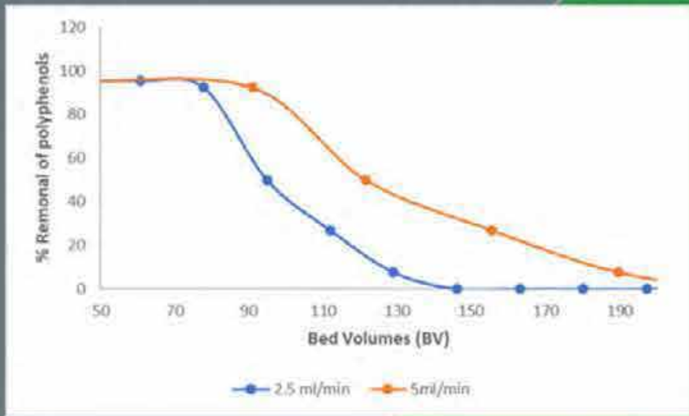
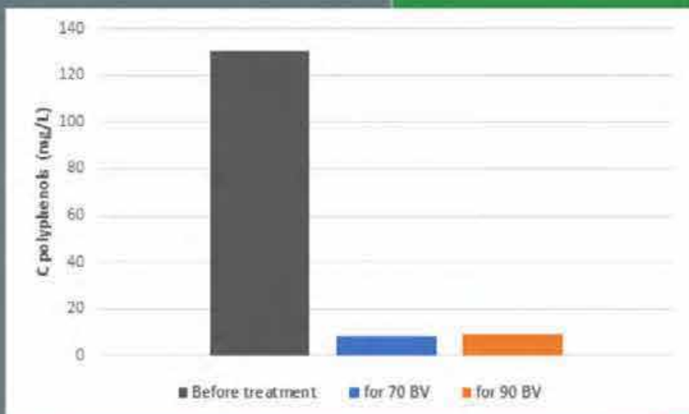
Dynamic Adsorption Results





- The adsorbent is capable of adsorbing polyphenols for at least 10 regeneration cycles
- 1.7 m^3 wastewater can be treated per kg of resin per cycle

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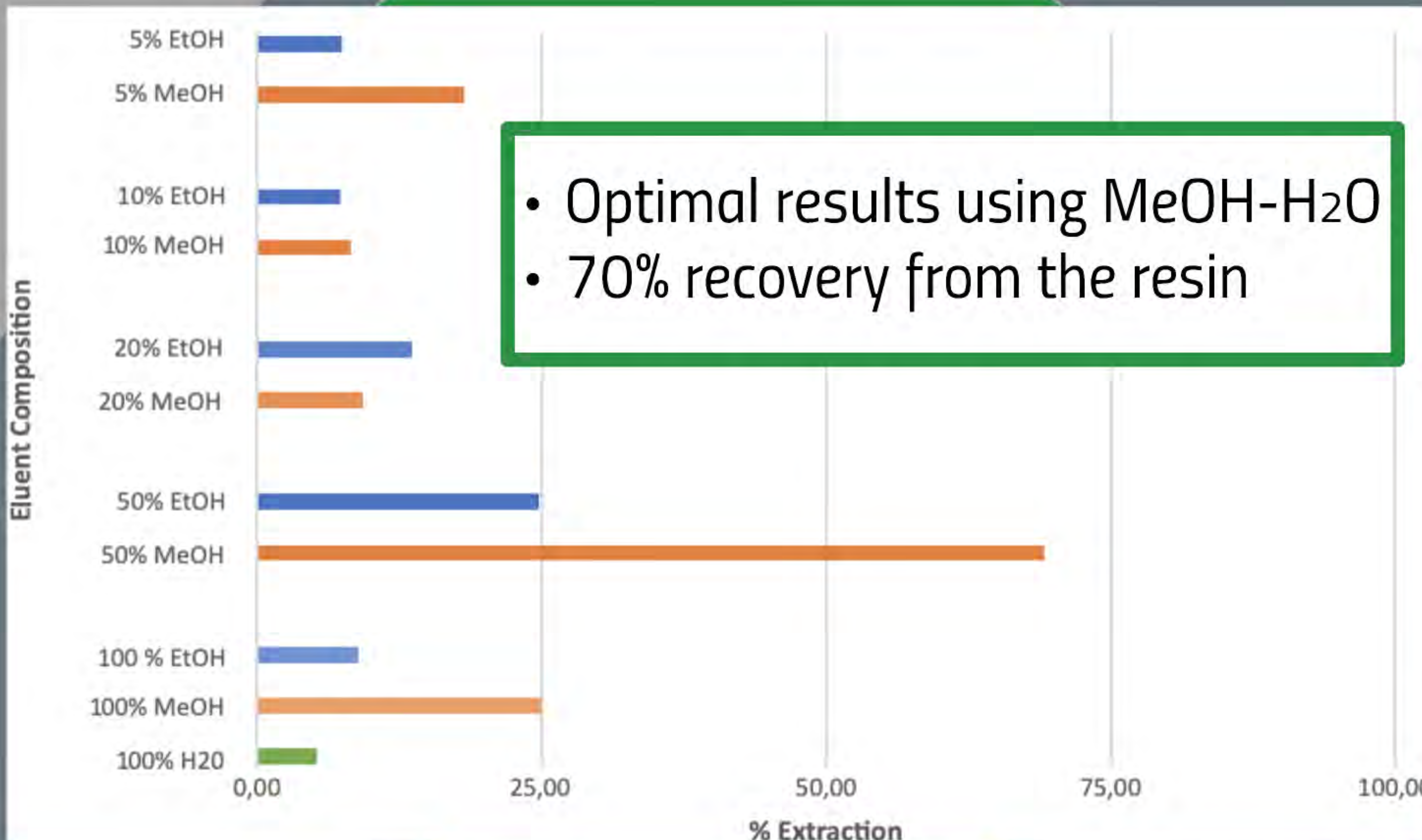
Recovery



- Optimal results using MeOH-H_2O
- 70% recovery from the resin

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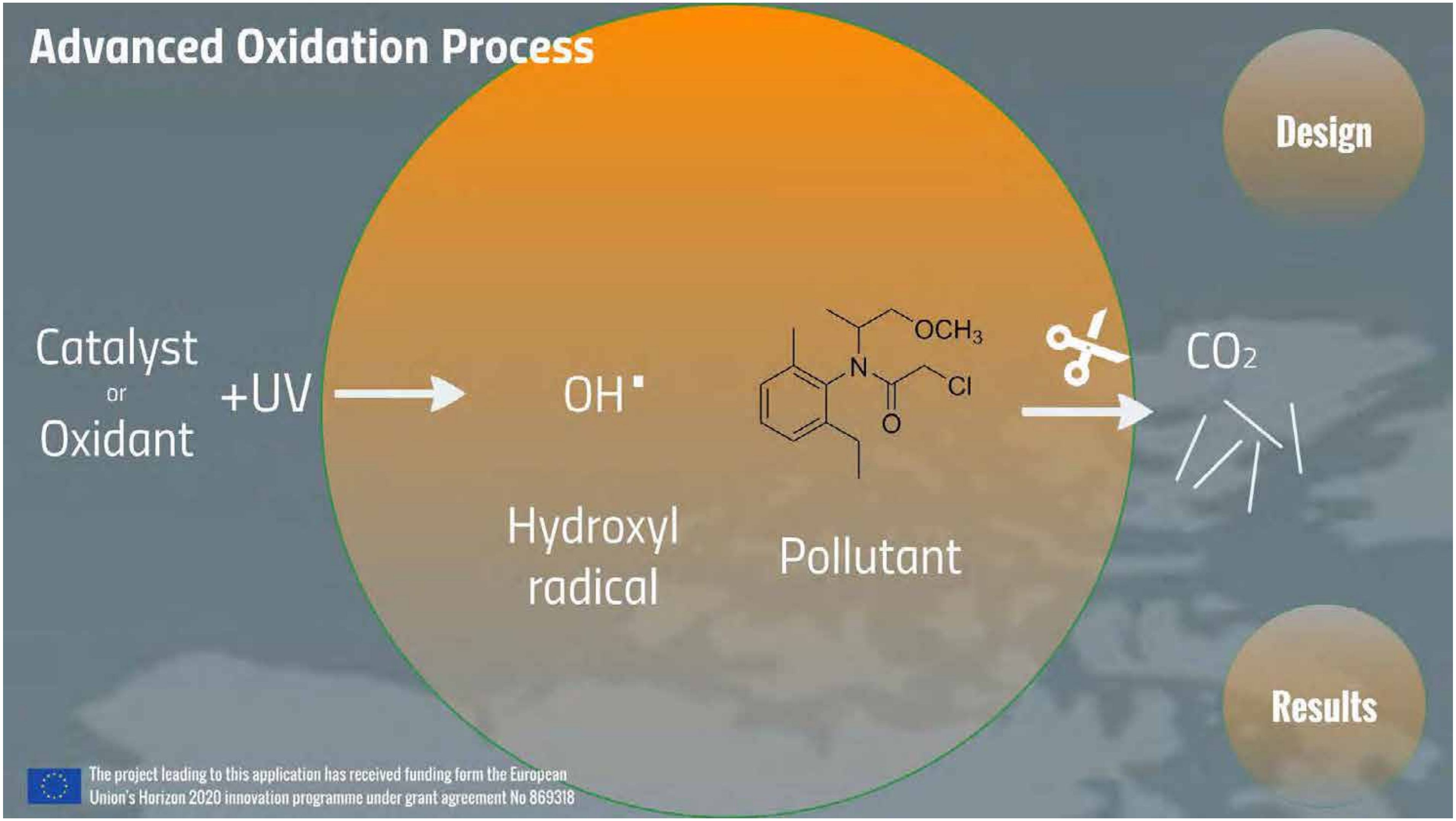
Advanced Oxidation Process
Catalyst
or
Oxidant
+UV
OH•
Hydroxyl
radical
OCH_3
N
Cl
O
Pollutant
CO_2
Design
Results
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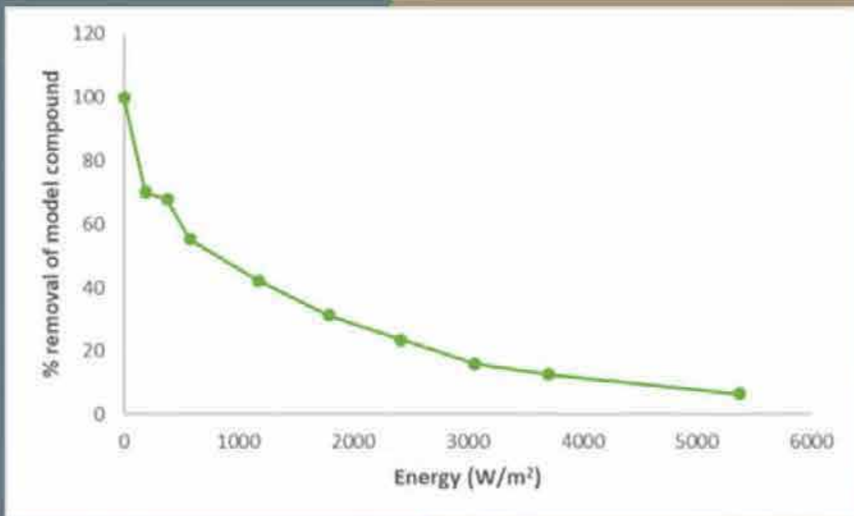
The CPC photocatalytic reactor

- Continuous flow
- Operates under either solar or artificial light

Degradation of model compound



Demonstrated ability to remove 90% of organic pollutants

Small Bioreactor Platform

Patented Technology by BioCastel, Israel

SBPs encapsulate bacteria within a porus membrane
Cellulose acetate
0.2 µm pore

The membrane:
- keeps bacteria safe from predators and other microorganisms
- prevents biomass from escaping to the environment

Problems addressed:
Controlling the type of bacteria needed
Defining the space they grow
Controlling the amount of biomass

SBP is a product of BioCastel, Israel
US Patent No. US 8,673,606
Europe Patent No. EP 2421544 (Germany, France, U.K, Nederland, Ireland and Switzerland)
Australia Patent No. 2010240486
Israel Patent No. 213072

How does it work

Benefits

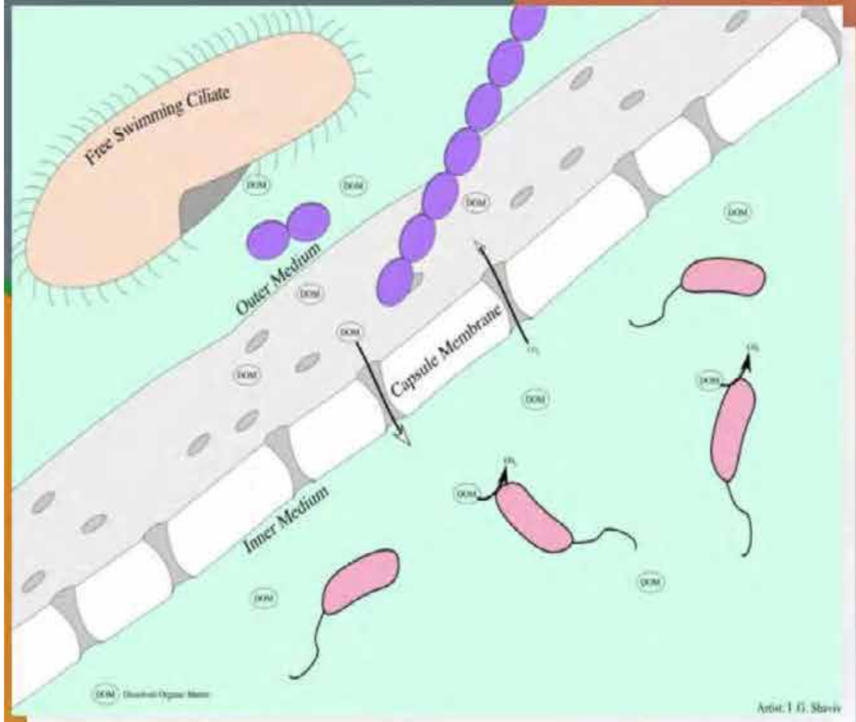
Applications

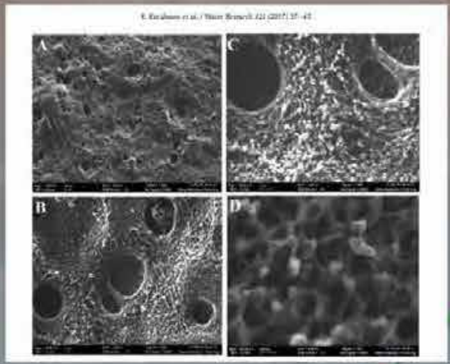
ULTIMATE

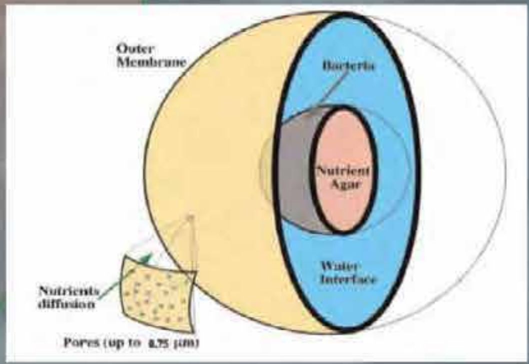
The project leading to this application has received funding form the European Union's Horizon 2020 innovation programme under grant agreement No 869318

How does it work

- A 0.2 µm cellulose acetate membrane encapsulates bacteria keeping it safe from predators and preventing biomass to escape
- Water and disolved pollutants migrate trough through the pores and are metabolised by bateria
- After the life cycle of the bacteria, approx. two month, the cellulose acetate membrane devomposes to sugars







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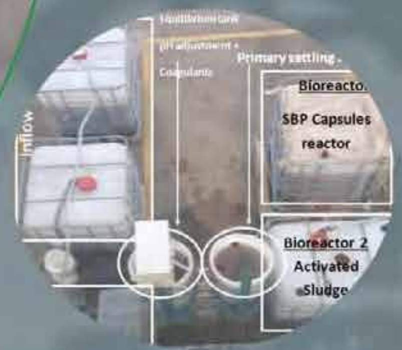
Benefits

SBP technology addresses certain biological treatment problems:

- Control of bacteria type growth
- Control of space bacteria grow
- Control of amount of bacteria

It can be implemented:

- to assist existing biological treatment units to cope with seasonal and unexpected shock load episodes
- to increase capacity with minimal CapEx
- as a small scale standalone solution with out the need of high-cost & extensive infrastructure



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Applications

Sanitary wastewater treatment examples:

- A20 5500 m3/d
- MBR 2400 m3/d
- AS 500 m3/d

Yield increase up to 15%
Increase in biodegradation rate
Increase in bioprocess stability

Industrial wastewater treatment:

- Food waste 200 m3/d
- Winery waste 0.5 m3/d

No need for natural biomass growing and all associated infrastructure
No need for professional manpower for plant operation
No need for waste sludge transporting and associated infastucture

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Case Study 6

Karmiel, Israel

Olive oil mill wastewater treatment

Partners: The Galilee Society, MEKOROT, GtG

Olive oil mill wastewater is reach in **polyphenols** which are toxic to bacterial and inhibit aerobic or anaerobic digestion in biological wastewater treatment plants

Goal

Polyphenol Extraction

Design

Lab-scale

The project leading to this application has received funding form the European Union's Horizon 2020 innovation programme under grant agreement No 869318

Goal

To remove polyphenolic compounds from waste water:

- Low cost unit & process
- Prevent inhibition of anaerobic digestion
- Increase biogas yield
- Commercially exploit polyphenols

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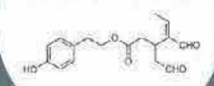
Polyphenol Extraction

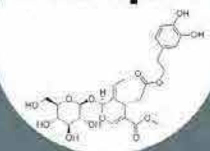
"Let food be thy medicine and medicine be thy food"
Hippocrates 460-377 BC

- Natural phytochemicals, a major class of semi-water-soluble compounds with one or more benzene rings that are generally found as glycosides
- Polyphenols from olives and grapes are probably the most studied

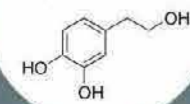
Oleocanthal



Oleuropein



3-Hydroxy tyrosol



Sorbents

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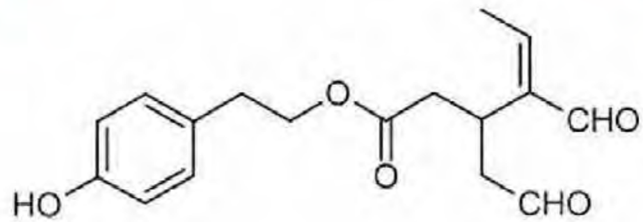
Oleocanthal

Market value:
€1620/g

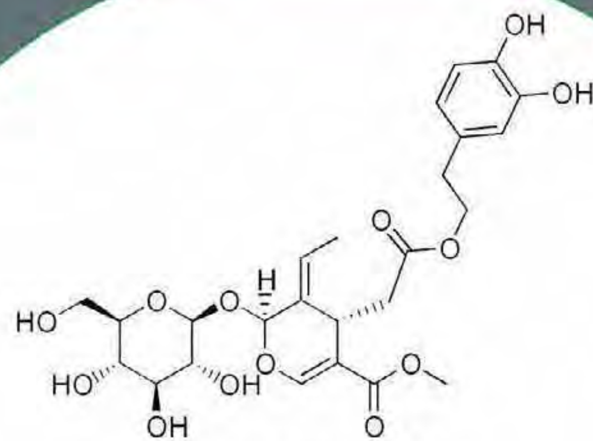


Properties:

- Antioxidant
- Anti-inflammatory
- Anti-cancer
- Reduce risk of AD
- Reduce risk of heart disease

Oleuropein

Market value:
€7.240/g



Properties:

- Antioxidant
- Anti-inflammatory
- Anti-cancer
- Protects skin & eyes
- Protection against pathogens

3-Hydroxy tyrosol

Market value:
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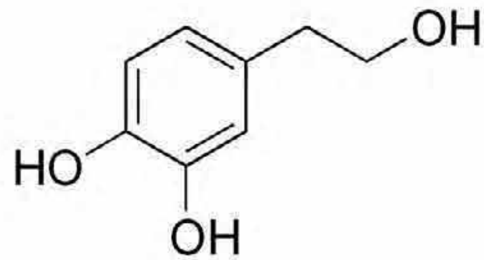

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Sorbents

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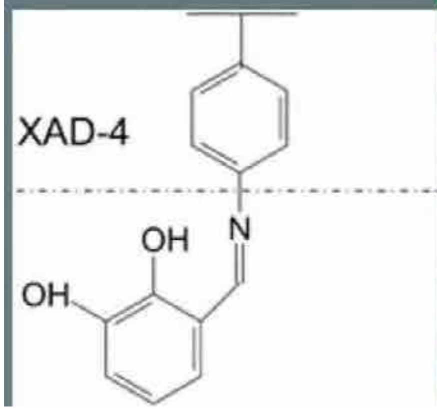
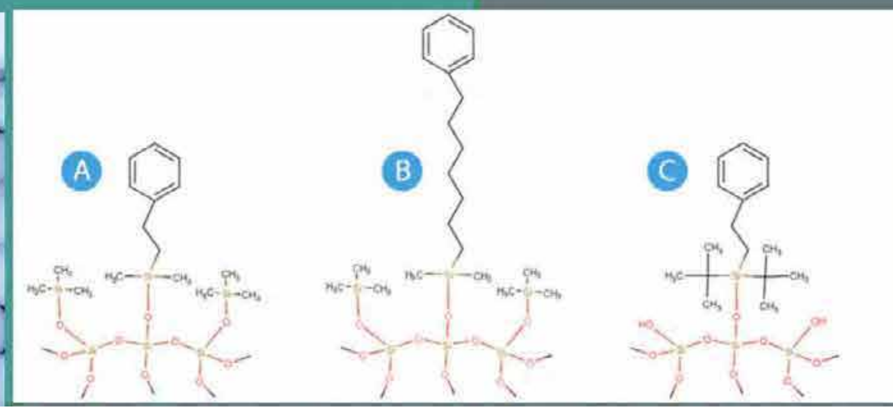
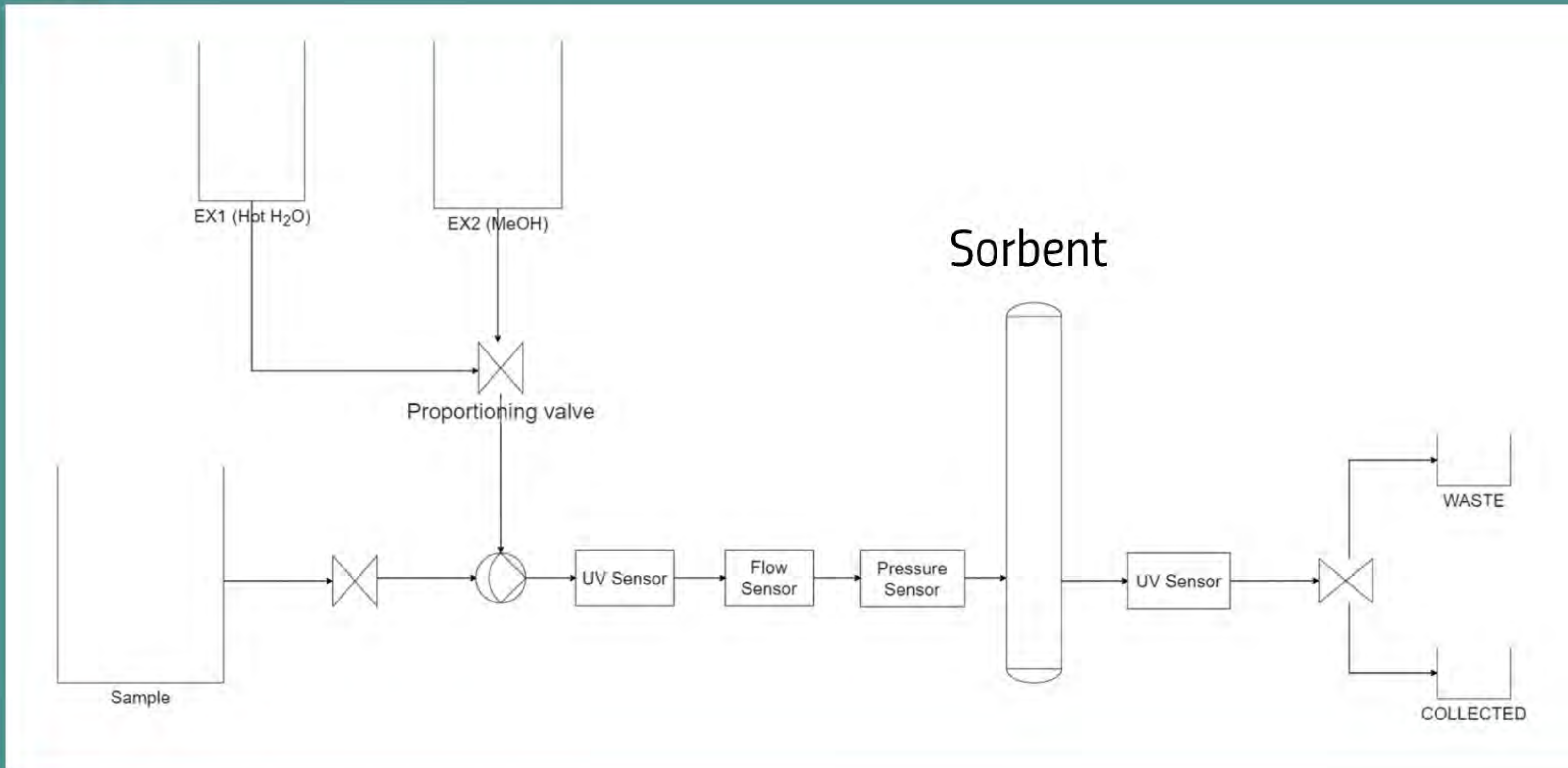




Design



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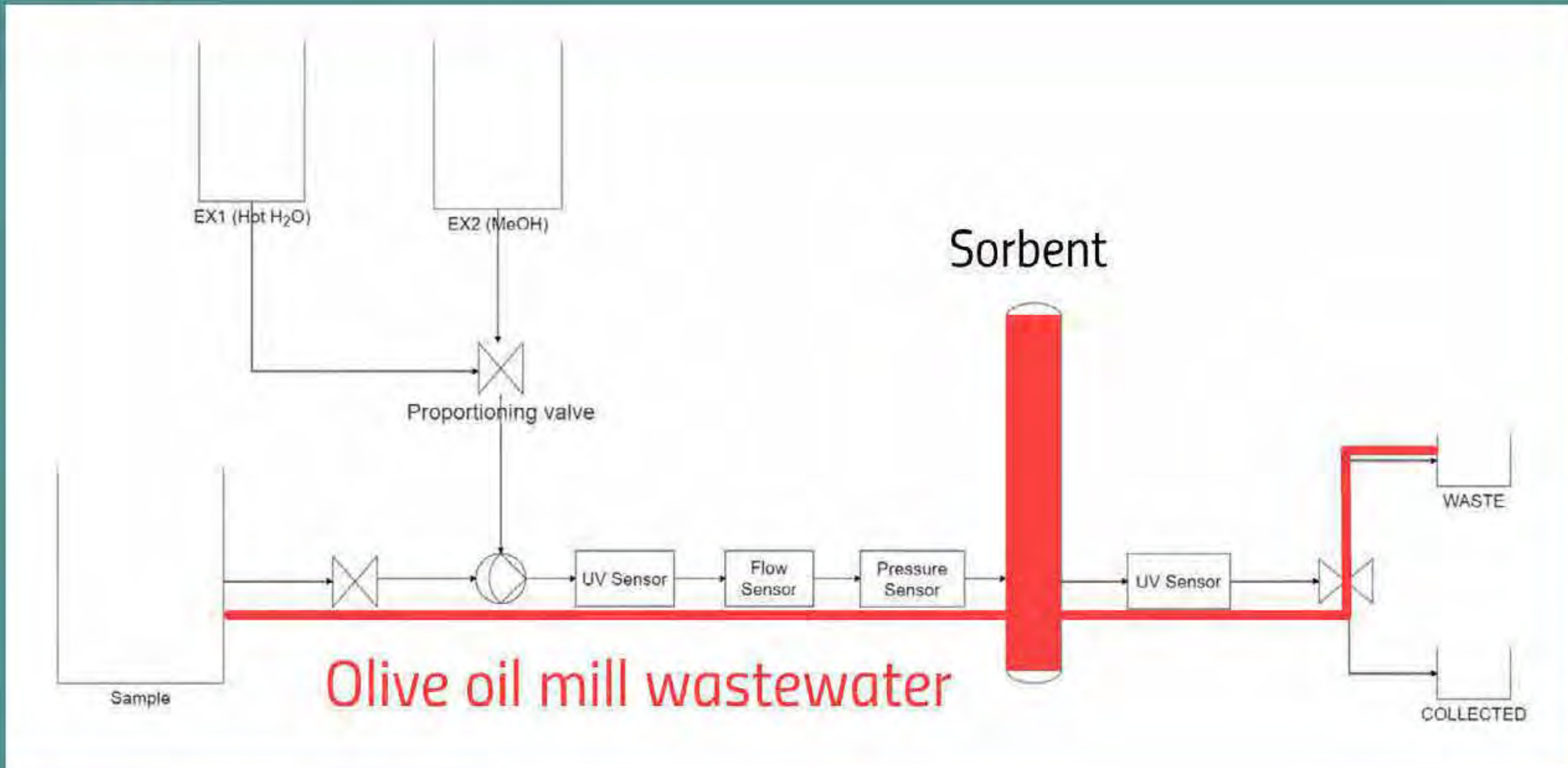
Loading



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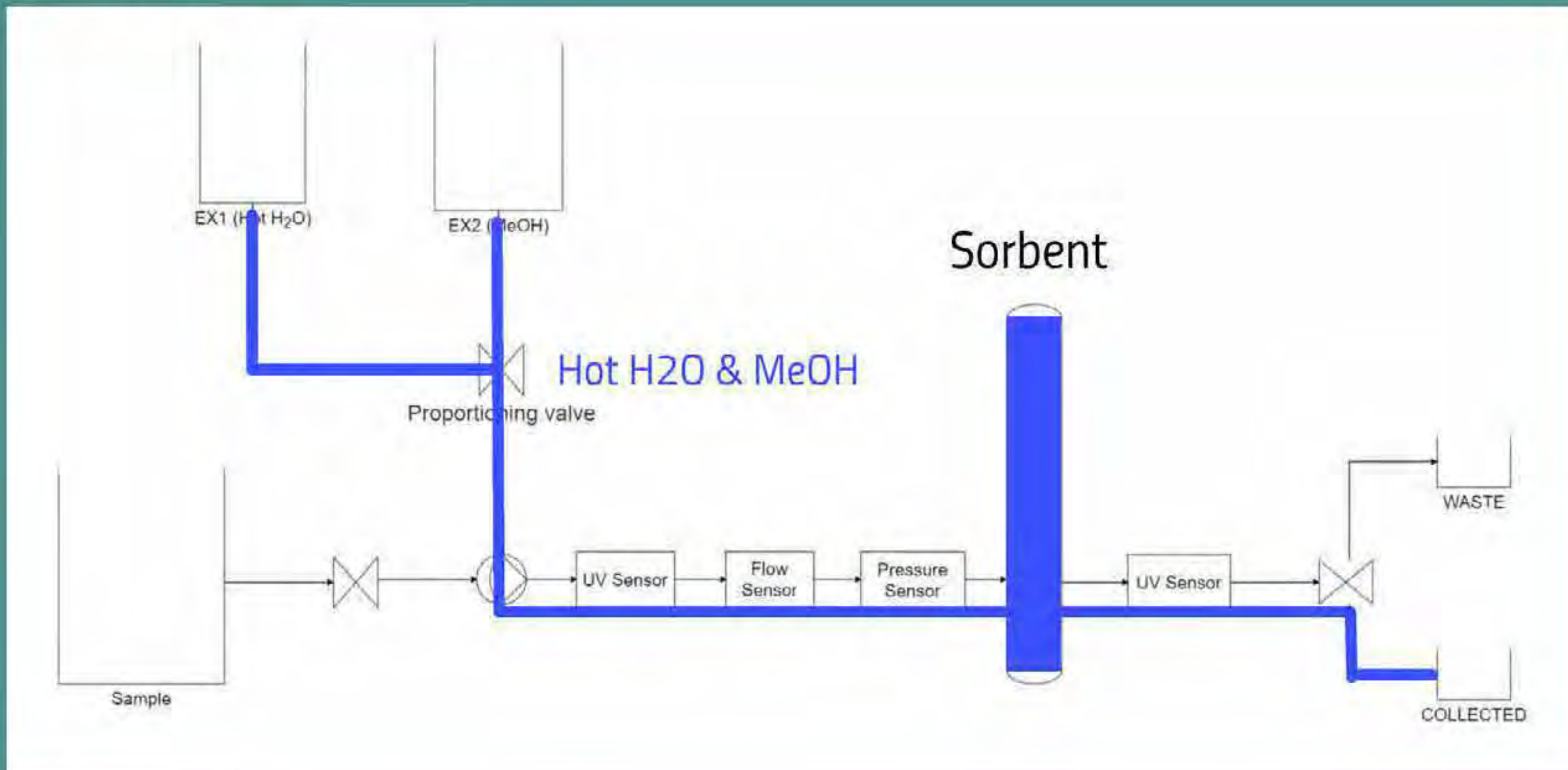
Extraction



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ULTIMATE

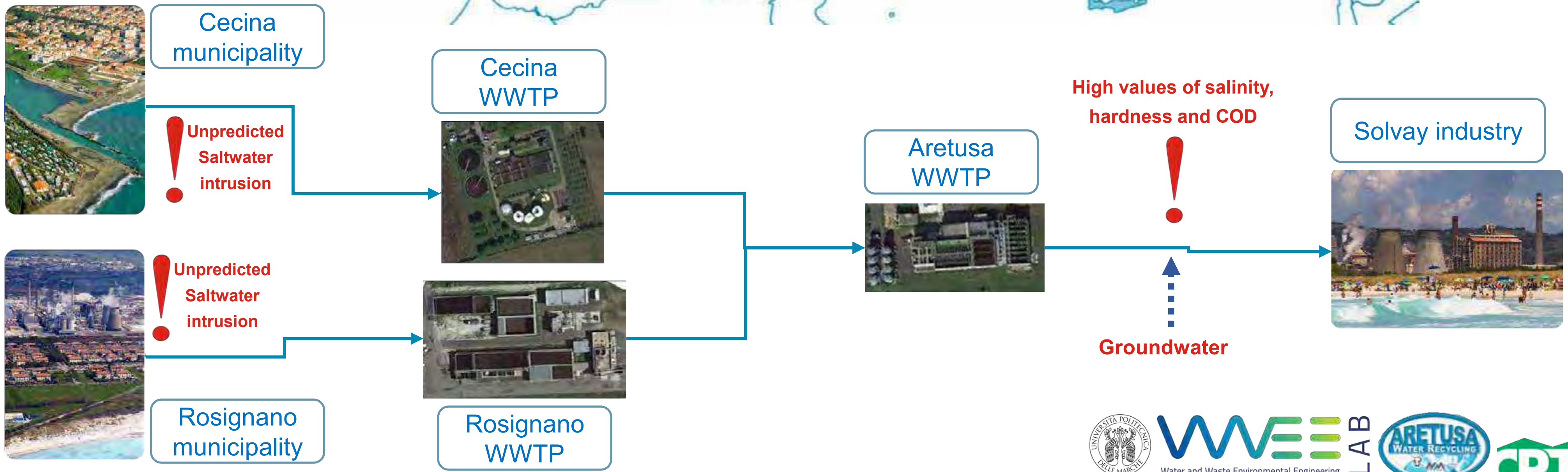
WATER SMART INDUSTRIAL SYMBIOSIS

Use of by-products of local industries for wastewater treatment in Rosignano

F. Fatone, F. Rossi

June, 23rd 2021

ULTIMATE Project

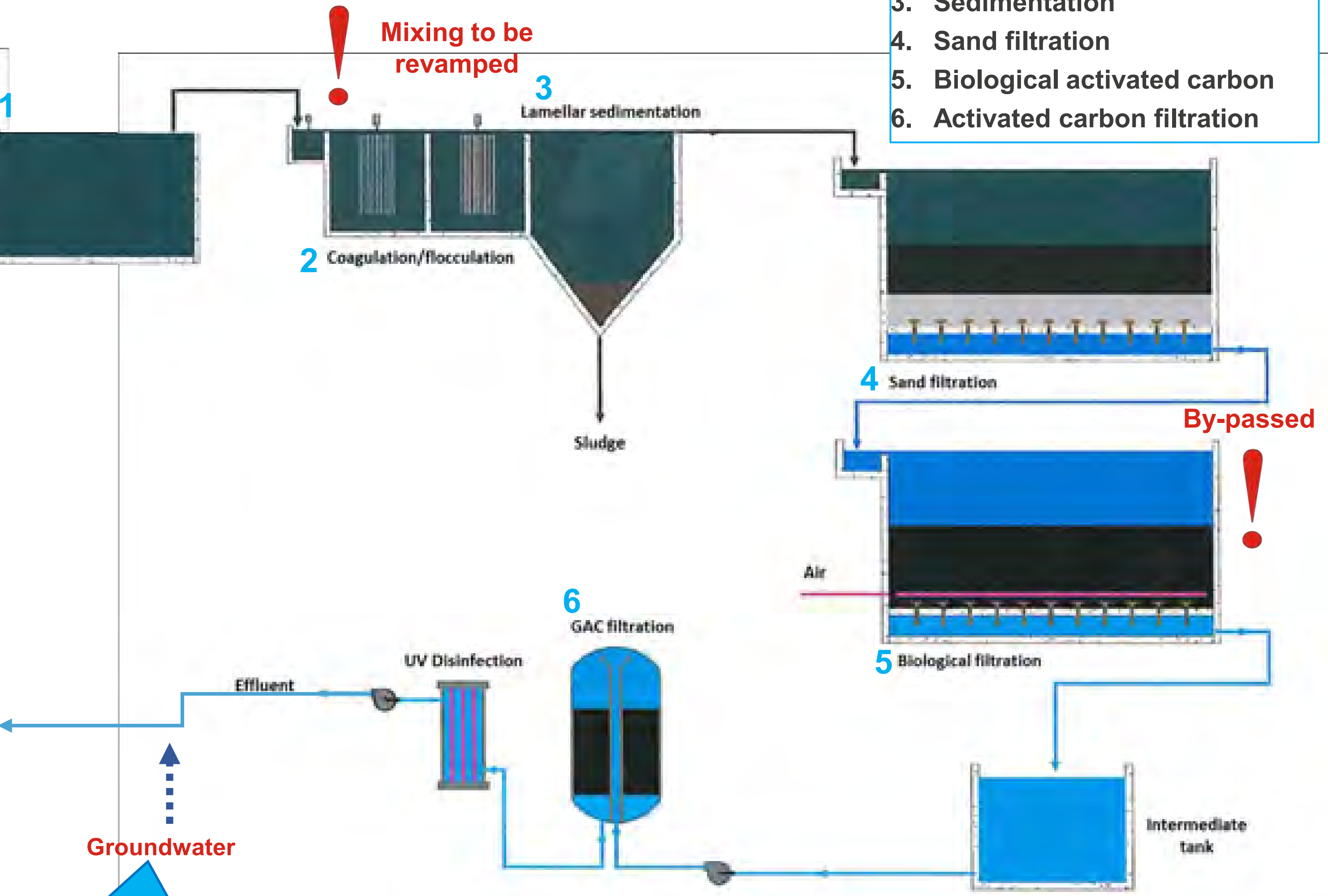


ARETUSA WWRP

1. Equalization
2. Coagulation/flocculation
3. Sedimentation
4. Sand filtration
5. Biological activated carbon
6. Activated carbon filtration

Contractual parameters to be respected for SOLVAY reuse

PARAMETRI SPECIFICI - SPECIFICA TECNICA DI QUALITA' DEI REFLUI POST-TRATTATI			
N°	Descrizione file:specar1	Unità di misura	Specifica Tecnica
			.Riferimento contrattuale
1	Cl-	ppm	≤ 500
2	NH4	ppm	≤ 8
3	Solidi Sospesi	ppm	≤ 2
4	Conduncibilità	microS.	≤1.030
5	Alcalinità	ppm CaCO3	≤ 340
6	Ca	ppm Ca	≤ 160
7	Mg	ppm	≤ 45
8	SO_4	ppm	≤ 140
9	Fe	ppm	≤ 0,1
10	Si	ppm SiO2	≤ 30
11	Mn	ppm	≤0,4
12	PO_4	ppm	≤ 3
13	Al	ppm	≤ 0,1
14	As	ppm	≤ 0,2
15	Ba	ppm	≤ 2,5
16	Fluoruri	ppm F	≤ 0,1
17	Grassi ed Olii Totali	ppm	≤ 1
18	COD	ppm O2	≤ 10
19	Tensioattivi Totali	ppm	≤ 0,5
20	BOD		≤10
21	Esch. Coli	CFU/100ml	≤ 250
22	Coli Tot.	CFU/100ml	≤ 250
23	Strep. Coli	CFU/100ml	≤ 20
24	Batteri Filamentosi		assenti



SOLVAY

When needed (internally agreed) water quality standard are not reached

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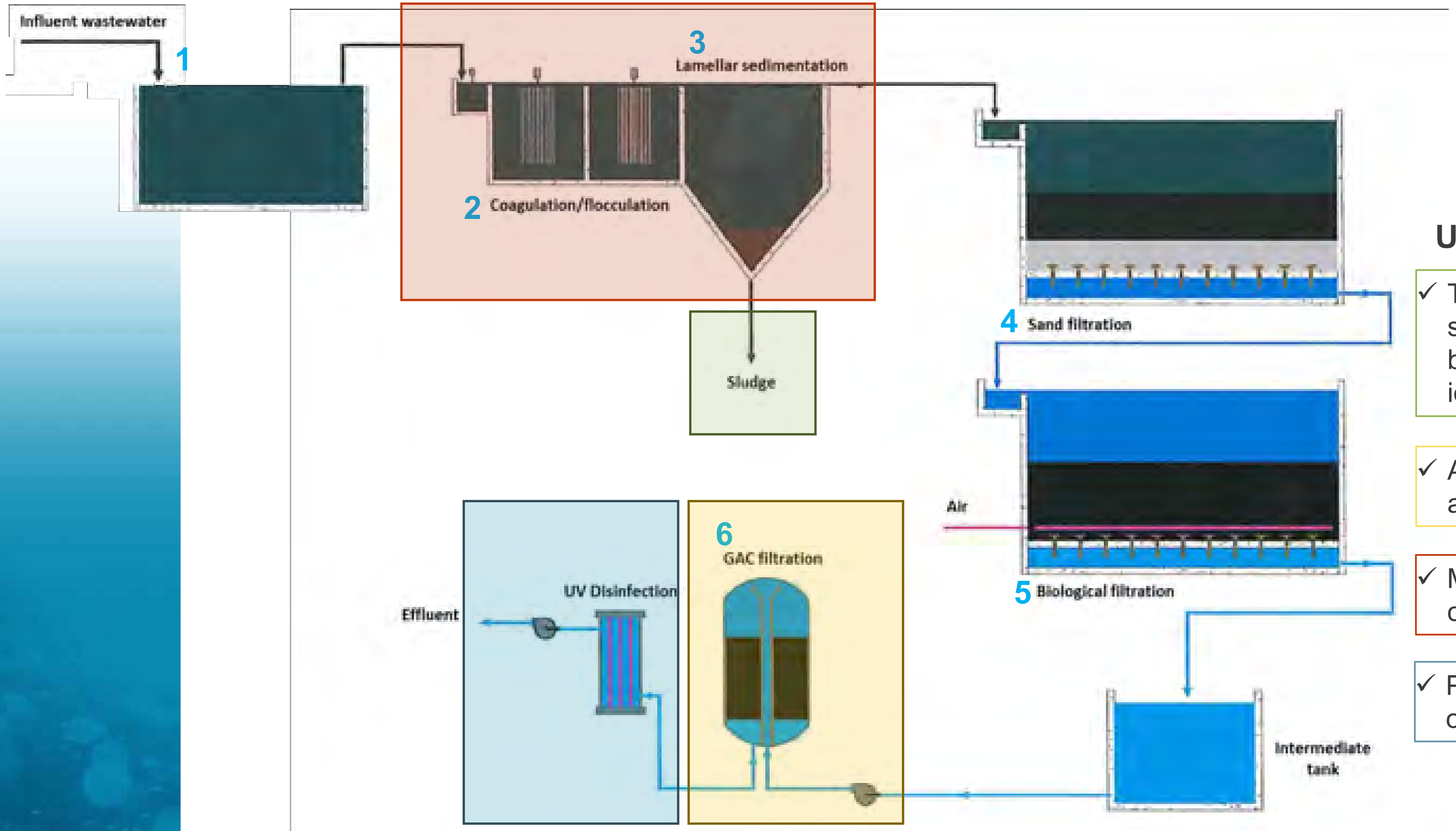
ULTIMATE Solutions



1. Equalization
2. Coagulation/flocculation
3. Sedimentation
4. Sand filtration
5. Biological activated carbon
6. Activated carbon filtration

ULTIMATE SOLUTIONS

- ✓ The possibility to re-use the chemical (alum/ferric) sludge from coagulation/flocculation in the WWRP will be analysed and potential users will (potentially) be identified via the Alu Circles initiative.
- ✓ A pilot scale adsorption system will be tested with alternative sludge-biowaste-originated GAC.
- ✓ Mineral by-products will be used as alternative coagulants and/or adsorbent.
- ✓ Possible residual disinfectant agents will be tested in order to improve disinfection.

The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

Possibility to re-use the chemical (alum/ferric) sludge and potential users identified via the Alu Circles initiative

The ALU Circles initiative (https://www.alliedwaters.com/project/alucircles/) is addressing the challenge to convert the alum sludge from one-off use of material into a sustainable solution, such as upcycling or recycling, at a lower cost.

PLANNED ACTIVITIES

1. Mass flow analysis : Production of Al/Fe sludge in Italy and contacts with major water utilities (problem owners)

2. Fate of the Al/Fe sludge: Current disposal/reuse routes and related costs

3. Characterization of Al/Fe sludge: Physical-chemical parameters

4. Preliminary assessment of possible applications: absorbents/coagulants in wastewater treatmnent, geotechnical, geo-environmental and building sectors

5. Experimental tests: Mechanical properties in construction materials / removal efficiencies in tertiary wastewater treatment

6. Local and regional impact by LCA and LCC of the most promising solutions

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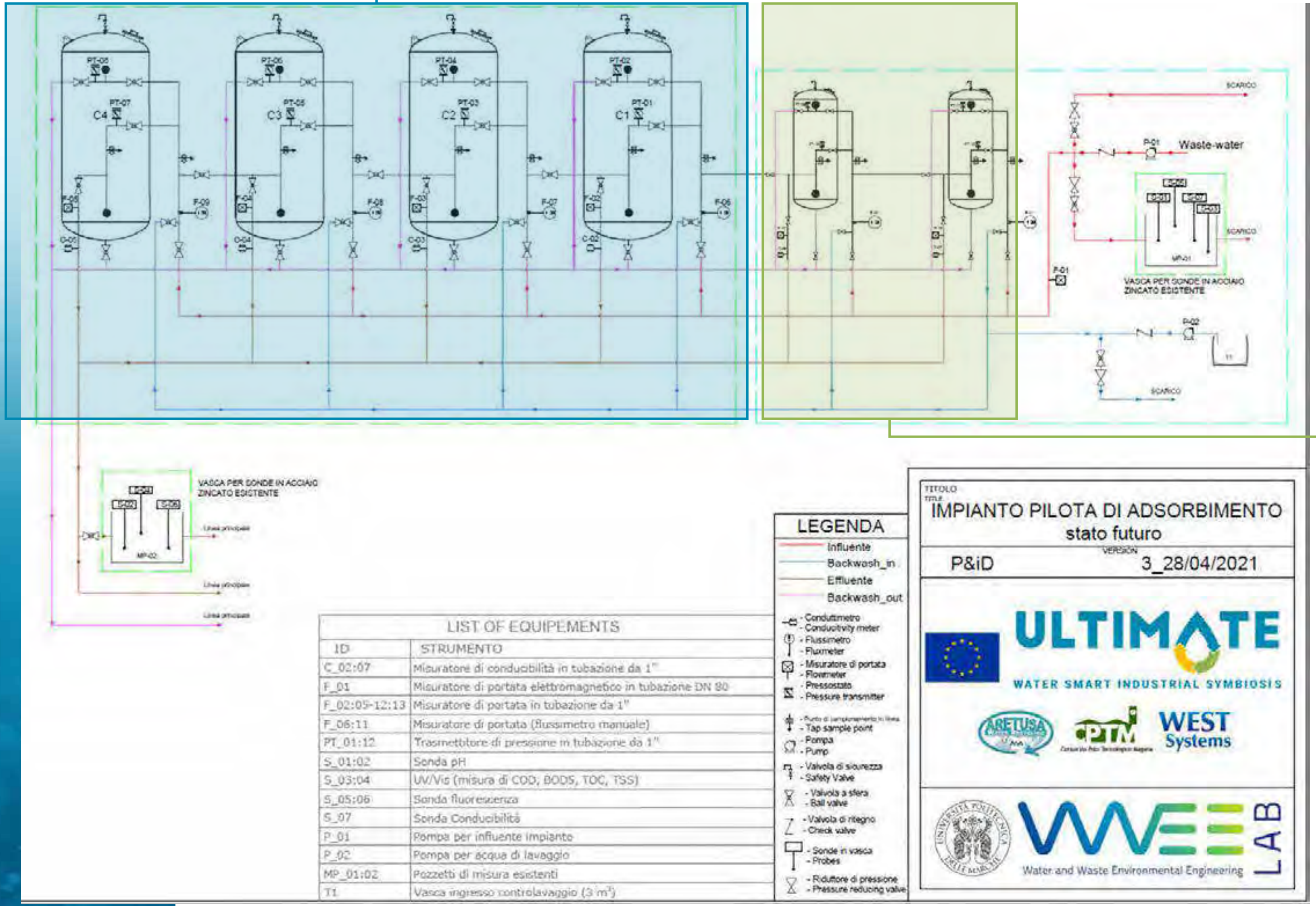
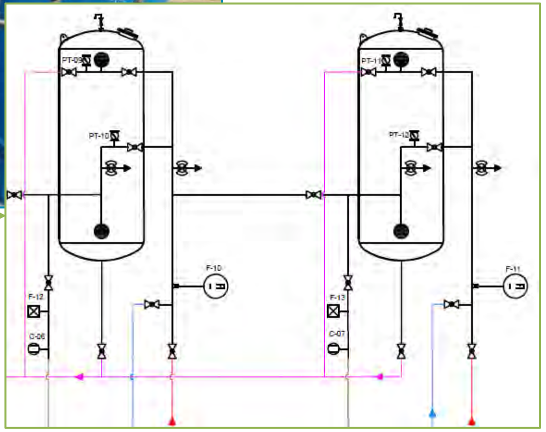
A pilot scale adsorption system will be tested with alternative GAC.





	Bigger columns	Smaller columns
Numbers	4	2
Volume (m3)	0.6	0.11
Diameter (m)	0.8	0.32
Material (kg)	325	60

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Water and Waste Environmental Engineering LAB
WEST Systems

A pilot scale adsorption system will be tested with alternative GAC.

ULTIMATE INNOVATIONS

✓ **Monitoring system → sensors and probes**

Influent and effluent from the pilot will be monitored with:
- Conductivity
- pH
- UV/Vis (COD, BOD5 and TOC)
- Fluorescence

ID	INSTRUMENTS	Q. ty	Position	Characteristics
PT-01:08	Pressure transmitter	12	Influent and effluent from each column	0 – 1 bar
F-02:05	Electromagnetic water meter	6	Effluent from each column	0 – 10 m3/h
C-02:05	Insertion inductive conductivity digital probe	6	Effluent from each column	250 µS - 2,5 S/cm
S-01:02	pH meter	2	Influent and effluent	pH:0-14; T=-5° C - 50° C
S-03:04	UV/Vis meter (254 nm)	2	Influent and effluent	Measuring cell: 5 mm Measuring range: 0.1-600.0 m-1 Calibrable on the COD and TOC parameters Compensation: 550 nm Cleaning system: automatic by wiper Measuring interval:> 1 min
S-05:06	Fluorimeter	2	Influent and effluent	filter band for wavelengths centered on ex/em 345/440 nm
S-07	Conductivity meter	1	Influent	250 µS - 2,5 S/cm
F-01	Electromagnetic water meter	1	Influent	0 – 50 m3/h

✓ **Innovative material as adsorbents →** **EXPERIMENTAL ANALYSIS ONGOING!**

The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

Mineral by-products will be used as alternative coagulants and/or adsorbent

! In the past 140 t per year of aluminium polychloride, and 12 t per year of polyelectrolyte were used. **At the moment no reagent is used, and some mixers needs revamping**

ULTIMATE will test and assess the possibility of using industrial by-products

EXPERIMENTAL ANALYSIS ONGOING

COAGULATION/FLOCCULATION UNIT	Rapid mixing (coagulation)	Medium agitation (primary flocculation)	Slow mixing (secondary flocculation)
Number of tanks	2	2	2
Volume (m3)	5.73	73	72

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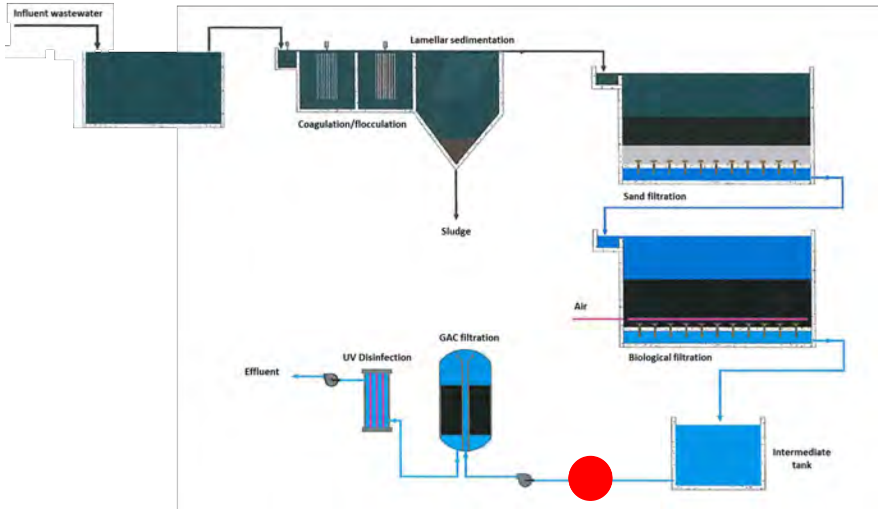
Characterization of the water sample collected in May 2021

Sample was collected at Aretusa plant before the final GAC stage in order to find a higher COD concentration.

Measured values are compared with the average, minimum and maximum from historical data, and with the Aretusa specification.

		Average	Min	Max	Measured	Aretusa-Solvay contractual constraint
pH	-	7.6	7.0	7.9	7.7	
Electrical conductivity	µS/cm	2580	1010	7340	2134	1030
Cl^-	mg/l	568	159	2079	398	400
$NO3^{--}$	mg NO3/l	57	8	128	45	
$PO4^{---}$	mg PO4/l	/	5	15	10	
$SO4^{--}$	mg/l	/	100	150	132	
Ca	mg/l	/	140	180	145	
Mg	mg/l	/	45	60	54	
K	mg/l	/	13	18	17	
Na	mg/l	/	225	305	232	
COD	mg O2/l	25	10	88	20	10



Sampling point

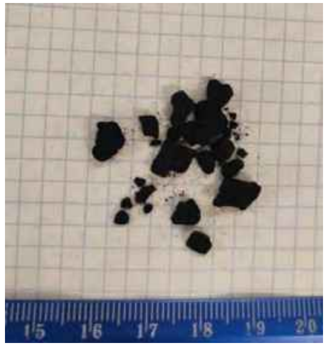
The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

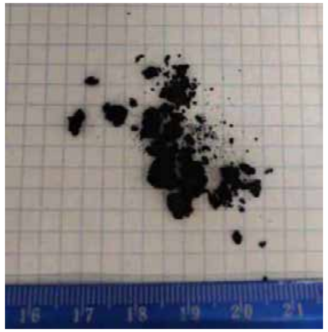
Industrial by-product

- Bentonite OC by-product "Scarto centrifuga"

- Hydro-char from municipal sewage sludge

Hydrochar activated with different processes

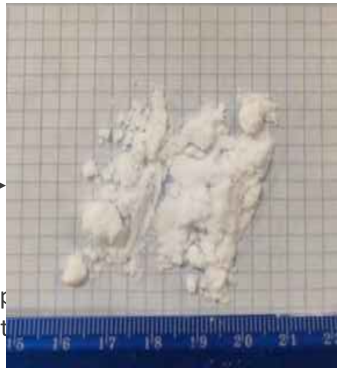




- Granulated Limestone rocks only partially calcinated

- Na2CO3 "Soda Solvay® Light" >> out of specification

- NaHCO3 >> out of quality standard



The project leading to this application has received funding from the Europ
Horizon 2020 research and innovation programme under grant agreement

Adsorbent materials for COD removal

Bentonite OC by-product “Scarto centrifuga” – LAV1

This **by-product** comes from **Laviosa Chimica Mineraria SpA** plant (located about 30 km from Aretusa).

Laviosa activities consists in extracting, processing and distributing industrial mineral products, in particular bentonitic products and special ‘modified’ bentonitic products called “Organo-clay”.

From the necessary purification stages in the organo-clay production process comes this **‘grit’ that is poor in bentonite but rich in zeolite and other silicates: it comes from a decanter separation and looks like a semi solid sludge.**

Bentonite stock → Bentonite suspension → Purification → Reaction → Filtration, Drying, Grinding → Packaging

Purification → Grit elimination

PRODUCTION
50 t/month

Technical specifications

Le analisi effettuate di diffrazione ai raggi X dimostrano che la fase più abbondante risulta quella zeolitica e le altre fasi sono silicate quali calcite, plagioclasio, miche ed altri riportati nella tabella sottostante:

XRD

Fase	Quantità [%]
Zeoliti	33
Calcite	28
Plagioclasio	15
Quarzo	10
Mica	8
K-feldspato	6

L’umidità risulta mediamente del 35 % in massa e la perdita alla calcinazione del 11,67 %.

La composizione degli ossidi invece risulta come nella seguente tabella:

Oxides composition

Analita	Quantità [%]
Na_2O	1,80
MgO	0,86
Al_2O_3	11,75
SiO_2	59,05
P_2O_5	0,35
K_2O	2,76
CaO	9,85
TiO_2	0,30
MnO	0,40
Fe_2O_3	1,22

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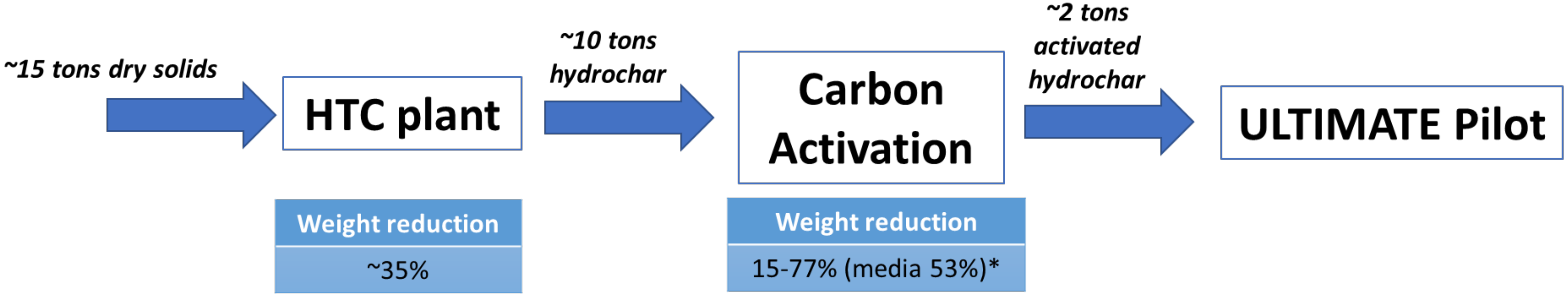
Adsorbent materials for COD removal

Activated Hydro-char from municipal sewage sludge

Hydrochar (HC) was supplied by the **Spanish company Ingelia SL**: this biocarbon is the product of a **Hydrothermal Carbonization (HTC)** process which, operating at relatively low temperature and pressure conditions in the presence of liquid water, **converts the biomass or municipal sewage sludge, in a carbonaceous solid (bio-lignite).**

Operating on small quantities, in CPTM laboratory, the **HC was activated** in order to be tested as an adsorbent material. **The activation procedures**, suggested by the scientific literature, **were physical (thermal) and chemical**.



Hydrochar from municipal sewage sludge

The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

Adsorbent materials for COD removal

Activated Hydro-char from municipal sewage sludge

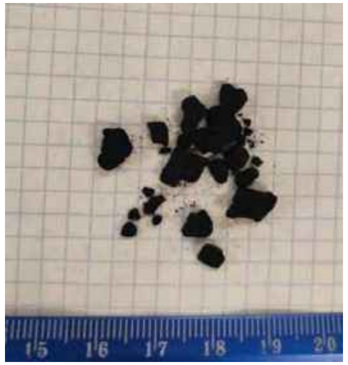
Physical activation – ATT1

- Heating of the char pellets in a tubular oven up to 700°C (5°C/min) with N_2 purging.
- CO_2 flushing and isotherm for 2 hr.
- Cooling of the tubular furnace in N_2 purging.

47% WEIGHT LOSS

Chemical activation – ATT4

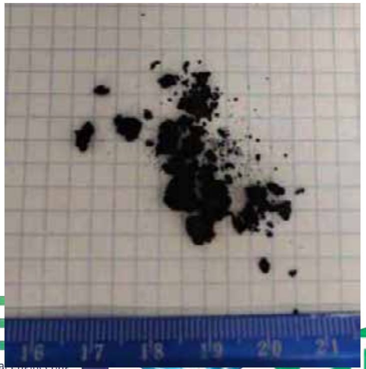
- Impregnation of char pellets in KOH aq. solution (KOH to char ratio: 1:1) at 60°C for 6 hr.
- Drying of the impregnated char at 105°C.
- Heating in a tubular oven up to 600°C (5°C/min), isotherm at 600°C for 1 hr and cooling (5°C/min) with N_2 purging.
- Washing with 1M HCl and demi water (up to pH 7).
- Drying at 105°C until constant weight.



55% WEIGHT LOSS

Chemical activation – ATT5

- Mixing of the char pellets (previously grounded) with KOH in flakes (KOH to char ratio: 1:1).
- Heating in a tubular oven up to 600°C (5°C/min), isotherm at 600°C for 1 hr and cooling (5°C/min) with N_2 purging.
- Washing with 5M HCl and demi water (up to pH 7).
- Drying at 105°C until constant weight.



60% WEIGHT LOSS

Horizon 2020 research and innovation programme under grant agreement No 869318

Adsorbent materials for COD removal

Commercial activated carbon – CA1

CARBONITALIA
activated carbon & bleaching earths

Review : 6
Date of issue : February, the 1st 2018

Technical Data Sheet

FILTERCARB GCC 8X30

Granular Activated Carbon obtained from specially selected grades of coconut shell, specially designed to remove pollutants from water, odours and bed tests from beverages like edible oils, wine, beer, ex...

STANDARD SPECIFICATIONS

Specification	Units	Values	Methods
BET Surface	m^2/g	1100-1150	BET N2
Ash content	%	2-4	CEFIC 1986
Bulk content	g/cm^3	0,45-0,50	CEFIC 1986
Moisture	%	5	CEFIC 1986
Iodine index	mg/g	1000-1100	CEFIC 1986
CTC	%	55-65	Method on request
Hardness	%	95	Method on request
Chlorine half-length value	cm	3	Method on request
Grain size distribution			Sieving analysis
> 8 mesh (2,36 mm)	%	5	
< 30 mesh (0,60 mm)	%	5	
Uniformity coefficient		max 1,7	

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Adsorbent materials for COD removal

Adsorbent materials characterization

<u>Leaching test</u>

Test followed the EN 12457-2:2002 for the waste characterization (liquid to solid ratio of 10 L/kg).

Concentrations are expressed as ppm in the leached solution.

	LAV1	HC	HC ATT1	HC ATT4	HC ATT5
F^-	< 0.1	54.2	0.2	0.4	< 0,1
Cl^-	2,5	44.4	62.5	26.4	1.7
$NO3^-$	0.2	1.3	< 0,1	< 0,1	< 0,1
$PO4^{---}$	3.2	38.5	< 0,1	54.3	8.4
$SO4^{--}$	32.9	147.3	143.9	110.2	103.4
COD	81	4200	< 15	< 15	< 15

- **NEED OF PRE-TREATMENT (WASHING) OF THE HC**
- **FURTHER TEST FOR ADSORPTION IN THE INTEGRATED SYSTEM (ROSIGNANO-CECINA WWTP)**

<u>BET analysis</u>

	LAV1	HC ATT1	HC ATT4	HC ATT5	CA1
Specific surface area (m^2/g)	6	117	449	752	1100÷1150
Specific pore volume (cm^3/g)	0.003	0.055	0.214	0.359	/
Average pore radius(Å)	50.23	13.61	15.16	16.08	/

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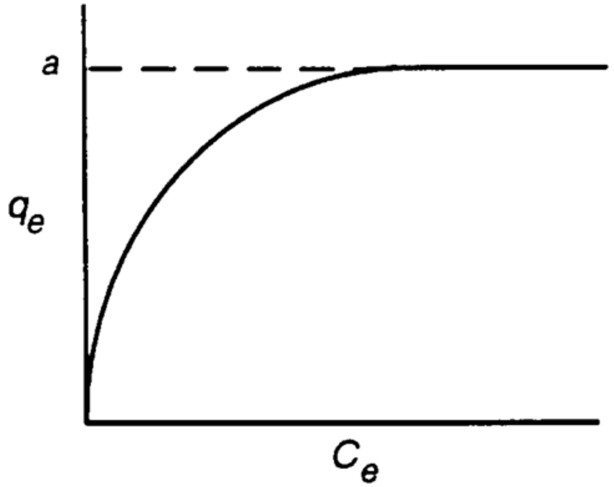
Adsorbent materials for COD removal

Preliminary adsorption tests with Methylene Blue (MB) solution

MB solutions are commonly used for comparative adsorption tests on activated carbon and they simulate chemical substances with an effective molecular diameter of 15 Å.

The Adsorption capacity (q_e) is the amount of adsorbate taken up by the adsorbent per unit mass of the adsorbent at equilibrium conditions. It changes with the final equilibrium concentration of the adsorbate in the solution (c_e) and an 'isotherm curve' can be realized for each material tested.



This is a 'Langmuir isotherm' that describes the most common adsorption mechanism of an activated carbon.

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Adsorbent materials for COD removal

Preliminary adsorption tests with Methylene Blue (MB) solution

CPTM is currently completing these preliminary tests in order to compare the different adsorbent materials.

PRELIMINARY RESULTS >> TEST STILL ONGOING!

	c_e (mg_{MB}/L)	q_e (g/kg)
LAV1	0.6	11
ATT4	0.1 4.0	305 321
CA1	0.1 0.9	304 383

LAV1 material (Bentonite OC by-product by Laviosa) **shows a lower adsorption capacity** compared to the chemically activated HC ATT4 and to the commercial activated carbon.

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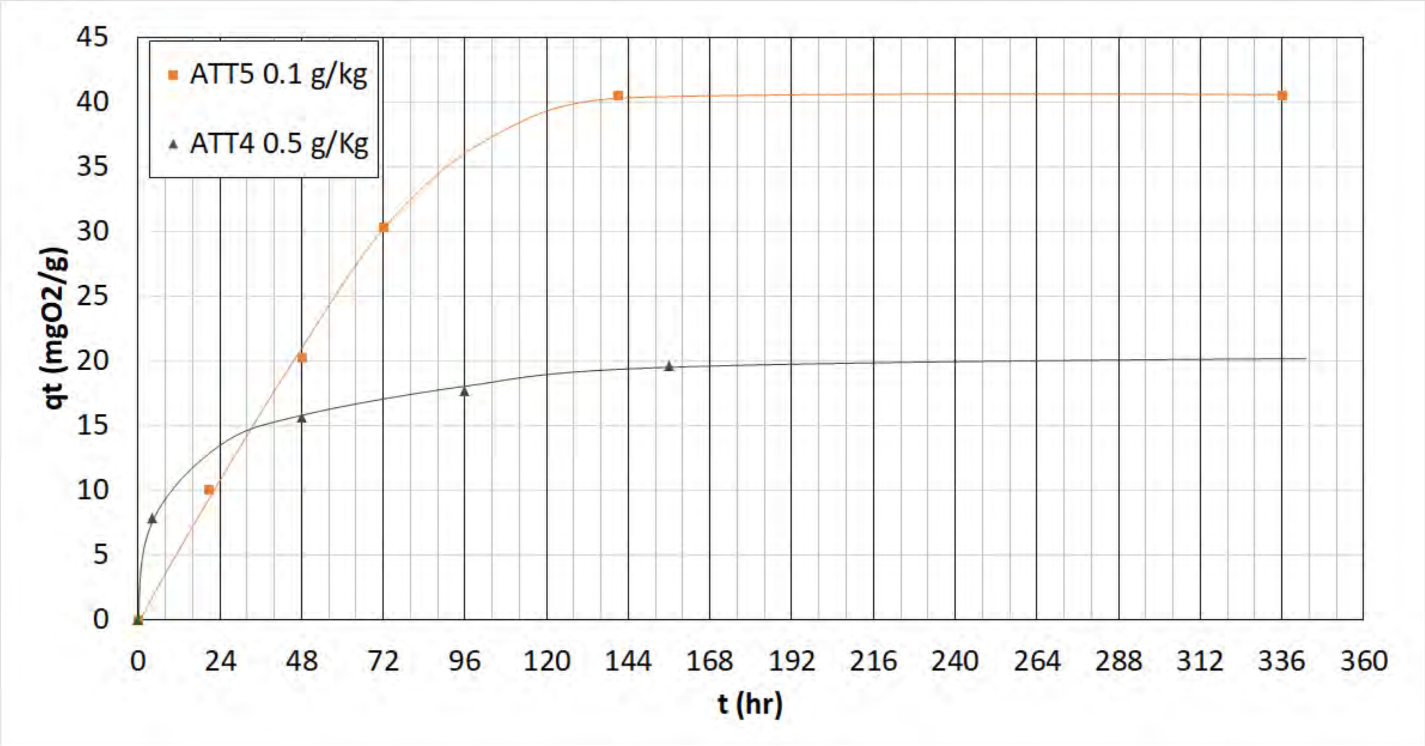
Adsorbent materials for COD removal

Adsorption tests with Aretusa water sample (COD reduction)

ARETUSA sample → **COD = ~20 mgO_2/L.**

Kinetic adsorption tests:

Here below an example of two kinetic adsorption curves: the scope of these tests is to evaluate the minimum time necessary to reach the equilibrium state and find the Adsorption capacity (qe) of the material.



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Adsorbent materials for COD removal

Adsorption tests with Aretusa water sample (COD reduction)

CPTM is currently completing these preliminary tests in order to compare the different adsorbent materials that can be used for the COD reduction in the Aretusa water.

PRELIMINARY RESULTS >> TEST STILL ONGOING!

	c_e (mgO_2)/L	q_e (g/kg)
LAV1	16	4.0
ATT4	7 17	19.6 20.0
ATT5	9 15	40.5 40.0

These tests confirmed that **LAV1 material** (Bentonite OC by-product by Laviosa) **shows a lower adsorption capacity compared to the chemically activated HC** ATT4 and ATT5.
ATT5 shows a better adsorption capacity than ATT4 probably caused by the higher specific surface area previously described (752 and 449 m2/g).

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Adsorbent materials for COD removal

Preliminary conclusions

- ✓ Both from the preliminary tests conducted with MB solutions and from those conducted with the real water sample, it can be anticipated that the adsorption capacity of LAV1 is much lower than that of activated HCs and unfortunately does not probably justify its possible use as an adsorbent material.

- ✓ The different activated HCs will be compared with the commercial activated carbon.

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Softening tests

HARDNESS (mg_{CaCO3}/L)	
Direct measure*	Aretusa-Solvay contractual limit
520	340

*Direct measure with EDTA complexometric titration

Hardness overcome the contractual limit requested by SOLVAY !

Specific analyses have shown that about 50% of the total hardness is temporary hardness essentially due to Ca(HCO3)2 while the remaining part of 50% is due to the permanent hardness which is mainly composed of chloride, sulphate and nitrate of Mg.

SOFTENING TECNIQUES: *lime and the lime-soda ash process.*

- ✓ "Precotto": granulated limestone rocks only partially calcinated and slacked, with a declared content of $Ca(OH)_2$ of about 9%.

- ✓ Na_2CO_3 "Soda Solvay® Light" product that resulted to be out of specification.

Solvay Chimica Italia SpA by-products tested

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Softening tests

Solvay by-product and OOS were compared to pure laboratory lime and soda ash.

Lime process

$Ca(OH)_2$	Pure product	'Precotto' Solvay
Concentration (mg/L)	583	1074
pH after the reagent addition	10.8	10.5
Final total hardness measured	277	238
Total hardness reduction	**46%**	**54%**

Lime - Soda ash process

$Ca(OH)_2$	Pure product	'Precotto' Solvay
Concentration (mg/L)	622	1349
Na_2CO_3	Pure product	'Soda Light' OOS
Concentration (mg/L)	631	1419
pH after each reagent addition	11.0 – 11.2	11.0 – 10.7
Final total hardness measured	69	71
Total hardness reduction	**87%**	**86%**

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Softening tests

Preliminary conclusions

- ✓ Solvay annual production of 'Precotto' and of out-of-spec 'Soda Light' is absolutely sufficient to treat the total Aretusa water output.

- ✓ The preliminary tests conducted shows a very good total hardness reduction.

- ✓ Specific tests will be carried out to optimize the exact dosage of the two reagents and to evaluate the generated sludge amount.

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sludge 4.0

Thermochemical treatment and down-stream strategies for materials recovery from sewage sludge

Massimo Aiello[1], Sandra Vitolo[2,4], Monica Puccini[2,4], Andrea Luca Tasca[2], Gemma Mannarino[3], **Riccardo Gori[3,4]**,

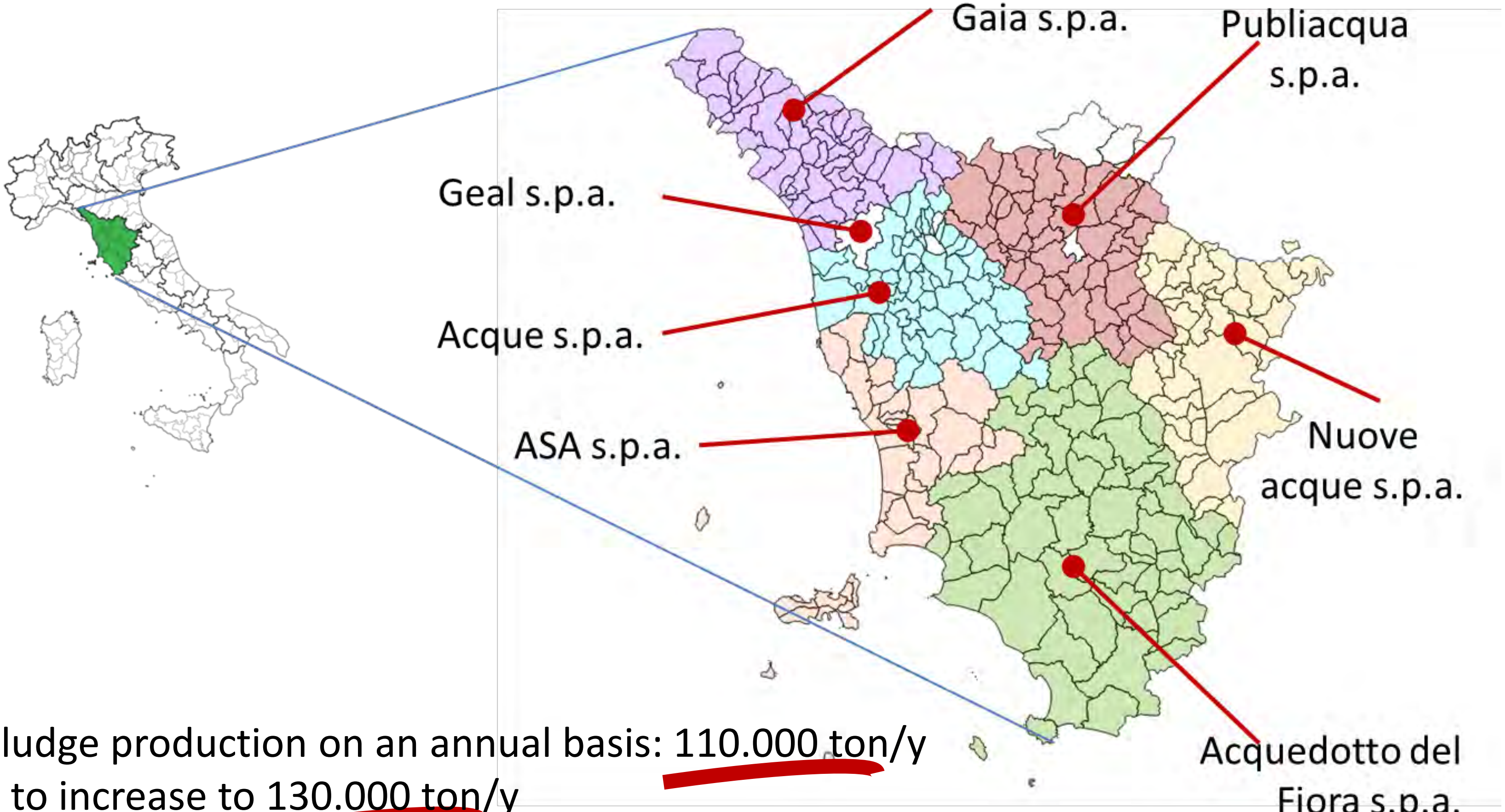
[1]ACEA Ambiente s.r.l., [2]Università di Pisa, [3]Università di Firenze, [4]Consorzio Interuniversitario Nazionale per la Scienza e Tecnologia dei Materiali (INSTM),

ULTIMATE
WATER SMART INDUSTRIAL SYMBIOSIS

CS meeting on "Material recovery and safe reuse"

Sludge production in Tuscany

SLUDGE 4.0 Project: Conversion of sewage sludge in biofertilizers



- Sewage sludge production on an annual basis: 110.000 ton/y
- Expected to increase to 130.000 ton/y
- About 47% produced in 11 WWTPs

sludge 4.0

Hydrothermal carbonization (HTC)

Sludge
(primary, secondary, digested)

→

HTC

T = 180 - 250 °C

P = 10 - 30 bar

t = 0.5 - 6 h

↑ **Gas** (<5%)

→

Slurry
(>95%)

↑ **Solids** (Hydrochar)

↓ **Process water**

Hydrothermal carbonization (HTC)

1 Untreated sludge

2 HTC reactor

3 Slurry

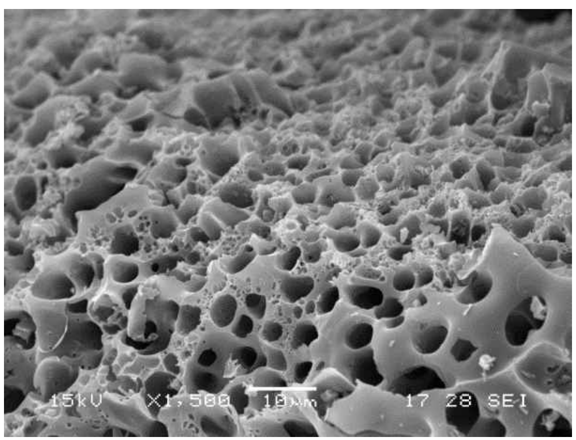
4 Hydrochar

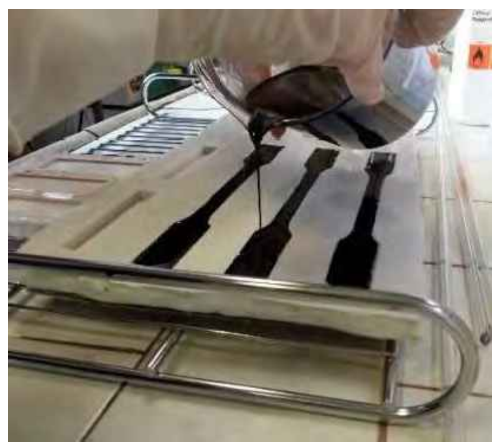
5 Process water

sludge 4.0

Valorization of HTC’s products

- Recovery of hydrochar in agricolture (possible but may be not allowed by the erupean/national laws)
- Recovery of liquid and solid products for the **production of fertilizers**
- Recovery of **P** and **Si**





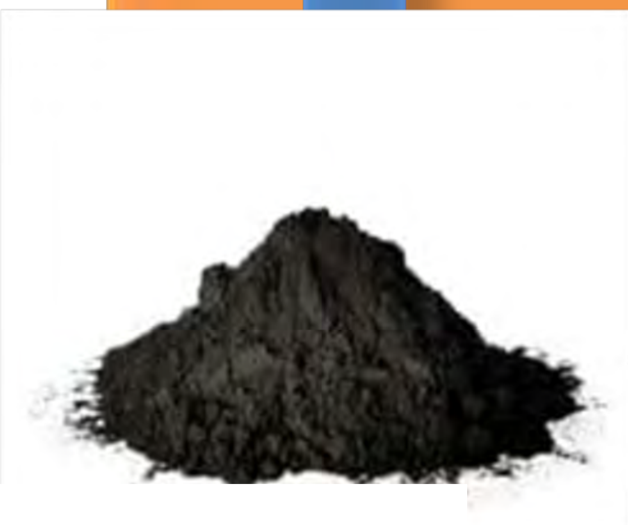
Production of:
- **materials adsorbent**
- **bio-based materials**

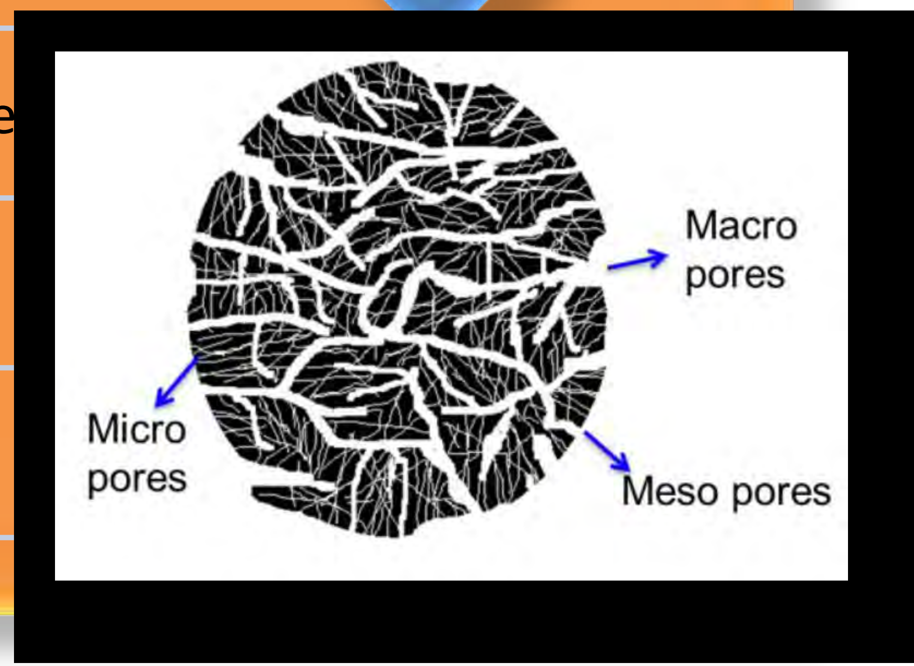
From hydrochar to activated carbon

Porous structure formation

Activating agent: KOH H, H_3PO_4

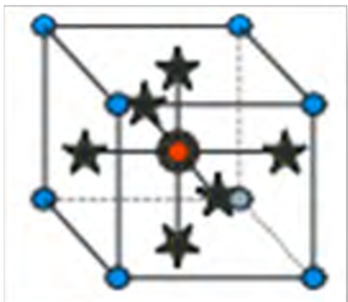
Te





Design of Experiments (DoE)

Application of the Design of experiment (DoE) approach to develop an empirical model to be used for the prediction of output variables on the basis of input variables



Target: Process optimization

[redacted]

Modello

$Y_i = f(X_i)$

[redacted]

$$\mathbf{Y = A - B + C + AB + A^2 + B^2}$$

Input and output variables

Selected input variables

- Temperature (550 – 750 °C)
- Time of contact (60 – 240 min)
- KOH : HC ratio (1 – 3 wt/wt)

Selected output variables

- Yield (mass of AH)
- Ash content
- Adsorption capacity

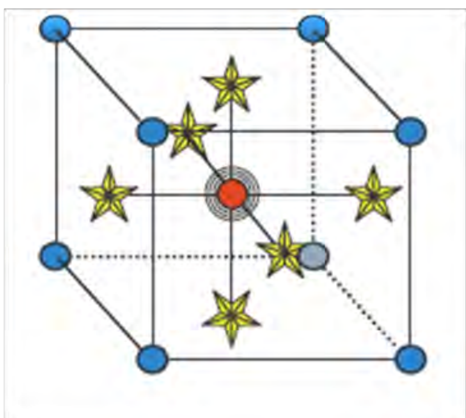
Terbuthylazine was selected as target compounds to evaluat the adsorption capacity. TBA has replaced atrazine as a broad-spectrum herbicide in most of the EU countries, becoming one the most detected compounds in surface and ground waters, coastal and marine areas.

Response Surface Method (RSM)

Central Composite Design (CCD) consists of
- $k \cdot 2^n$ factorial runs (k is the number of replicates)
- $2 \cdot n$ axial runs
- n_c center runs

$$N = k \cdot 2^n + 2 \cdot n + n_c$$

28 runs



Factorial points

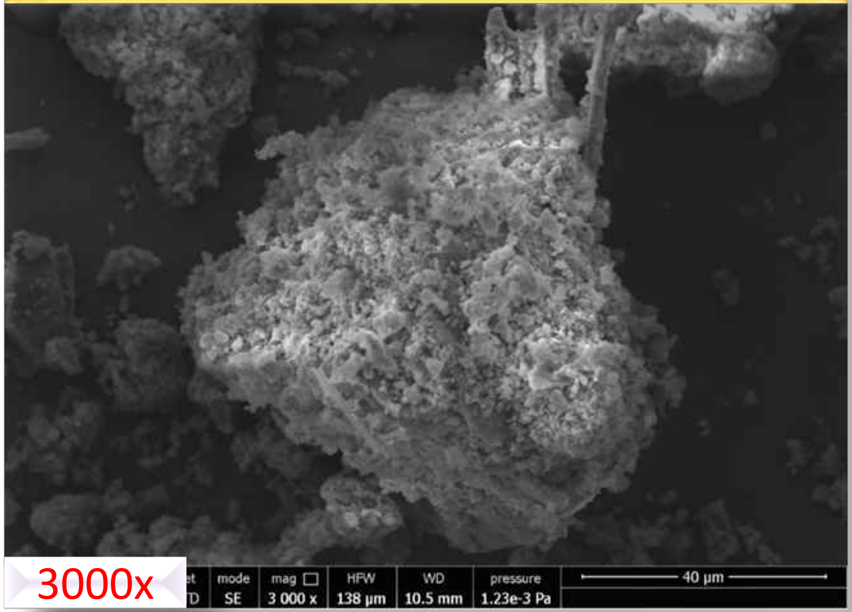
Center points

Axial points

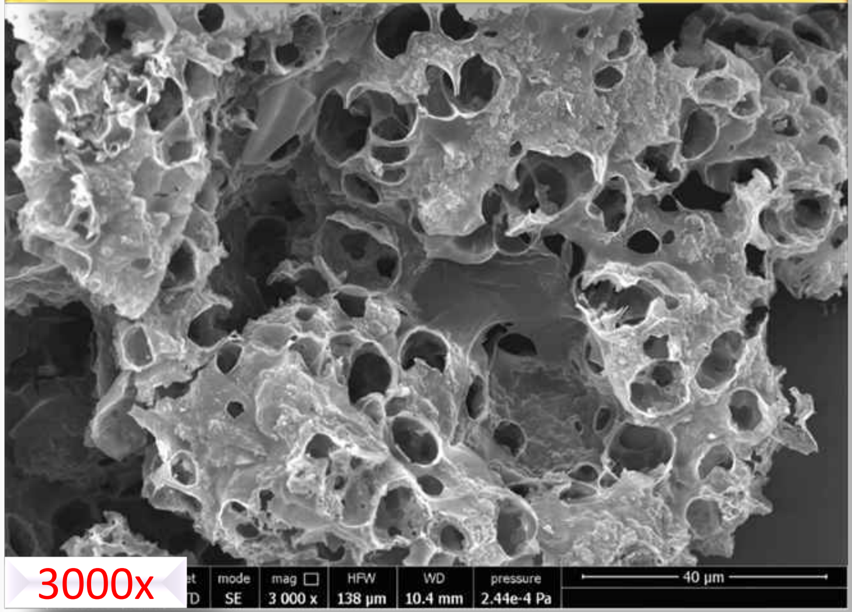
Run	Temperature (°C)	Time (min)	KOH:HC (wt/wt)
1	750	60	3
2	550	60	3
3	750	60	1
4	550	240	3
5	550	240	1
6	750	240	1
7	650	150	2
8	750	240	3
9	550	240	1
10	650	150	2
11	750	240	1
12	550	240	3
13	750	60	1
14	750	240	3
15	650	150	2
16	650	150	2
17	550	60	3
18	750	60	3
19	550	60	1
20	550	60	1
21	650	150	1
22	550	150	2
23	650	240	2
24	650	150	2
25	650	60	2
26	750	150	2
27	650	150	3
28	650	150	2

SEM analysis

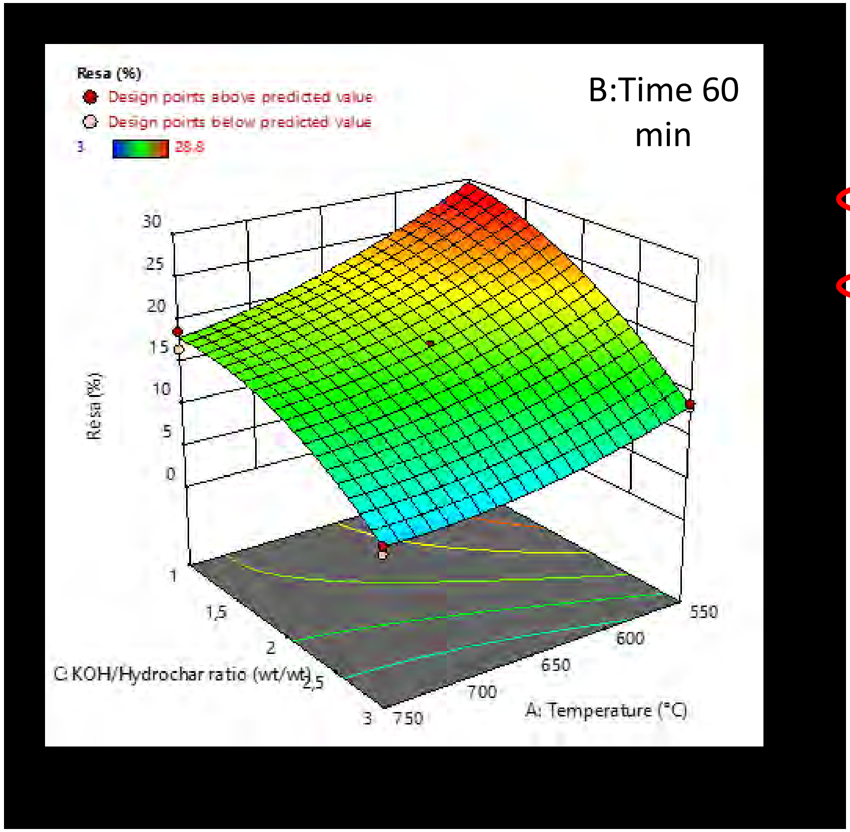
HYDROCHAR



ACTIVATED HYDROCHAR



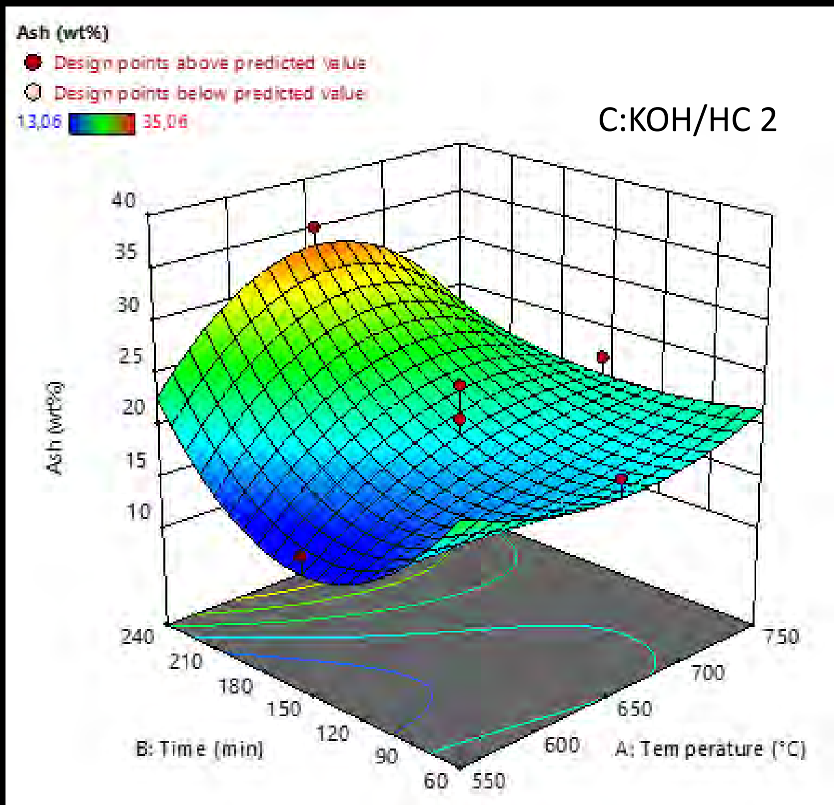
Yield



Source	Sum of Squares	df	Mean Square	F-value	p-value	
Block	20,24	1	20,24			
Model	1272,01	9	141,33	130,50	< 0.0001	significant
A-Temperature	367,48	1	367,48	339,29	< 0.0001	
B-Time	3,25	1	3,25	3,00	0,1013	
C-KOH/HC ratio	767,01	1	767,01	708,19	< 0.0001	
AB	0,9264	1	0,9264	0,8554	0,3680	
AC	36,63	1	36,63	33,82	< 0.0001	
A^2	6,70	1	6,70	6,18	0,0236	
B^2	18,72	1	18,72	17,28	0,0007	
C^2	22,82	1	22,82	21,07	0,0003	
A^2B	16,89	1	16,89	15,59	0,0010	
Residual	18,41	17	1,08			
Lack of Fit	3,74	5	0,7482	0,6120	0,6930	not significant
Pure Error	14,67	12	1,22			
Cor Total	1310,66	27				

Std. Dev.	1,04		R^2	0,9857
Mean	15,93		Adjusted R^2	0,9782
C.V. %	6,53		Predicted R^2	0,8822
			Adeq Precision	39,4085

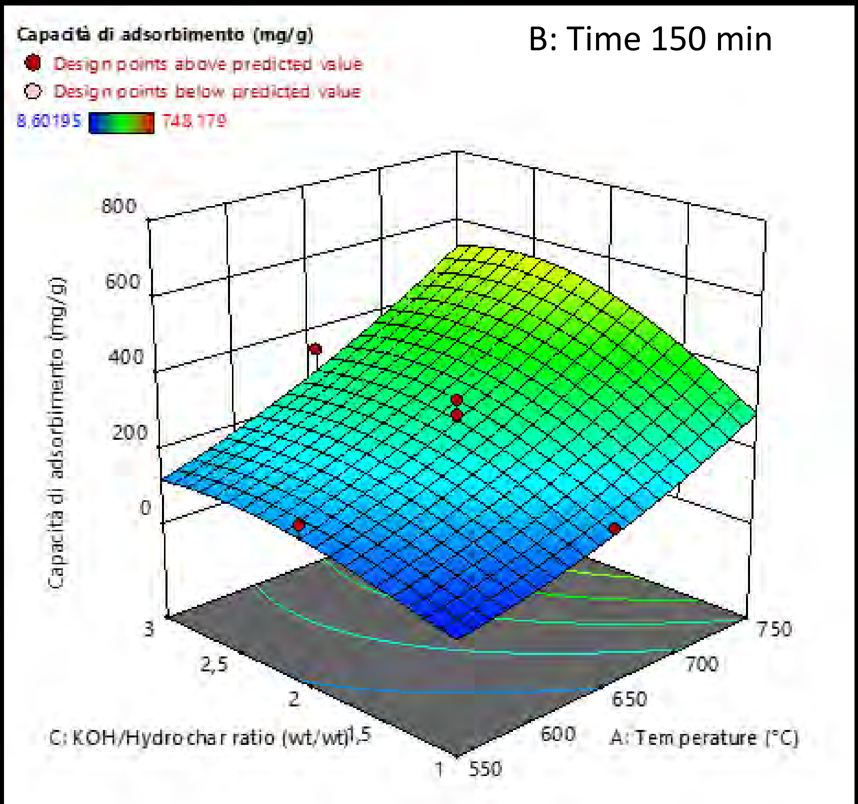
Results – Ash conten t



Source	Sum of Squares	df	Mean Square	F-value	p-value	
Block	39,32	1	39,32			
odel	397,45	9	44,16	8,63	< 0.0001	significant
A-Temperature	40,14	1	40,14	7,84	0,0123	
-Time	108,93	1	108,93	21,29	0,0002	
C-KOH/HC ratio	21,02	1	21,02	4,11	0,0587	
B	1,41	1	1,41	0,2756	0,6064	
AC	79,34	1	79,34	15,51	0,0011	
²	36,78	1	36,78	7,19	0,0158	
B²	142,30	1	142,30	27,81	< 0.0001	
²B	85,30	1	85,30	16,67	0,0008	
AB²	36,90	1	36,90	7,21	0,0156	
esidual	86,99	17	5,12			
Lack of Fit	13,29	5	2,66	0,4326	0,8175	not significant
ure Error	73,70	12	6,14			
Cor Total	523,75	27				

Std. Dev.	2,26		R^2	0,8204
Mean	20,39		Adjusted R^2	0,7254
C.V. %	11,09		Predicted R^2	0,4201
			Adeq Precision	15,5169

Results - Adsorption capacity



Source	Sum of Squares	df	Mean Square	F-value	p-value	
Block	18,41	1	18,41			
Model	888,71	6	148,12	48,42	< 0.0001	significant
A-Temperature	665,86	1	665,86	217,68	< 0.0001	
B-Time	10,76	1	10,76	3,52	0,0754	
C-KOH/HC ratio	147,54	1	147,54	48,23	< 0.0001	
AB	15,43	1	15,43	5,05	0,0361	
BC	15,77	1	15,77	5,16	0,0344	
C^2	33,35	1	33,35	10,90	0,0036	
Residual	61,18	20	3,06			
Lack of Fit	29,08	8	3,64	1,36	0,3046	not significant
Pure Error	32,09	12	2,67			
Cor Total	968,30	27				

Std. Dev.	1,75		R^2	0,9356
Mean	14,86		Adjusted R^2	0,9163
C.V. %	11,77		Predicted R^2	0,8710
			Adeq Precision	20,7909

sludge 4.0

Results - Models and Optimization

Yield

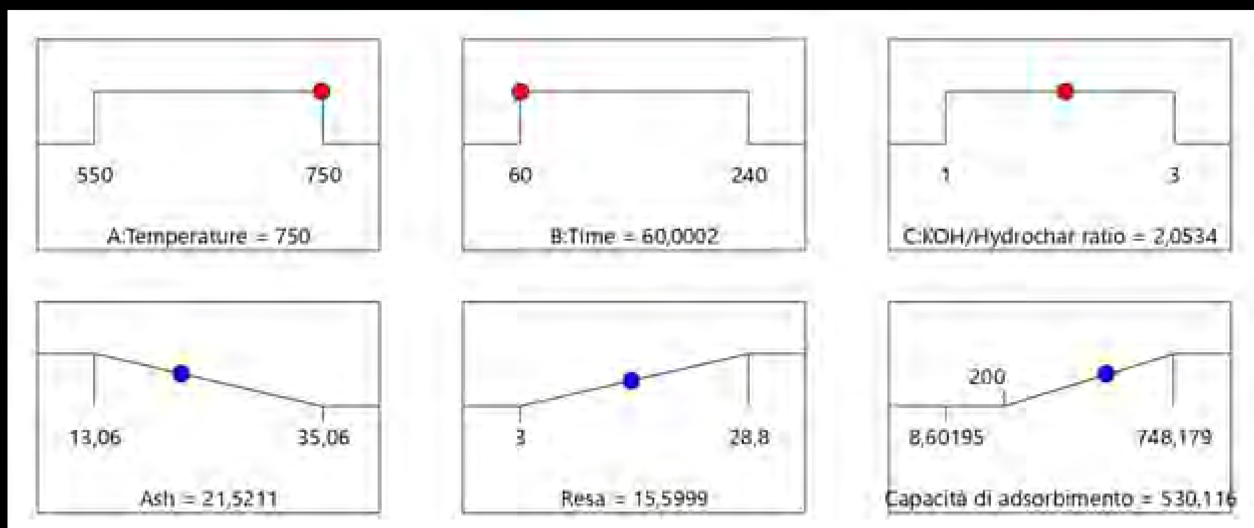
$$y = 17{,}29 - 4{,}52\,\mathbf{A} + 1{,}27\,\mathbf{B} - 6{,}53\,\mathbf{C} - 0{,}2406\,\mathbf{AB} + 1{,}51\,\mathbf{AC} - 1{,}57\,\mathbf{A^2} + 2{,}62\,\mathbf{B^2} - 2{,}89\,\mathbf{C^2} - 3{,}08\,\mathbf{A^2B}$$

Ash content

$$y = 19{,}22 + 4{,}48\,\mathbf{A} + 7{,}38\,\mathbf{B} - 1{,}08\,\mathbf{C} + 0{,}2969\,\mathbf{AB} - 2{,}23\,\mathbf{AC} - 3{,}42\,\mathbf{A^2} + 6{,}72\,\mathbf{B^2} - 6{,}93\,\mathbf{A^2B} - 4{,}56\,\mathbf{AB^2}$$

Adsorption capacity

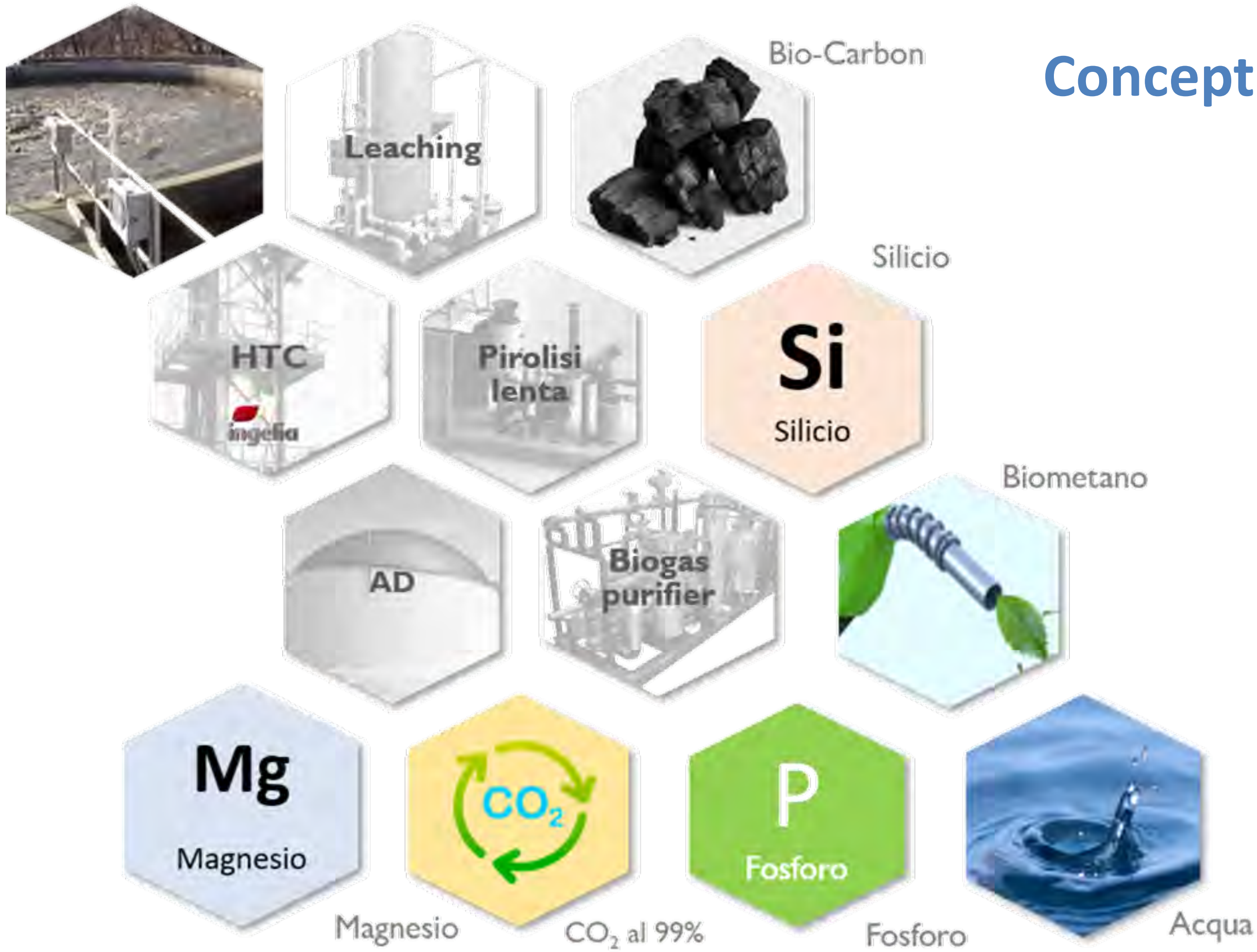
$$y^2 = 16{,}64 + 6{,}08\,\mathbf{A} + 0{,}7732\,\mathbf{B} + 2{,}86\,\mathbf{C} - 0{,}9822\,\mathbf{AB} + 0{,}9929\,\mathbf{BC} - 2{,}66\,\mathbf{C^2}$$



sludge 4.0

SLUDGE MINING project

Concept



Acknowledgements

Thanks for your attention!

Riccardo Gori – Università di Firenze

riccardo.gori@unifi.it

The project SLUDGE 4.0 has been funded by Regione Toscana within the framework of the POR-FESR (2014 – 2020) as a research and development strategic project.

Material recovery and safe reuse

Cellulose recovery from sewage

Marit van Veen

CirTec B.V.
Nijverheidsweg 26
1442 LD Purmerend
www.CirTec.nl

SMART-Plant

CirTec

About CirTec

Cellulose recovery from sewage

Screening and filtration

Evaporation and scrubbing

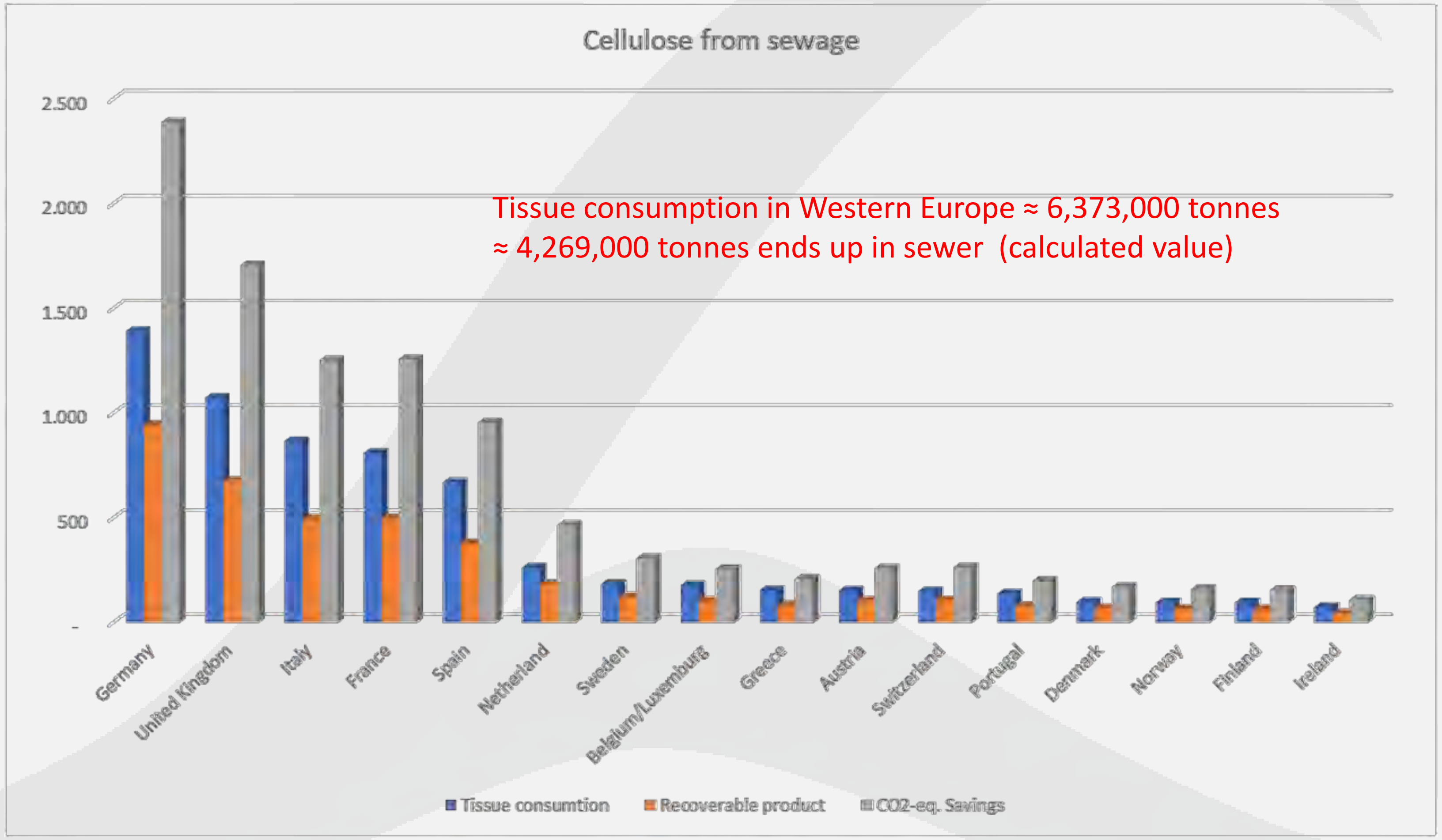
Sludge dewatering

Sludge drying

Recovery and valorisation of cellulose from sewage

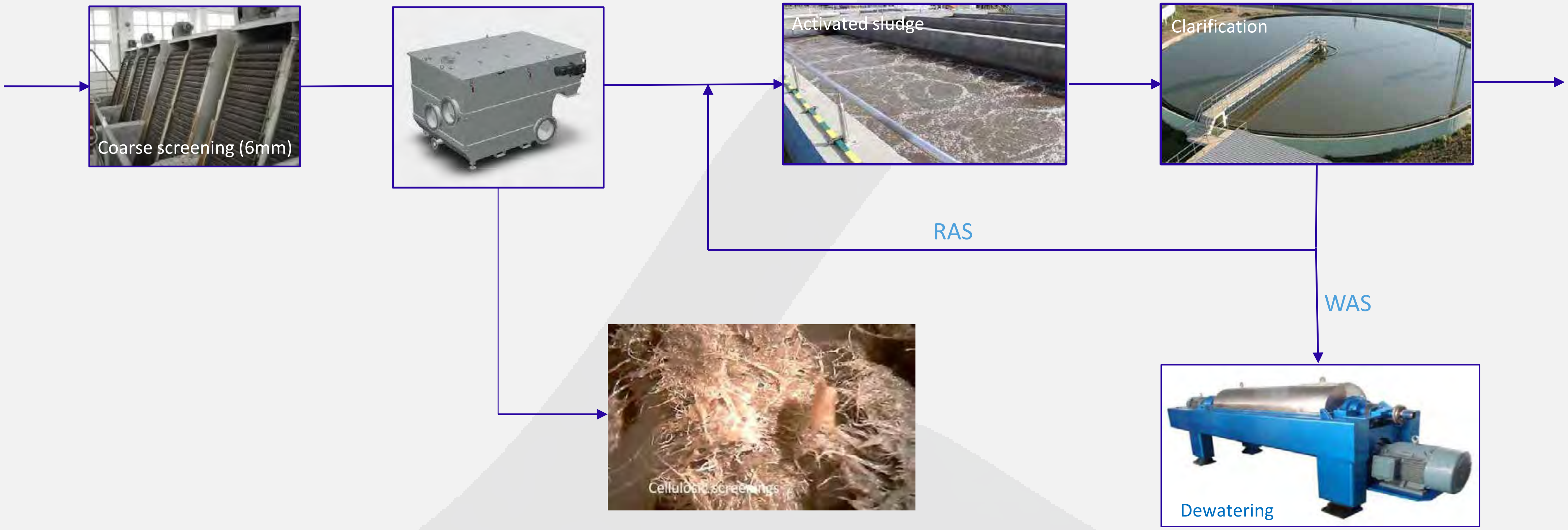
What is it about?

X 1.000 tonnes



Dynamic rotating belt finescreens for primary treatment

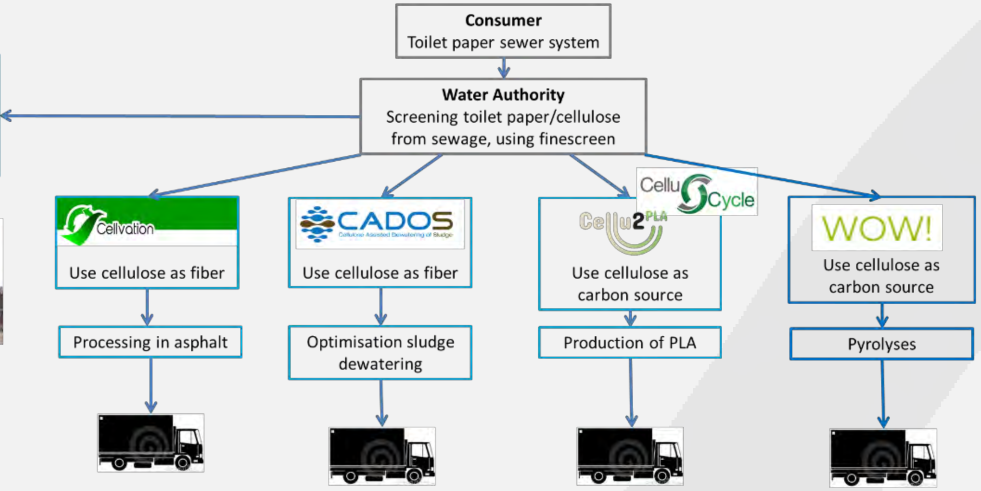
Saving energy by removing solids



knowledge development through small and large-scale research

SMART-Plant

Impact on dewaterability, denitrification, control, flow distribution, etc

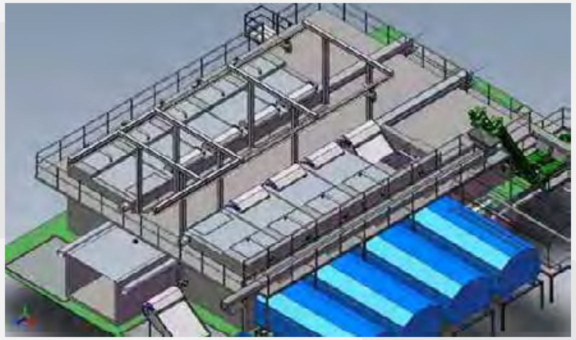


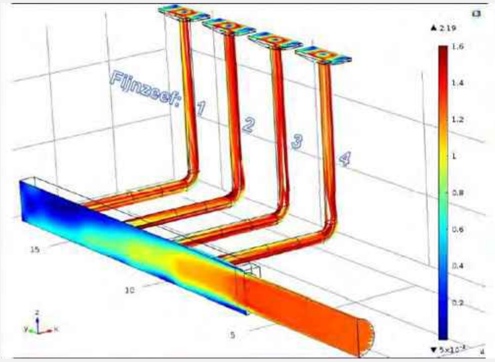
STP Aarle-Rixtel

STP Leeuwarden

STP Ulrum

STP Beemster





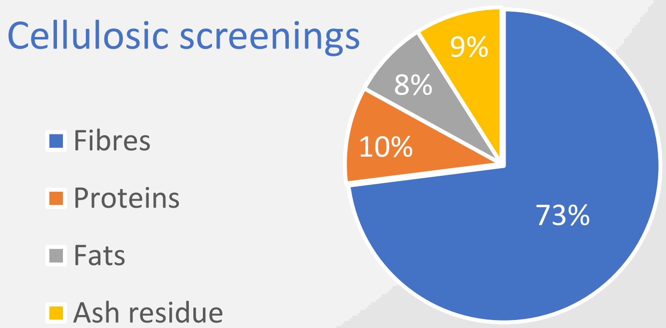
CFD analyses

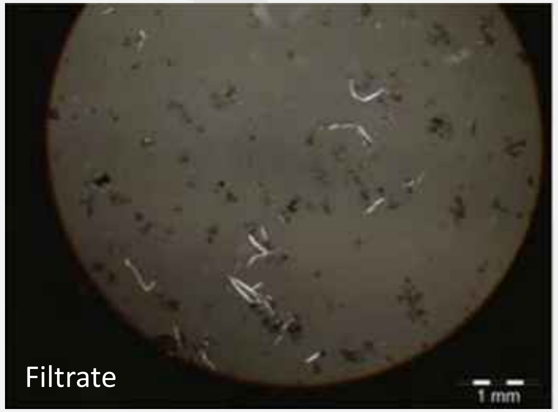
CIRTEC

Impact of dynamic rotating belt finesieves

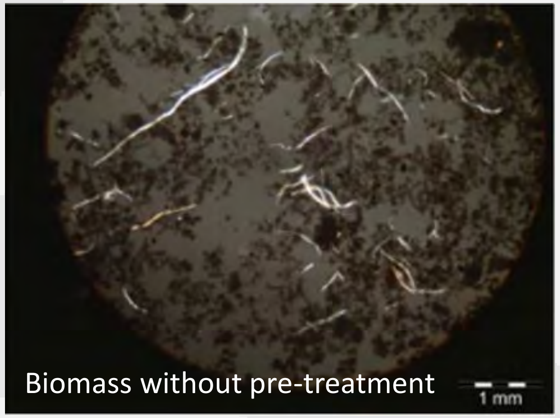
Application of dynamic rotating belt fine sieves for primary treatment

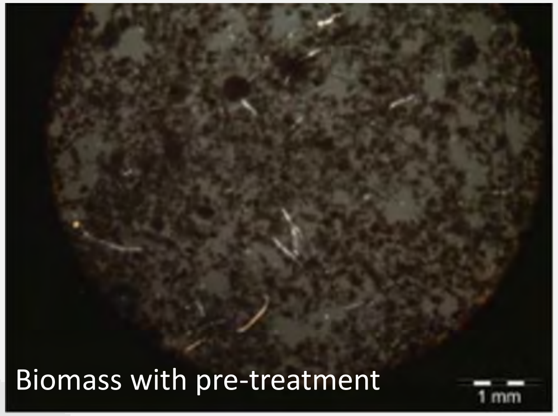
- Reduction of energy requirement (15 to 20%);
- Less sludge (20%) = less sludge dewatering;
- Reduction of chemical use (approx. 20%);
- Lower maintenance costs;
- a marketable recovered raw material;
- Reduction of the CO_2 footprint





Visible reduction of fibers in raw influent



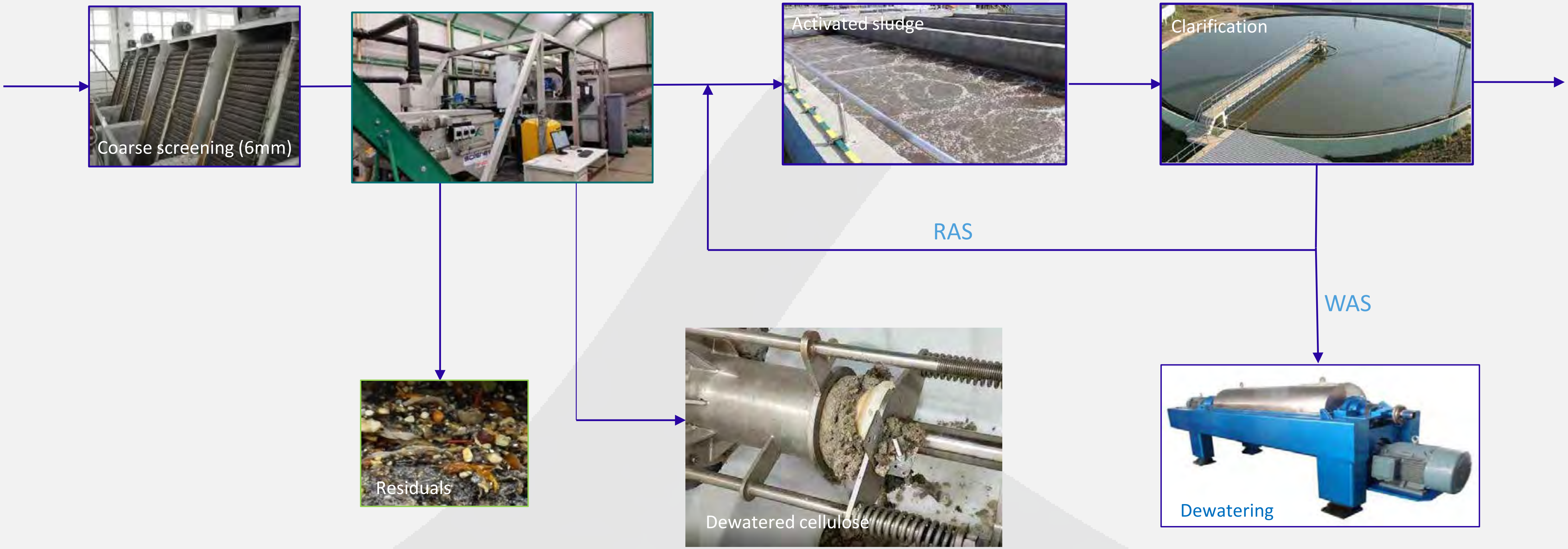


Difference in fiber content in activated sludge (after 12 months)

In-line cellulose extraction

SMART-Plant

Screenings are not salable (too many polluting components)



SMART-Plant: Pilot installation at a capacity of 120 m^3/h (expected 300 mg/l TSS)

CIRTEC

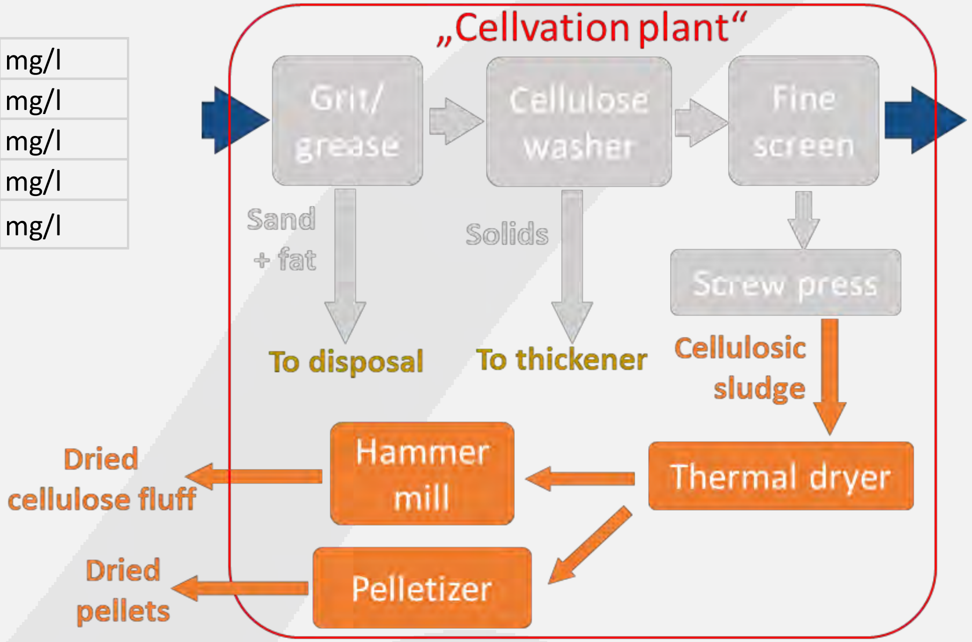




In-line cellulose extraction

Screenings are not salable (too many polluting components)

TSS	360,00	mg/l
COD	604,00	mg/l
BOD	289,00	mg/l
Ntot	37,20	mg/l
PO_4-P	9,40	mg/l



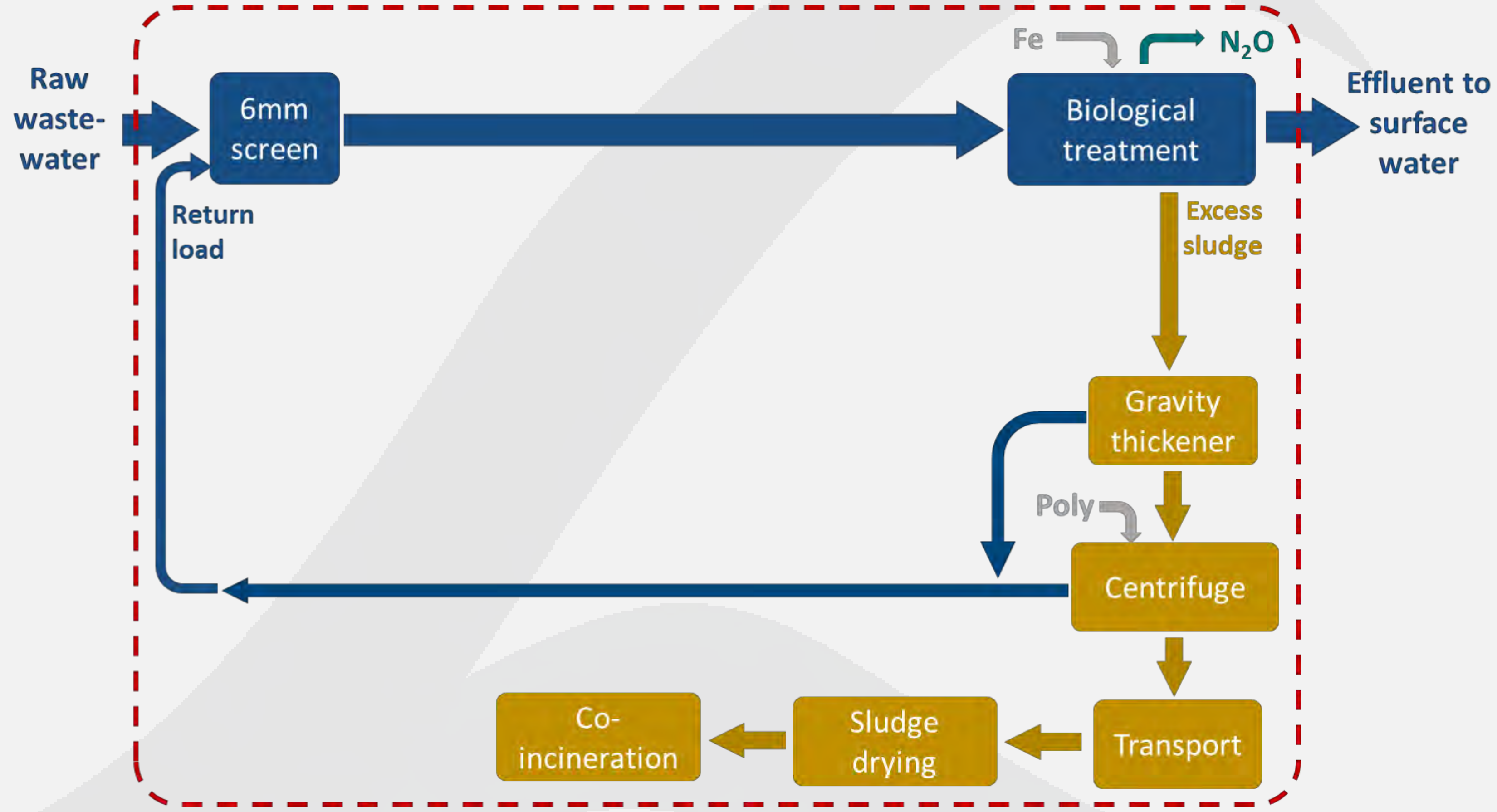
TSS	198,72	mg/l
COD	477,16	mg/l
BOD	228,31	mg/l
Ntot	35,67	mg/l
PO_4-P	9,11	mg/l

Recell®

TSS	44,80%
COD	21,00%
BOD	21,00%
Ntot	4,10%
PO_4-P	3,10%

LCA of SMARTech1 - cellulose recovery

System boundaries



SMART-Plant

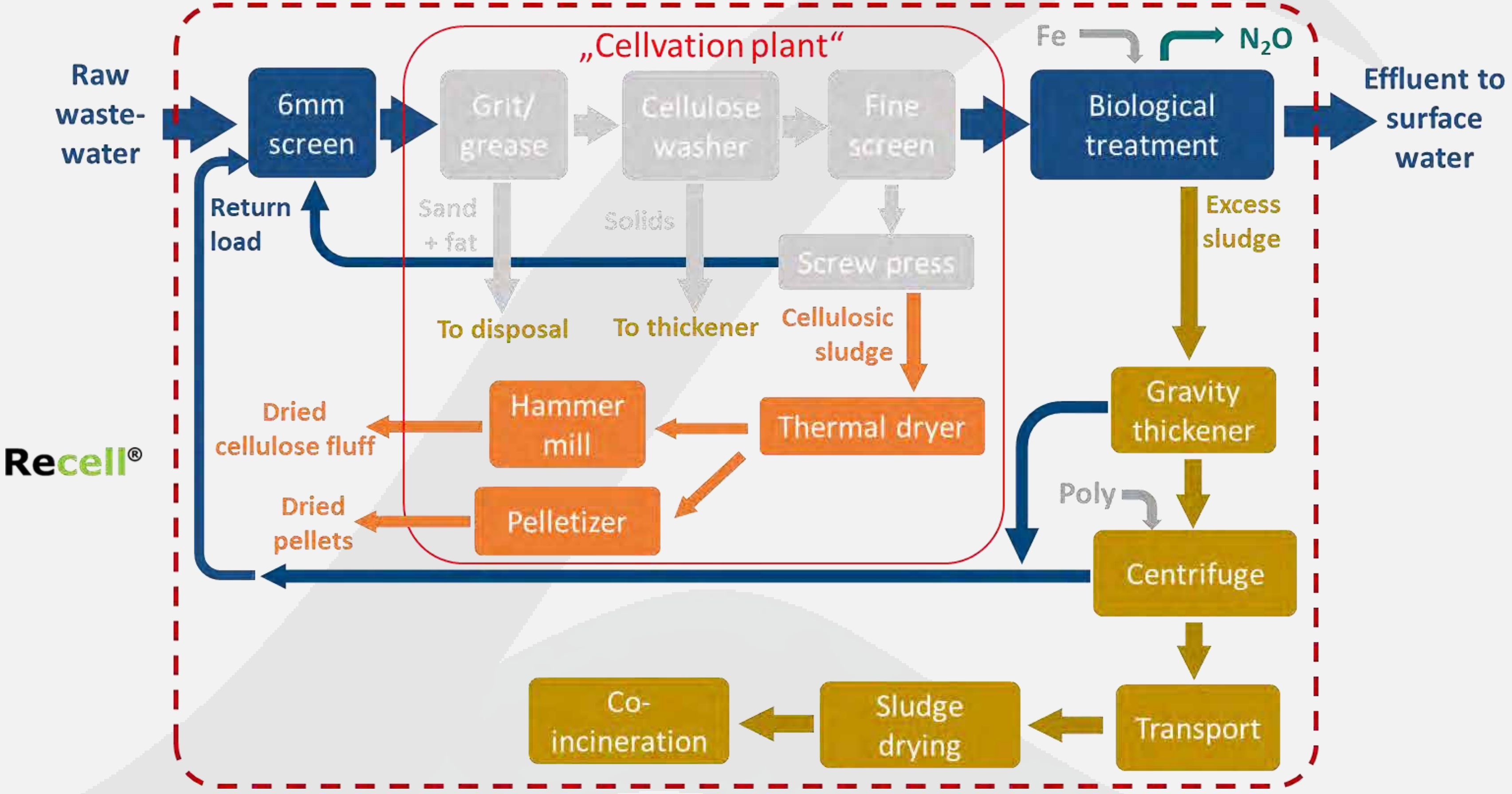
KOMPETENZZENTRUM WasserBerlin

CIRTEC

Cellvation

LCA of SMARTech1 - cellulose recovery

System boundaries



SMART-Plant

KOMPETENZZENTRUM WasserBerlin

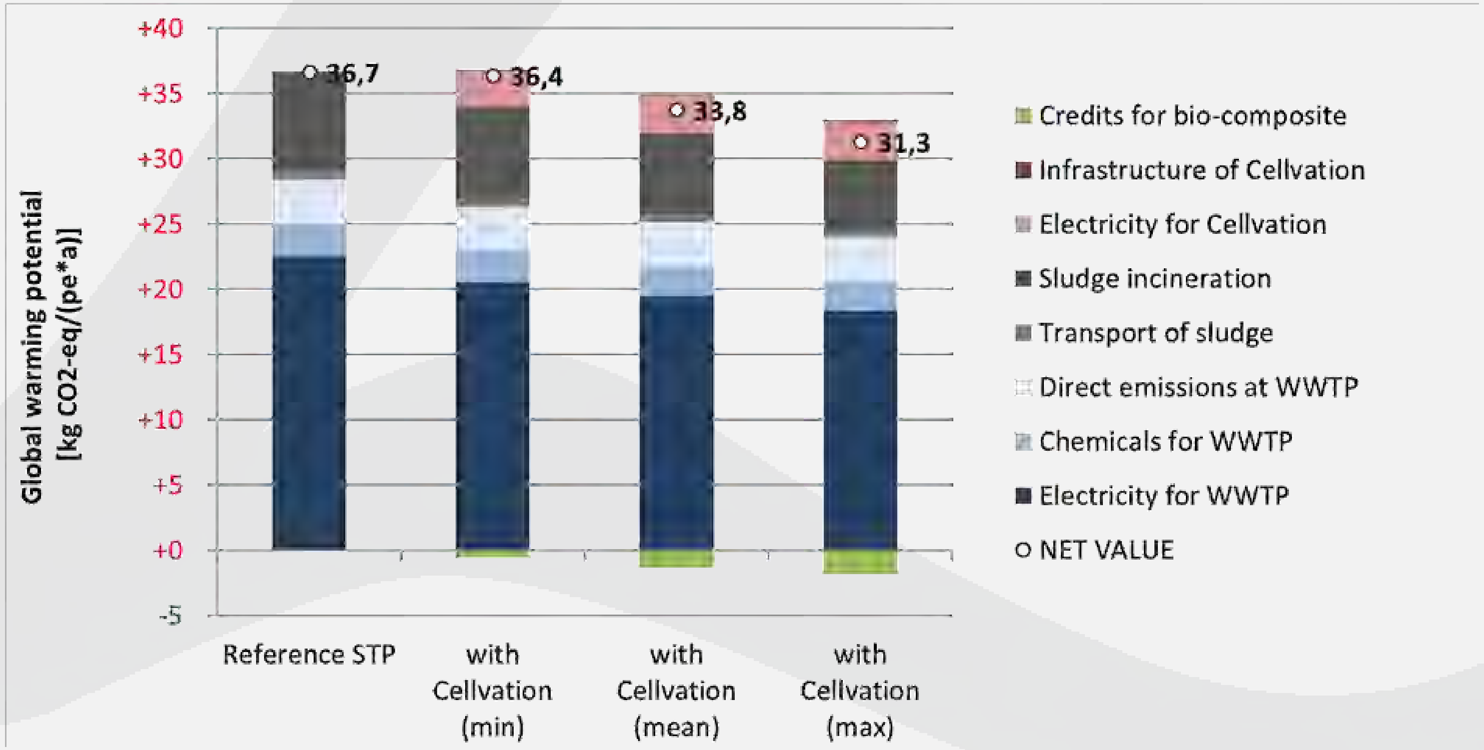
CIRTEC

Cellvation

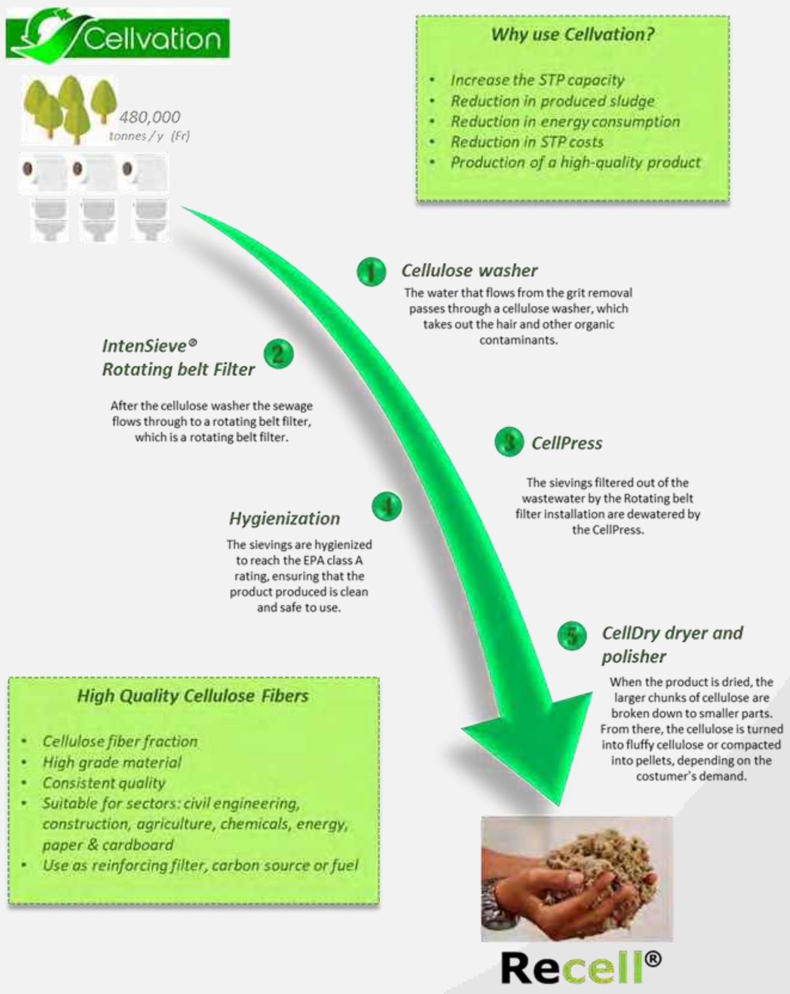
LCA of SMARTech1 - cellulose recovery

Conclusions

Parameter	Unit	Minimum value	Mean value	Maximum value
Removal of total suspended solids	%	-25	-40	-55
Removal of chemical oxygen demand	%	-10	-20	-30
Excess sludge to disposal (as dry matter)	%	-10	-20	-30
Savings in aeration energy	%	-10	-15	-20
Savings in polymer for sludge dewatering	%	-5	-10	-15



Conclusions



Recell-based products

Recell®

SMART-Plant


Asphalt Additive


Biocomposite granulate


Biocomposite board


Blown-in Cellulose Insolation flocs


Insulation boards


Mycelium board


Building blocks chemical industry


Road constructor KWS uses recycled toilet paper to improve asphalt pavement in Amsterdam


A cycling path in Utrecht with asphalt containing Recell®!

CIRTEC

Cellvation

Further development
Current state of the technology

CellCap

two-stage sieving technique consisting of, a cellulose washer and a dynamic rotating belt finesieve.

The pre-separation consists of a fine-meshed drumtype sieve where, through an inventive feedsystem, the cellulose fibers can escape, where hair, leaves, seeds and other components are caught.

Both process components are fully tuned to each other:

- No additional pumping;
- A cellulose washer can easily be fitted in (if space is provided), even when the RBF is already installed.
- The hydraulic profile hardly changes by installing the Cellulose Washer.

"We cannot solve our problems with the same thinking we used when we created them"

- Albert Einstein -

Towards a cleaner circular future

CirTec B.V.
Nijverheidsweg 26
1442 LD Purmerend
www.CirTec.nl

Resource recovery with algae

"Material recovery and safe reuse"

Robert Reinhardt

robert@algen.eu

May 23, 2021

Hello to the host

ULTIMATE

ULTIMATE aims to create economic value and increase sustainability by valorising resources within the **water cycle**. **Wastewater** is not only a reusable **resource** but also a carrier for energy and components that can be extracted, treated, stored, and reused. Drawing on "**Water Smart Industrial Symbiosis**" (WSIS) we promote wastewater recycling in various industrial settings. We have selected nine large-scale demonstration cases from the **four most important industrial sectors** in Europe:

AGRO-FOOD PROCESSING

HEAVY CHEMICAL / PETROCHEMICAL

BEVERAGES

BIOTECH INDUSTRY

TURNING WASTEWATER INTO A RESOURCE, WE WILL

Recover, refine and **reuse wastewater**,

Extract and **exploit energy**

Extract and **exploit materials**

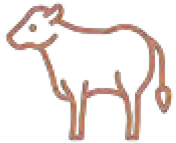
... CONTAINED IN INDUSTRIAL WASTEWATER.

Water2REturn project

ULTIMATE aims to create economic value and increase sustainabi … water cycle. **Wastewater** is not only a reusable **resource** but also a car … can be extracted, treated, stored, and reused. Drawing on "**Water Smar** … omote wastewater recycling in various industrial settings. We have selec … ases from the **four most important industrial sectors** in Europe:

AGRO-FOOD PROCESSING

HEAVY CHEMICAL / PETROCHEMICAL



BEVERAGES

BIOTECH INDUSTRY

Slautherhouse wastewater

TURNING WASTEWATER INTO A RESOURCE, WE WILL

Agricultural products

Recover, refine and **reuse wastewater**,

Extract and **exploit energy**

Extract and **exploit materials**

... CONTAINED IN INDUSTRIAL WASTEWATER.

Project Summary

- REcovery and REcycling of nutrients TURNing wasteWATER into added-value products for a circular economy in agriculture
- **Call:** H2020-IND-CE-2016-17
  Type of Action: Innovative Action
  GA no: 730398
  Duration: 57 months (after extension by 15 months)
  Start Date: 01 Jul 2017 **End date:** 31 Mar 2022
  Estimated Project Cost: 7,13 M€
  Requested EU Contribution: 5,9 M€
  Project Coordinator: BioAzul, Spain

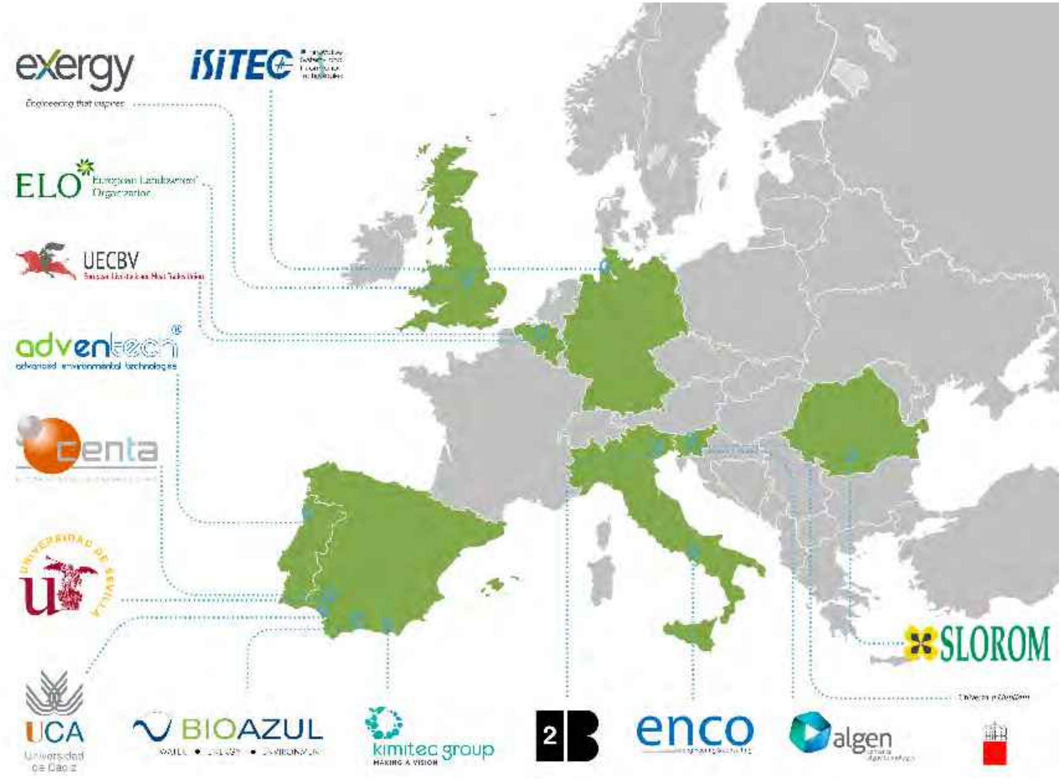
Water2REturn

- **recover and recycle nutrients from slaughterhouse wastewater** in the framework of a **Circular Economy model;**
- recovered nutrients are turned into **value added products for the agro-chemical industry**, for the **agricultural sector;**
- solve slaughterhouse wastewater management problem and **reduced costs related to water consumption**
-

Products

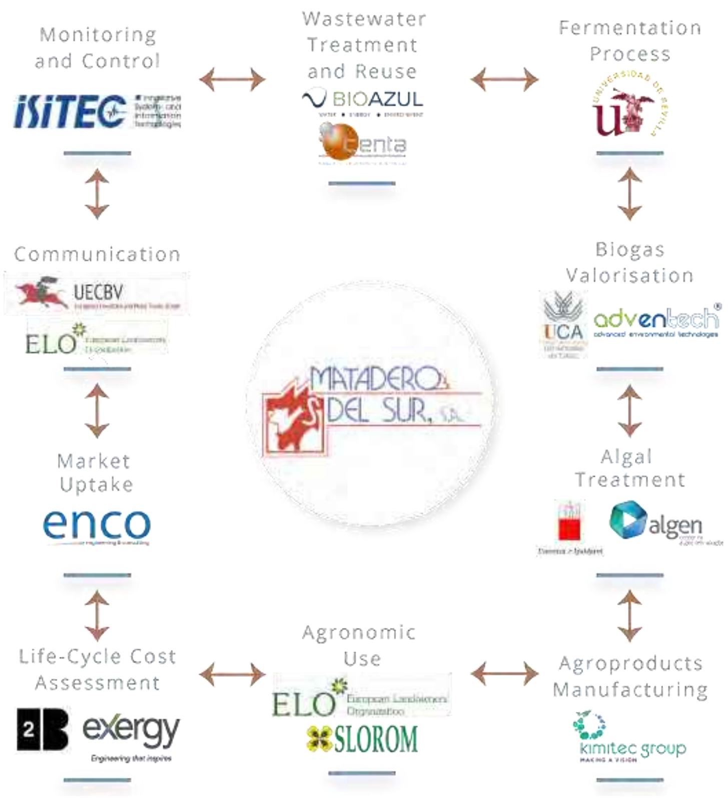
- 3 different raw materials
  - nitrate and phosphate concentrate,
  - hydrolysed sludge
  - algal biomass
- 3 agronomic products:
  - organic fertiliser
  - Bacillus subtillis based biostimulant
  - Algal biomass based biostimulant

Consortium



exergy
Engineering that inspires
ISITEC
ELO
European Landowners' Organization
UECBV
adventech
advanced environmental technologies
centa
UCA
Universidad de Cádiz
BIOAZUL
kimitec group
MAKING A VISION
2B
enco
algen
SLOROM

Consortium & Activities



Demo design and implementation
- slaughterhouse wastewater treatment and reuse
- fermentation process
- anaerobic digestion and biogas process
- algal treatment
- monitoring and control tool

Agronomic valorisation
- agronomic products manufacturing.
- agronomic products testing and use

Environmental, economic, social and risk assessment

Market update

Capacity building and awareness raising

Small test installation Ljubljana

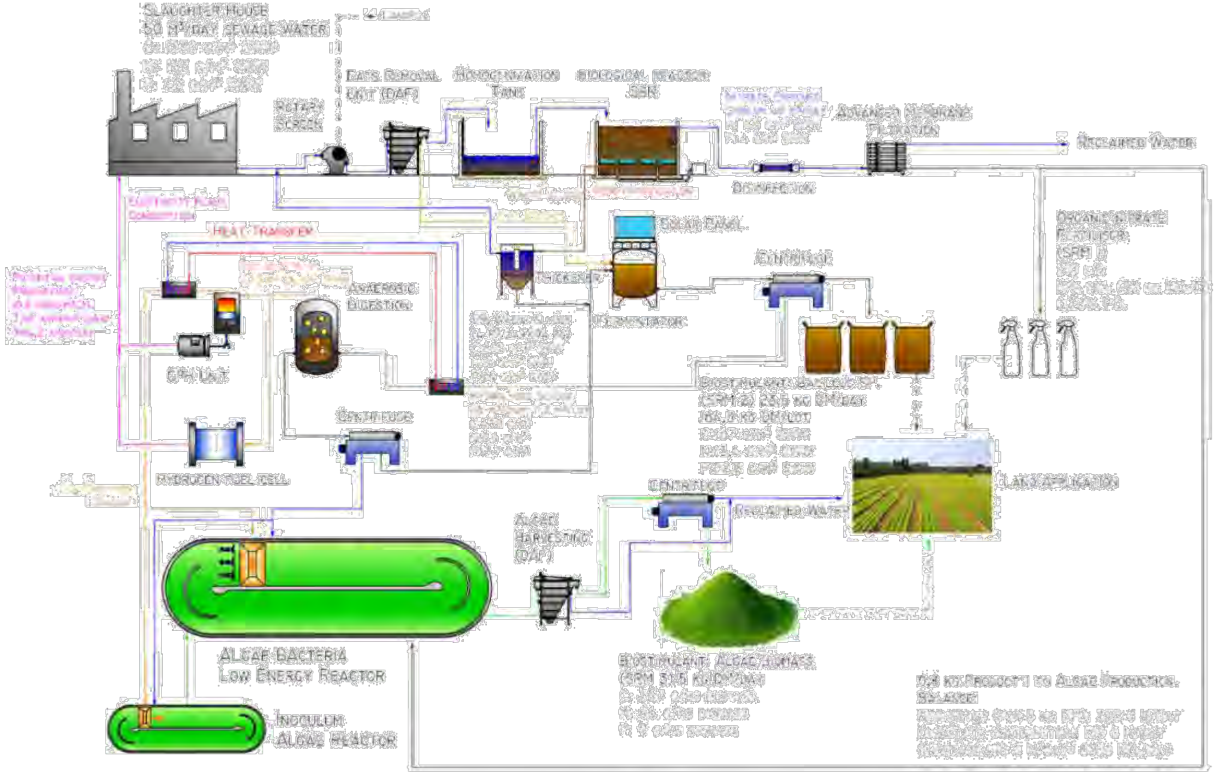





Preliminary Sprouting tests

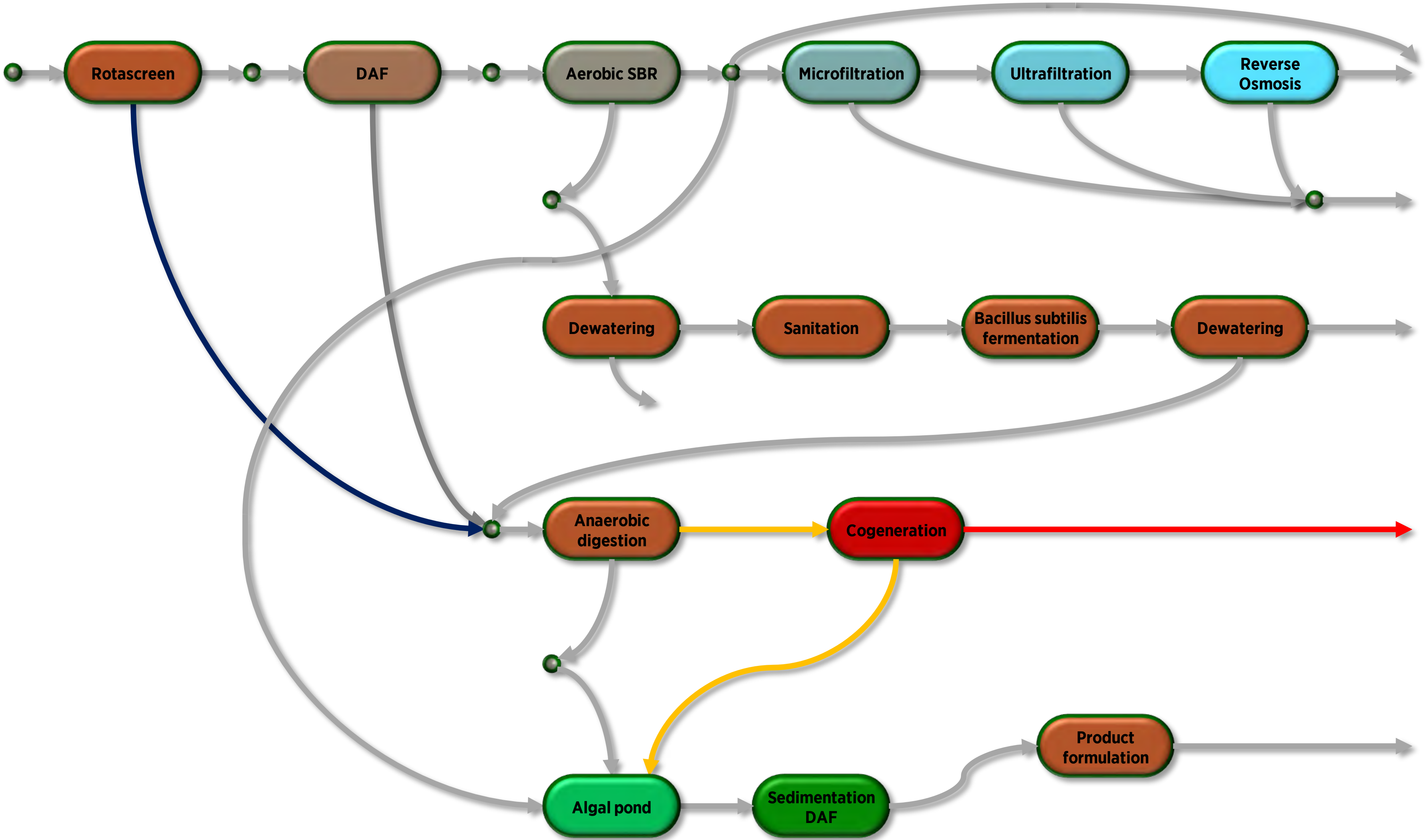
Pot tests

Process



Slaughter House
50 m³/day sewage water
Rotary Screen
Fats Removal Unit (DAF)
Homogenization Tank
SBR
Advanced Membrane Filtration
Reclaimed Water
Disinfection
Heat Transfer
Solar Panel
Centrifuge
Anaerobic Digestion
Thickener
Fermentator
Hydrogen Fuel Cell
Centrifuge
Land Application
Reclaimed Water
Algae Harvesting (DAF)
Algae Bacteria
Low Energy Reactor
Inoculum
Algae Reactor

Process


Rotascreen
DAF
Aerobic SBR
Microfiltration
Ultrafiltration
Reverse Osmosis
Dewatering
Sanitation
Bacillus subtilis fermentation
Dewatering
Anaerobic digestion
Cogeneration
Product formulation
Algal pond
Sedimentation DAF

Water2return

Present

- On-going agricultural field tests
- LCA & techno-economic analysis
- Workshops August 2021 – March 2022

- Nutrient density will limit the logistics
- Biostimulants seem to be successful

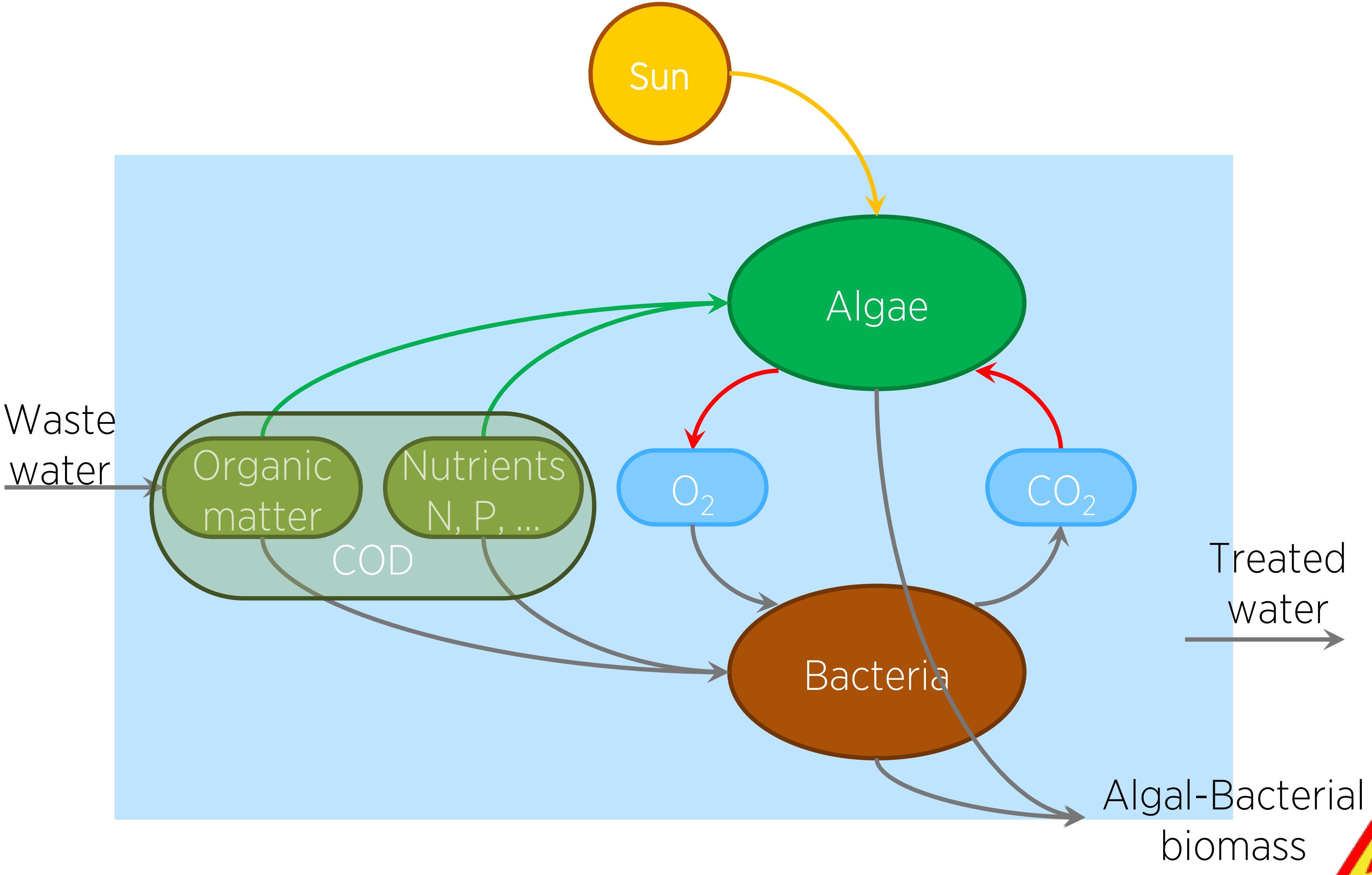
Thank you for attention

Questions

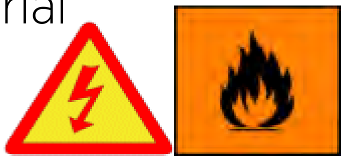
Where do algae fit?

- More than one option
- Depends on
  - Wastewater
  - Area available
  - Use of algal biomass
  - Legislative requirements

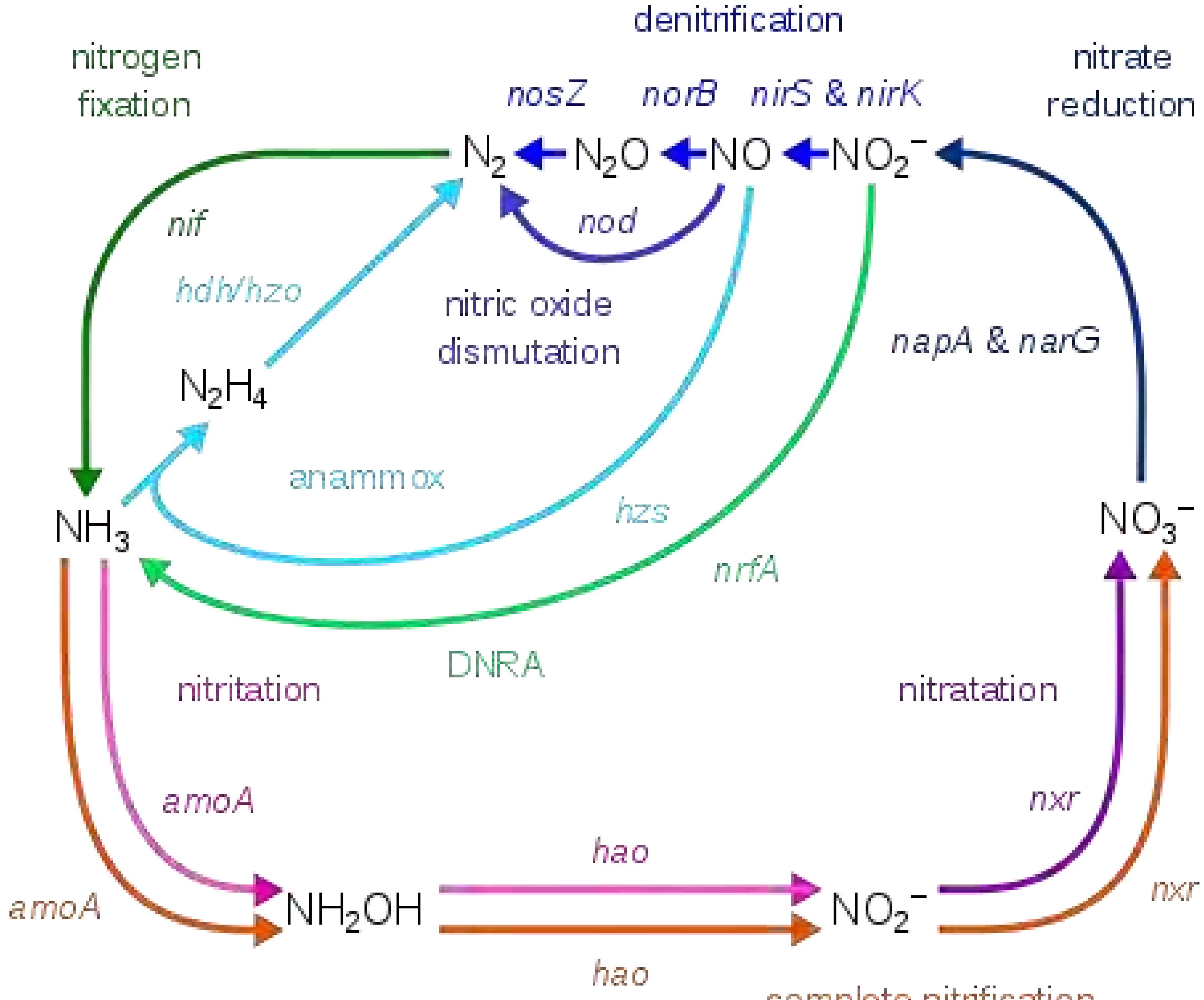
Basic concept



- Treatment by symbiotic algal bacterial community
- O2 provided in-situ (from sunlight)
- CO2 recycled in-situ
- Better matched community, more diverse community ↔ better nutrient and micropollutant removal
- More biomass ↔ more nutrients and energy recycled

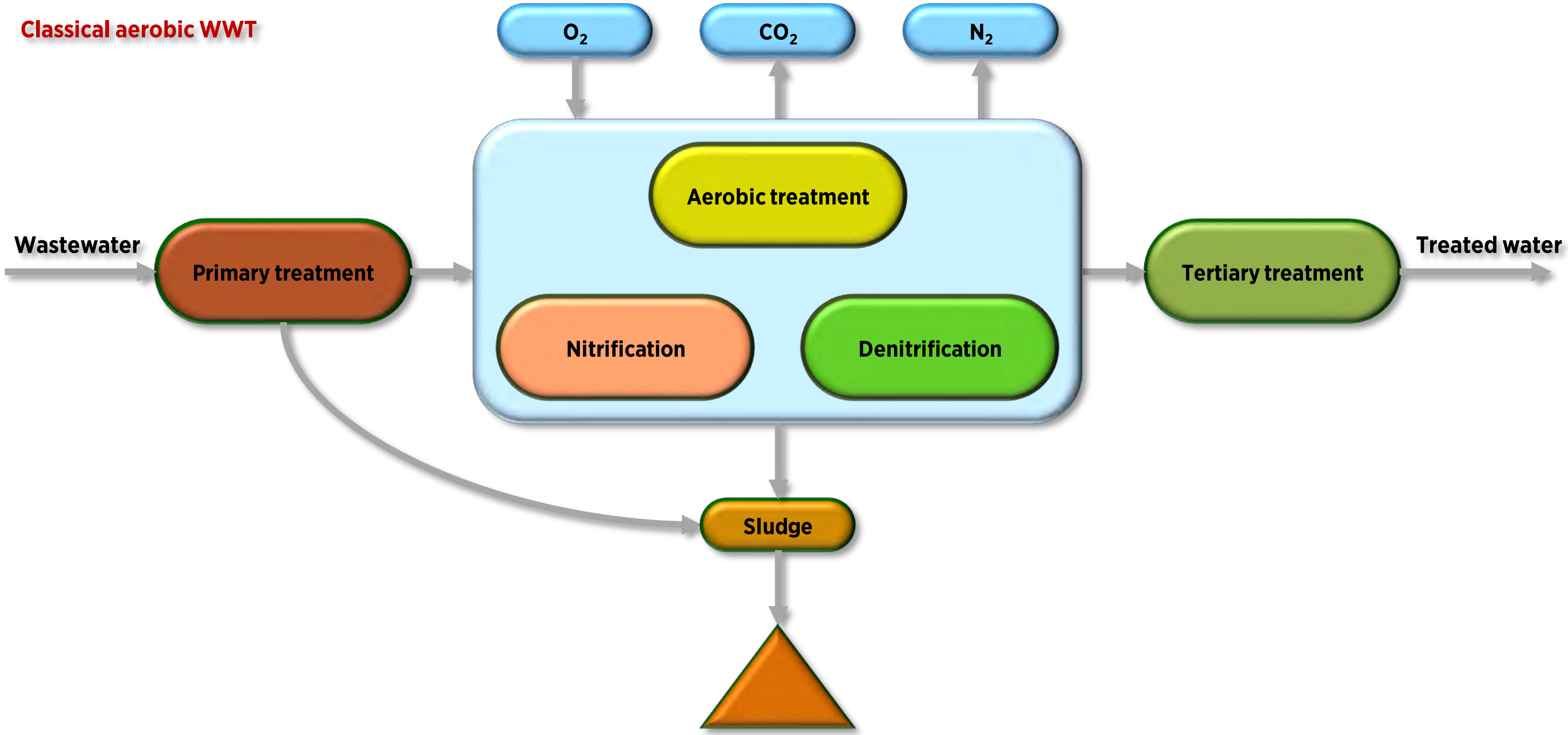


Nitrogen

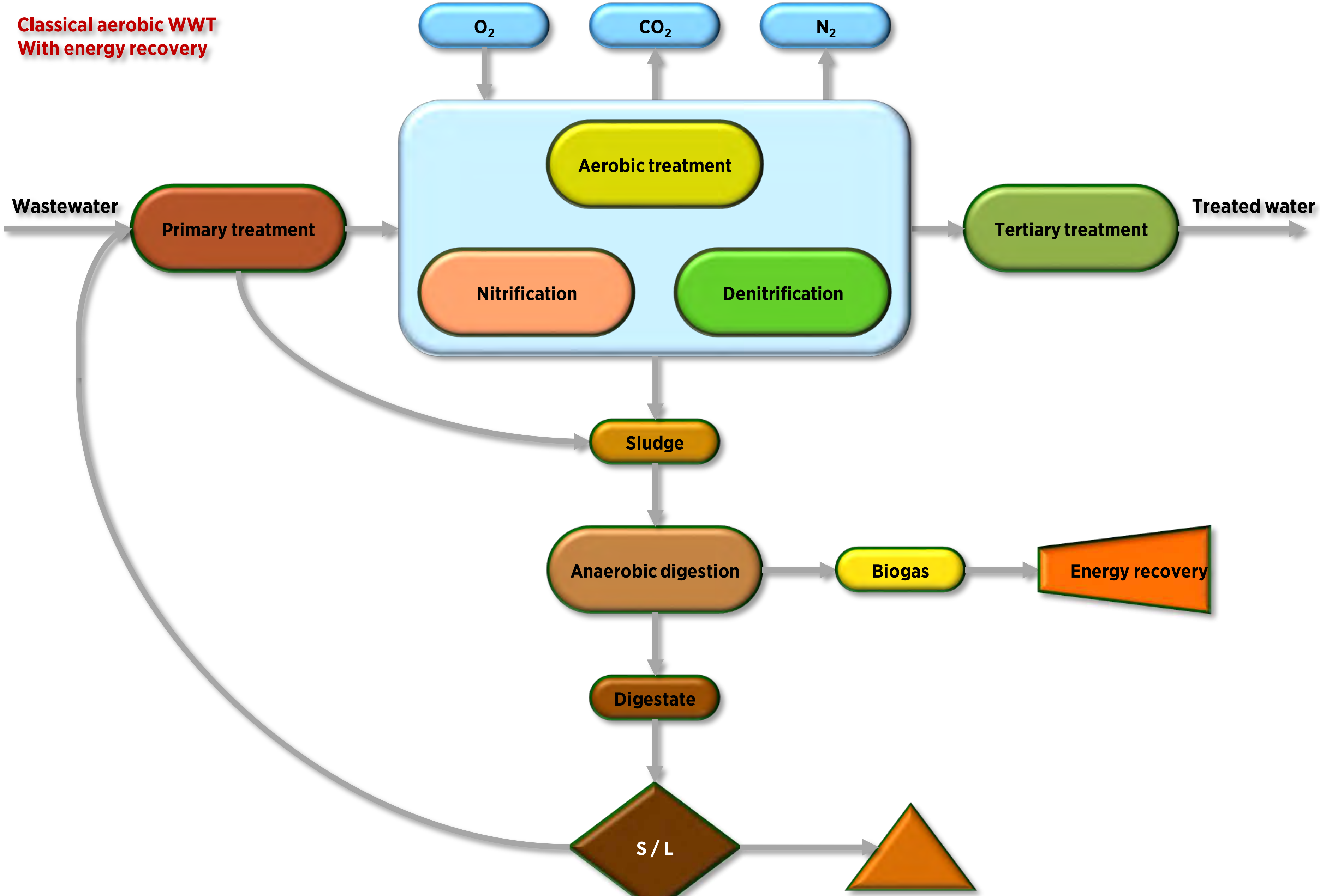


https://en.wikipedia.org/wiki/Nitrogen_cycle#/media/File:Nitrogen_Cycle_-_Reactions_and_Enzymes.svg

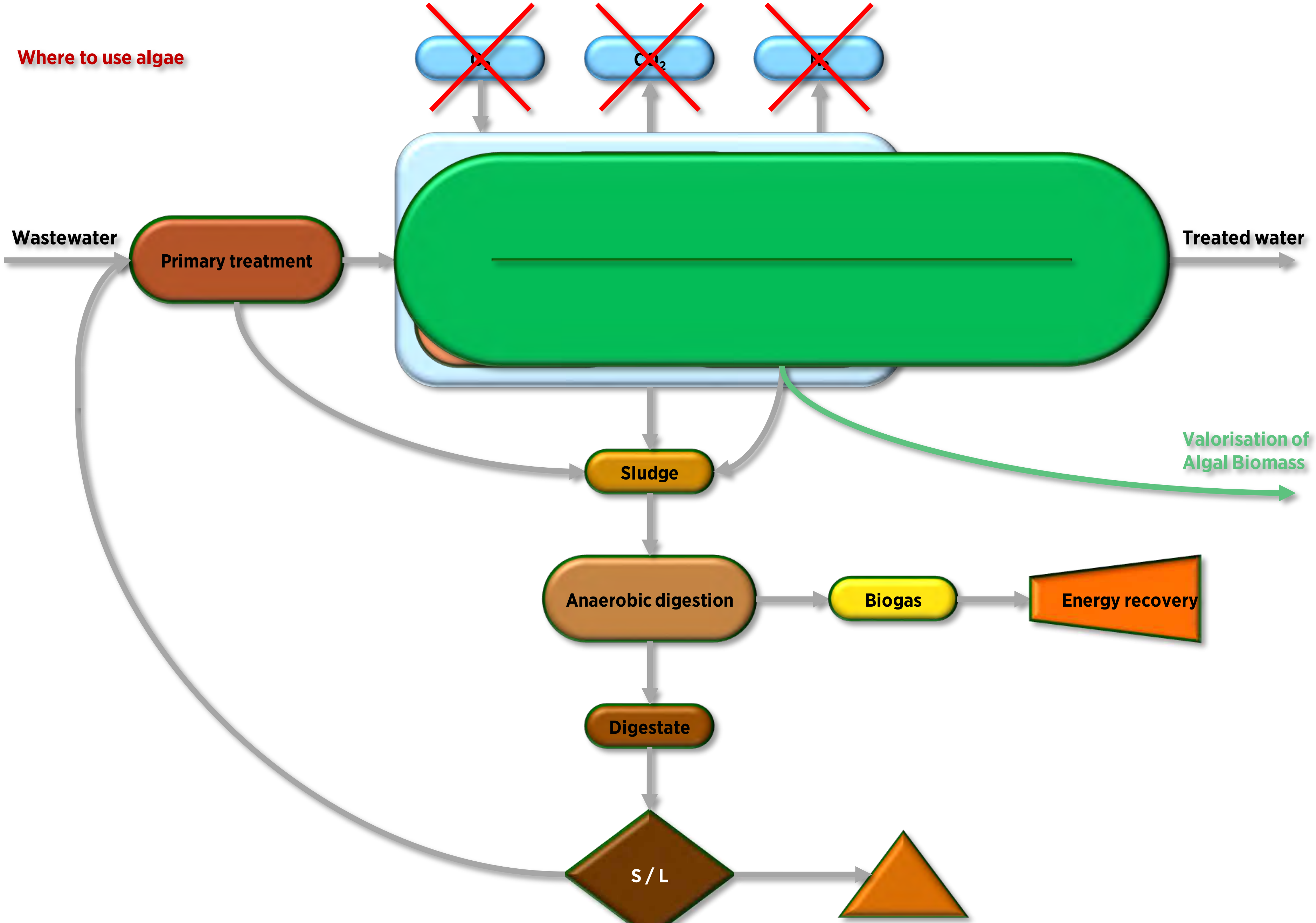
Classical aerobic WWT

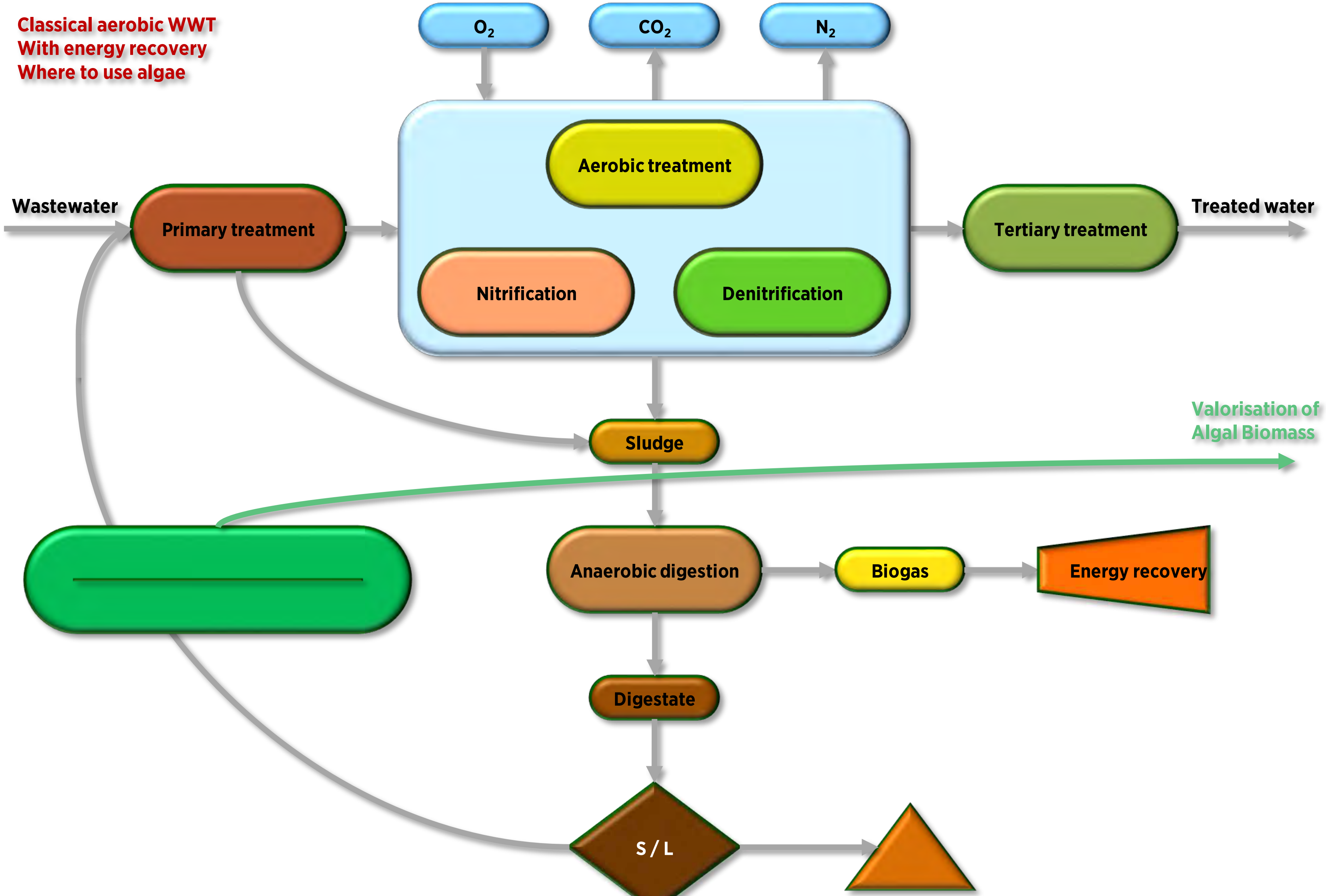


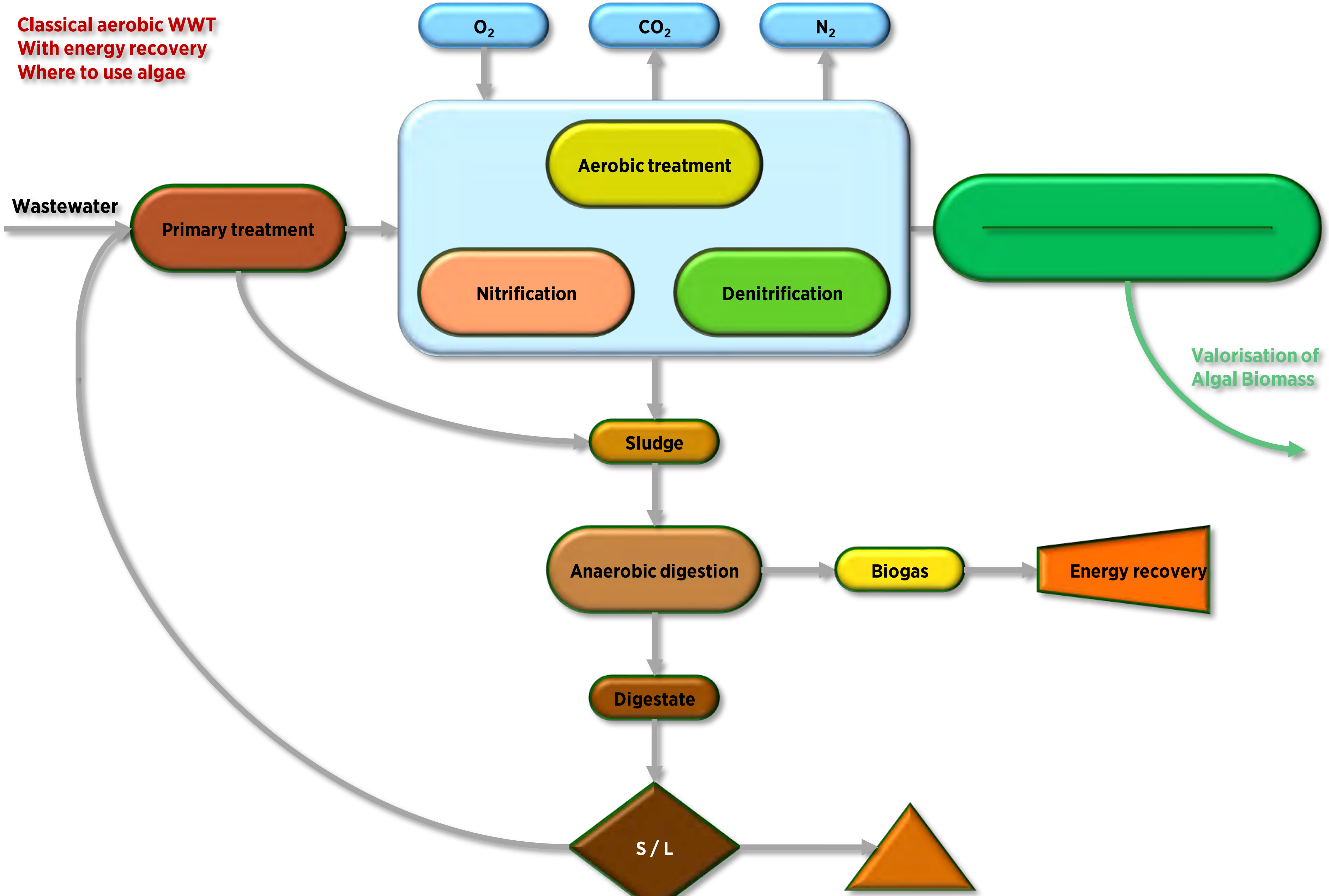
Classical aerobic WWT
With energy recovery



Where to use algae




Classical aerobic WWT
With energy recovery
Where to use algae
O2
CO2
N2
Aerobic treatment
Wastewater
Primary treatment
Nitrification
Denitrification
Tertiary treatment
Treated water
Valorisation of
Algal Biomass
Sludge
Anaerobic digestion
Biogas
Energy recovery
Digestate
S / L


Classical aerobic WWT
With energy recovery
Where to use algae
O_2
CO_2
N_2
Aerobic treatment
Wastewater
Primary treatment
Nitrification
Denitrification
Valorisation of
Algal Biomass
Sludge
Anaerobic digestion
Biogas
Energy recovery
Digestate
S / L

Algaebiogas

Algal treatment of biogas digestate and feedstock production

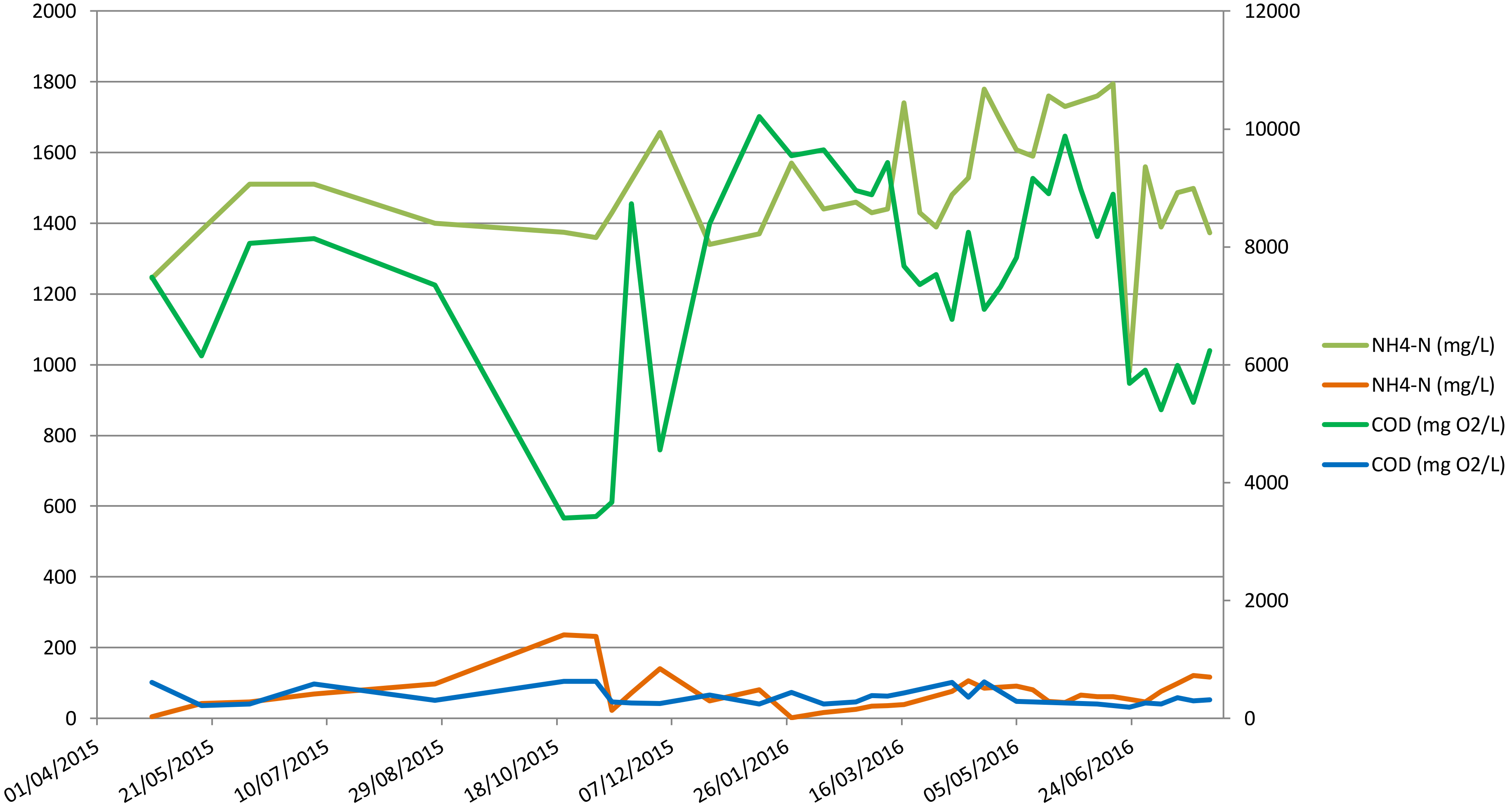
- Eco-Innovation project (CIP-EIP-Eco-Innovation-2012)
- 2013 – 2016 in Ljubljana, Slovenia
- Pilot and market replication project
- Demo centre has been in operation for 5 years
- Legislation analysis, LCA, business plan
- Complementary technology trials

Algaebiogas

S/L Separation
Anaerobic filter

Digestate color!

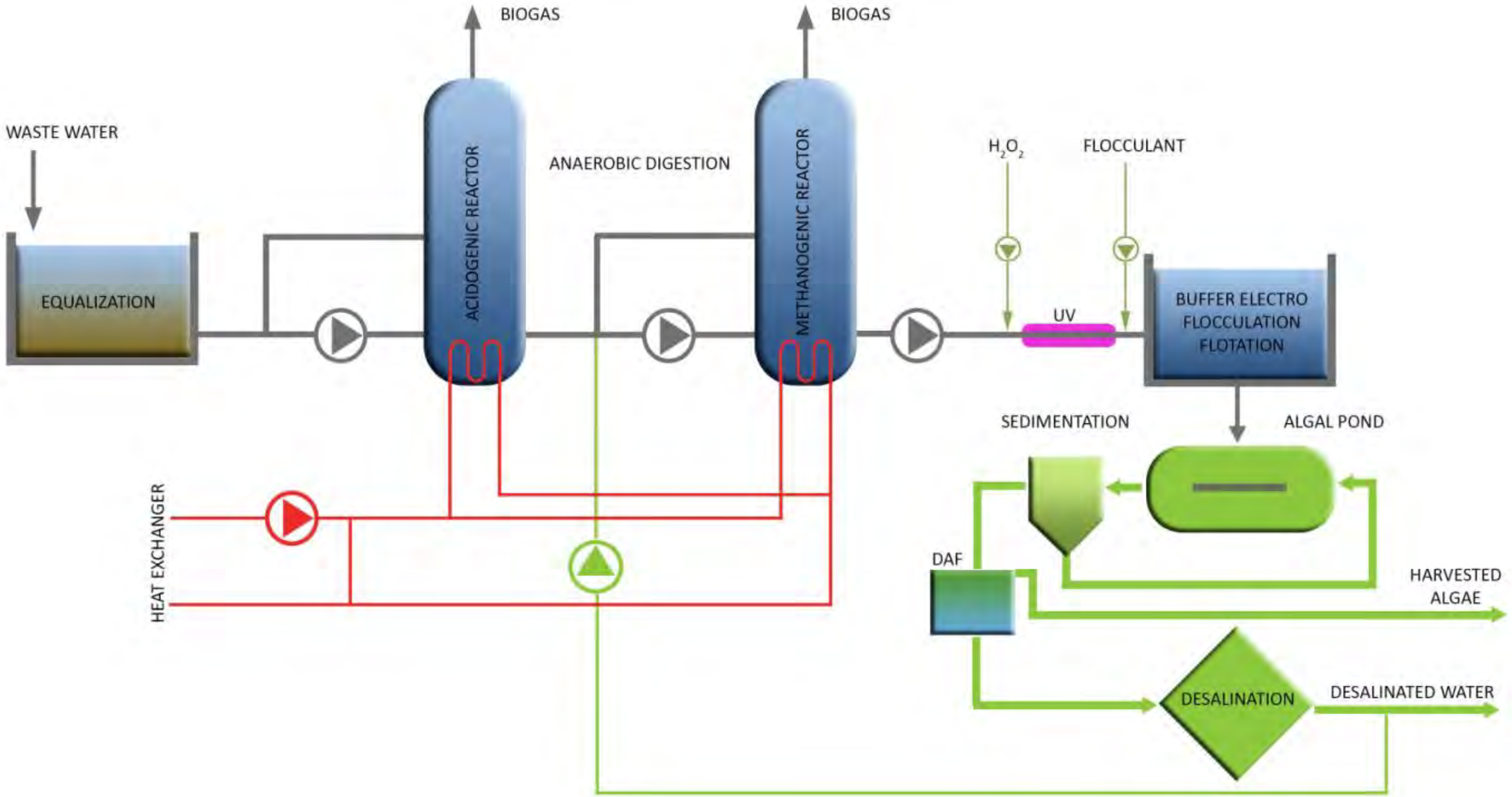
Algaebiogas



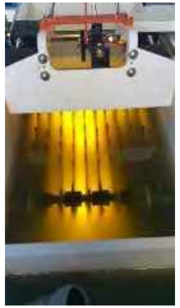
Saltgae

- Demonstration project exploring techno-economic options for use of algae to treat saline wastewater from food & beverage industry
- Innovative Action Horizon 2020
- June 2016 – September 2019
- Three demo locations
  - Camporosso, Italy (dairy cleaning water)
  - Ljubljana, Slovenia (animal hide warehouse WW KOTO)
  - Arava, Israel (fishery)

Saltgae

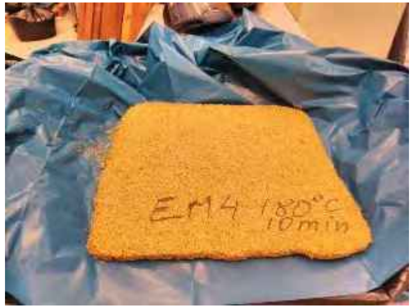

BIOGAS
BIOGAS
WASTE WATER
ACIDOGENIC REACTOR
ANAEROBIC DIGESTION
METHANOGENIC REACTOR
H_2O_2
FLOCCULANT
EQUALIZATION
UV
BUFFER ELECTRO FLOCCULATION FLOTATION
SEDIMENTATION
ALGAL POND
HEAT EXCHANGER
DAF
HARVESTED ALGAE
DESALINATION
DESALINATED WATER

Saltgae – demo Ljubljana



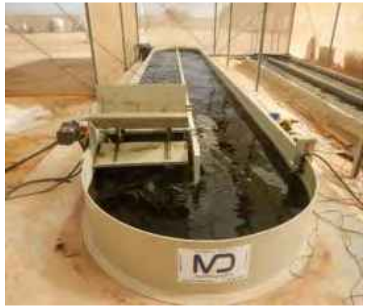
Saltgae – demo Camporosso, Arava, applications

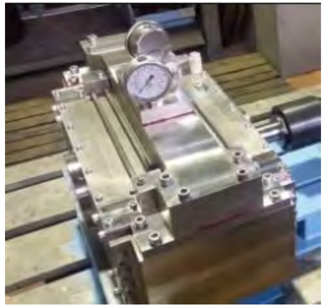










WATER SMART INDUSTRIAL SYMBIOSIS

Grant Agreement No 869318

CS meeting on “Material recovery and safe reuse” June 23, 2021

ROUTES – SMART-Plant – RES URBIS

Polyhydroxyalkanoate (PHA) recovery from sewage sludge and food waste

Mauro Majone
Department of Chemistry
Research Center for the Protection of the Environment and Cultural Heritage

SAPIENZA UNIVERSITÀ DI ROMA

Research and Innovation from 3 EU projects (FP7 and Horizon 2020)

Innovative system solutions for municipal sludge treatment and management (ROUTES),

FP7 Call: ENV.2010.3.1.1-2

GA 265156, 3 years, started May 1° 2011, 18 partners, 9 countries

EU Grant: 3 364 600 €

Coordinator: Giuseppe Mininni, IRSA-CNR, Italy

Scale-up of low-carbon footprint material recovery techniques in existing wastewater treatment plants (SMART-Plant)

H2020 Call: WATER-1b-2015 - Demonstration/pilot activities (IA)

GA 690323, 4 years, started June 1° 2016, 29 partners, 10 countries

EU Grant: 7 536 300 €

Coordinator: Francesco Fatone, Technical University of Marche, Italy

www.smart-plant.eu

REsources from URban BIo-waSte (RES URBIS)

H2020 Call CIRC-05-2016: **Unlocking the potential of urban organic waste (RIA)**

GA 730349, 3 years, started January 1° 2017, 20 partners, 8 countries.

EU Grant: 2 996 688 €

Coordinator: Mauro Majone, Sapienza University of Rome, Italy

www.resurbis.eu

SEVENTH FRAMEWORK PROGRAMME

THE FRAMEWORK PROGRAMME FOR RESEARCH AND INNOVATION HORIZON 2020

3 projects with some common features

Focusing on **"waste" streams** as a renewable and largely available resource (no land, no water, no energy is needed to produce it)

Mild biotechnologies basen on **open microbial cultures** (no axenic cultures, no OGMs)

→

Sludge and municipal wastewater
The organic fraction of municipal solid waste
Park/garden waste
Food-industry wastewater

A large portfolio of bioproducts with market value under investigation (e.g. cellulose, biofuels, biofertilizers, biosolvents, biomethane) and one in common: **polyhydroxyalkanoate (PHA) and derived bioplastics and biocomposites**

As time went on, also taking care of

✓**the whole technology chain**

Different industrial sectors to be linked each other, each one having its own business targets, needs and specifications.

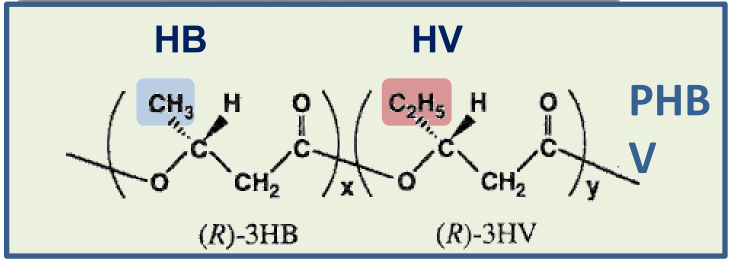
✓**territorial conditions**

Affordable economic strategies to be tailored with respect to territorial **clusters**, i.e by taking into account present collection and management systems and where available "feedstock " is large enough

✓**technical and non technical constraints**

Regulatory (e.g. **"end of waste"**), environmental, and social constraints, as function of local, regional and national conditions

Why focusing on PHA?



Product related Pro's

PHA is not a single polymer but a family of copolymers with tunable composition and properties,
so that, PHA can be the main constituent of several bioplastics, with a wide portfolio of applications.

Fully and quickly biodegradale

Production process Pro's

- A novel PHA production process (**open microbial cultures instead of pure strains**), which can better cope with **large heterogeneity of the waste/wastewater feedstock**,
- An upstream step, the **acidogenic fermentation**, which is both robust and tunable
- Overall, PHA production process is mostly **biological, under mild conditions and reliable**.
- Thus, an **easier integration with existing biological plants for waste and wastewater treatment**.
- Combining no-cost feedstock and novel processes, the **cost of PHA can significantly decrease**

Appealing: PHA is 3 times "Bio"
- Produced from renewable feestock (**but no food**)
- Produced through biological process (**but no OGM**)
- Easily and "truly" **biodegradable**

and it's not recycled: it's virgin material

Applications and economics
High market potential.
As higher as more PHA cost decreases; but still higher value than biogas and compost
Already under investigation at TRL 6

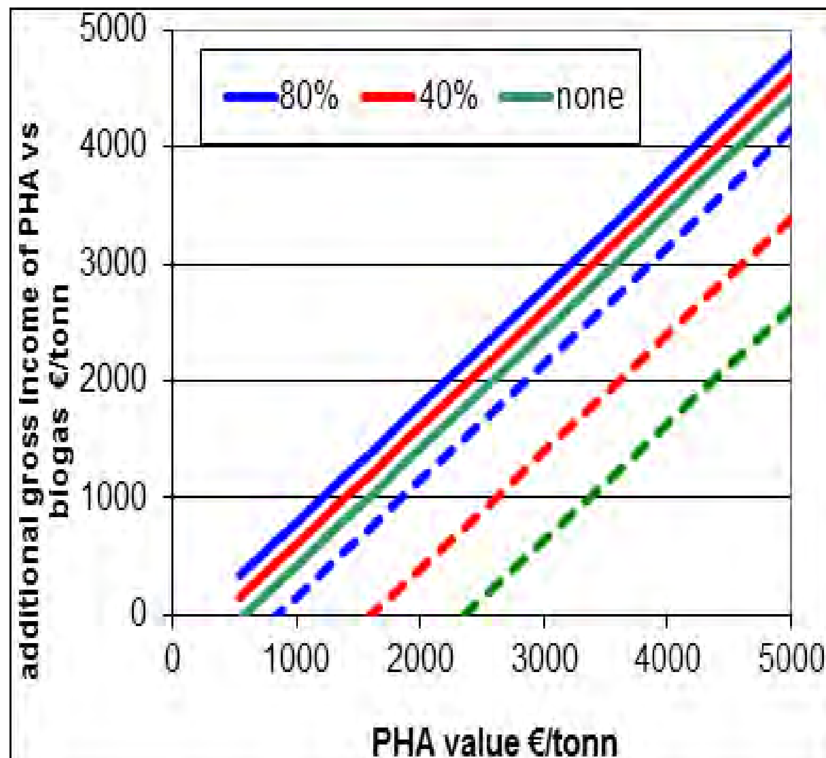
Comparison of income of PHA production with respect to biogas, as function of PHA value on the market and of biogas incentives

A) PHA production, biogas recovery from downstream with incentives
B) Biogas only

- PHA yield 0.1 kg/kgTVS (**worst case**);
- PHA value ranging between 500 and 5000 €/ton
- Either 0, 40, or 80 % of residual TVS are recovered into biogas
- Biogas yield 0.75 m^3/kgTVS; electric energy **2.56** kWh/m^3
- EE value: **60** €/MWh (no incentives) - continuous lines
  246/MWh (present italian incentives, **worst case**) - dotted lines

- In most conditions, PHA production offers an additional income with respect to biogas only **(alternative b minus alternative a)**
- Competition with biogas is negligible if PHA maintain present high cost and if biogas has no incentives
- However, biogas recovery from PHA production residual streams is especially needed if incentives are high
- The additional income should overcompensate the larger costs for PHA production with respect to biogas only (however, still lack of full scale data)

Income only, production costs not included



An old story: PHA is often present in activated sludge

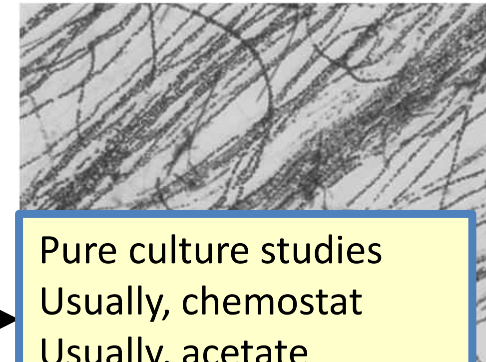
- Enhanced bio-P removal
- Bulking control

Late 80'

Time-changing conditions are imposed to the microbial consortium (non Monod-like growth)
-anaerobic/anoxic /aerobic cycles,
-and/or feast & famine

Physiological adaptation of each microbial species

Early 90'



Pure culture studies
Usually, chemostat
Usually, acetate

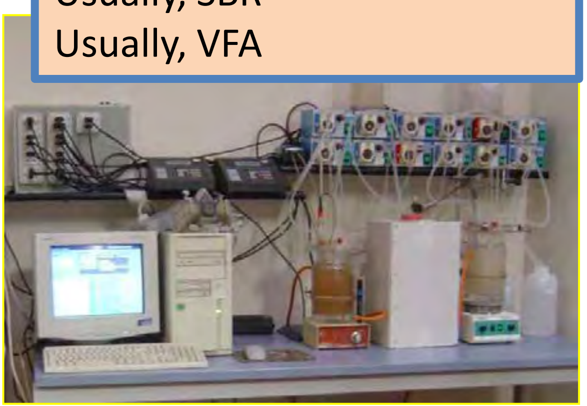
Half 90'

Selection of species that are more adaptable to growth under changing conditions

Early 00'

Biomolecular tools, eg. FISH

Mixed culture studies
Usually, SBR
Usually, VFA



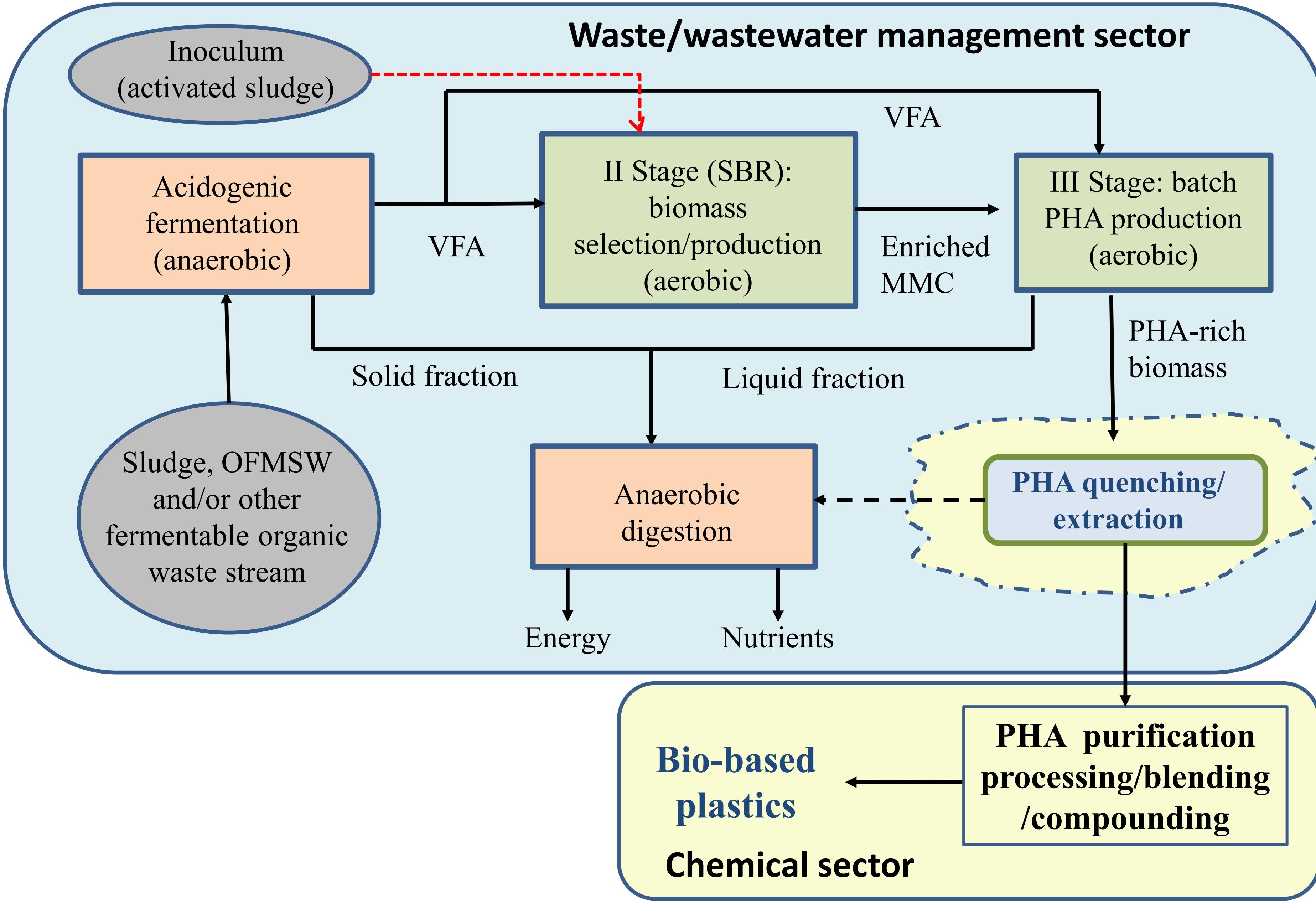
Mixed culture studies
Usually, batch

✓Ad hoc regulation of the process towards dynamic storage response
✓acidogenic fermentation to increase VFA
✓True feedstock
✓Scaling up

Half 00'

Toward PHA production

Typical process for PHA production from MMC and organic waste stream



Pilot scale optimisation of PHA production process from urban bio-waste

Although the main steps of MMC process are largely validated at lab-scale,
pilot scale experimentation is essential for several reasons

Process-related challenges

- Given the process has many steps, pilot-scale is essential to supply robust technical-economic data, especially because cost decrease remains a key target
- Long term experimentation with “true” waste feedstock is needed to address effects of feedstock heterogeneity
- An integrated process is required for optimal management of water/solid overflows and related energy recovery. This is also essential for making appropriate LCA
- The extraction step still requires optimization (as milder conditions as possible)

Product-related challenges

- PHA batches have to be steadily produced and delivered to investigate downstream processing, including by using industrial equipments (i.e in the range 1-100 Kg/batch).
- Same as for development of novel products, including low-purity end-uses; product samples to be checked for performance and acceptance (e.g. consumers panels).
- Contaminant migration and abatement and possible transfer into the products has to be investigated under close-to reality conditions.

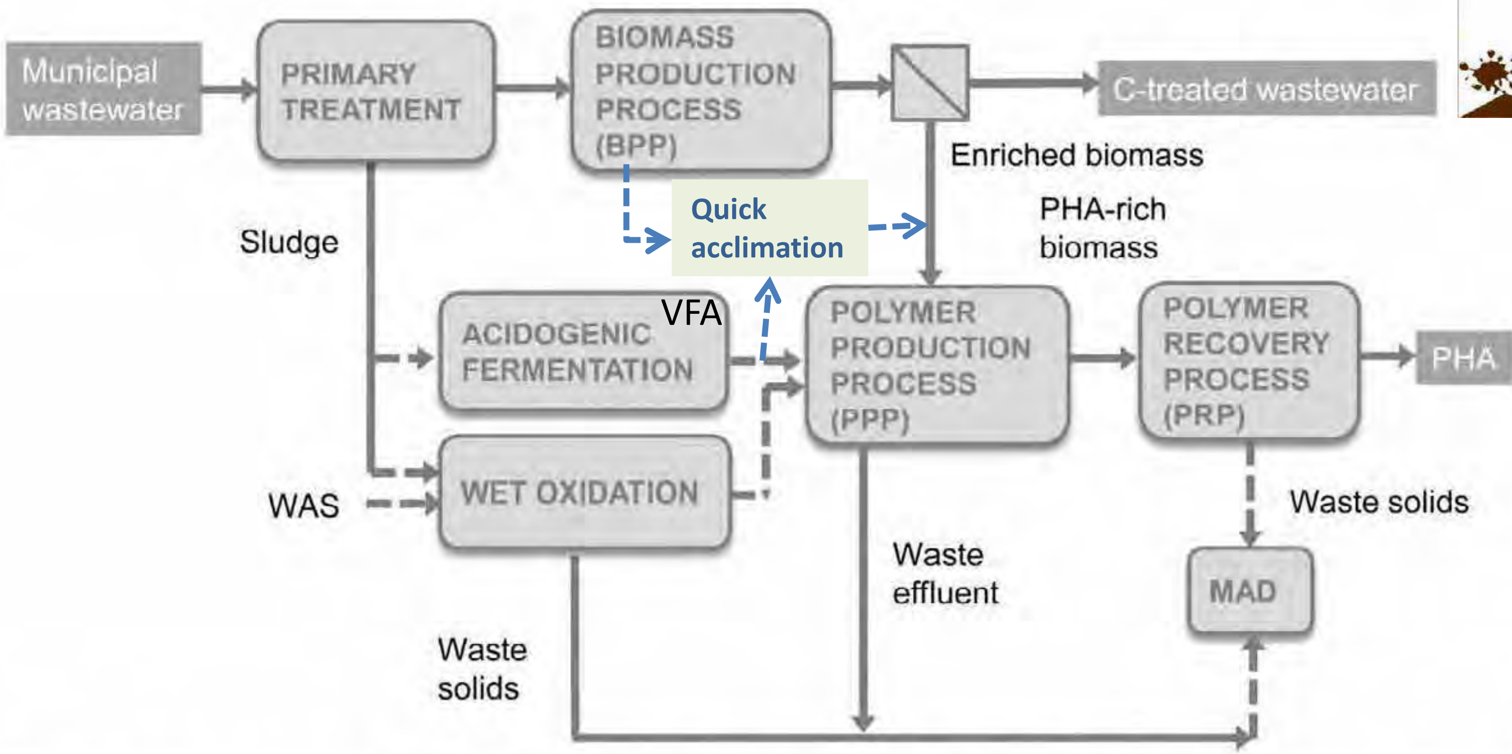


Figure 1 | Schematic process flow diagram of municipal wastewater and sludge treatment in conjunction with PHA production under study in the project Routes (MAD = mesophilic anaerobic digestion). Laboratory-scale studies are conducted on BPP, PPP and PRP (La Sapienza University of Rome/AnoxKaldnes), advanced/ primary treatment and sludge fermentation (Italian Water Research Institute IRSA-CNR). Pilot-scale studies are conducted on fermentation, BPP, PPP and PRP (AnoxKaldnes/Veolia) and sludge wet oxidation for producing a VFA rich liquid stream (3VGreen Eagle). Results from WAS fermentation, BPP, PPP are reported here.

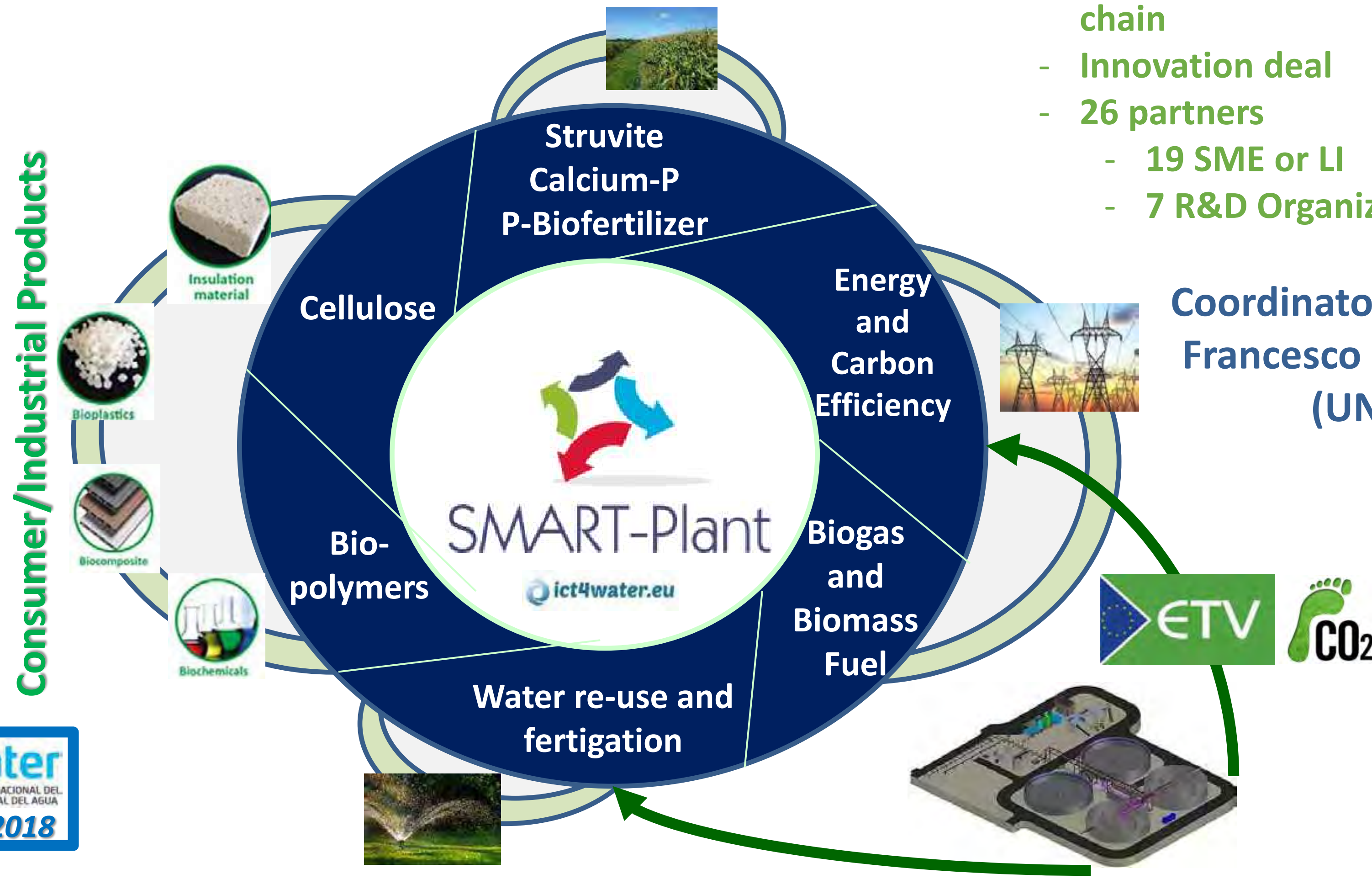
F. Morgan-Sagastume et al. Polyhydroxyalkanoate (PHA) production from sludge and municipal wastewater treatment, Water Science & Technology, 69, 1, 177-184, 2014; https://doi.org/10.2166/wst.2013.643

Morgan-Sagastume, F., Valentino, F., Hjort, M. *et al.* Acclimation Process for Enhancing Polyhydroxyalkanoate Accumulation in Activated-Sludge Biomass. *Waste Biomass Valor* **10,** 1065–1082 (2019). https://doi.org/10.1007/s12649-017-0122-8

Scale-up of low-carbon footprint MAterial Recovery Techniques in existing wastewater treatment PLANTs (SMART-PLANT)

- Horizon2020 IA
- 9 demo SMARTechs
- Cross-sectorial value chain
- Innovation deal
- 26 partners
  - 19 SME or LI
  - 7 R&D Organization

Coordinator: Prof. Francesco Fatone (UNIVPM)



iwater SALÓN INTERNACIONAL DEL CICLO INTEGRAL DEL AGUA AWARD 2018

***Unique Selling Point** of the SMARTechs: high water quality, energy-efficiency, carbon footprint, sludge reduction and…materials recovery and reuse via SMART-Products*

SMART-Plant UNIVERSITÀ POLITECNICA DELLE MARCHE

SMARTechs integrated in existing WWTPs (revamped/upgraded to WRRFs)

	SMARTech n.	Integrated municipal WWTP	Key enabling process(es)	SMART-product(s)
Mainstream	1	Geestmerambacht (Netherlands)	**Upstream dynamic fine-screen** and post-processing of cellulosic sludge	**Cellulosic sludge, refined clean cellulose**
Mainstream	2a ЄTV	Karmiel (Israel)	Mainstream polyurethane-based **anaerobic biofilter**	**Biogas, Energy-efficient water reuse**
Mainstream	2b	Manresa (Spain)	Mainstream **SCEPPHAR**	**Struvite, PHA**
Mainstream	3	Cranfield (UK)	Mainstream **tertiary hybrid ion exchange**	**Nutrients**
Sidestream	4a ЄTV	Carbonera (Italy)	**Sidestream SCENA**	**P-rich sludge, VFA**
Sidestream	4b	Psyttalia (Greece)	**Sidestream Thermal hydrolysis – SCENA**	**P-rich sludge**
Sidestream	5	Carbonera (Italy)	**Sidestream SCEPPHAR**	**PHA, struvite, VFA**

SMART-Plant

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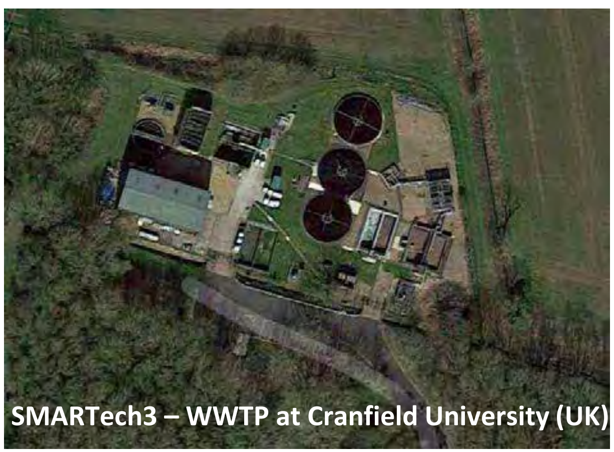
SMARTechs integrated in existing WWTPs (revamped/upgraded to WRRFs)

SMARTech1 - Geestmerambacht WWTP (NL)

SMARTech2a – Karmiel WWTP (IL)

SMARTech2b and Downstream
SMARTech B - Manresa WWTP (Spain)



SMARTech3 – WWTP at Cranfield University (UK)

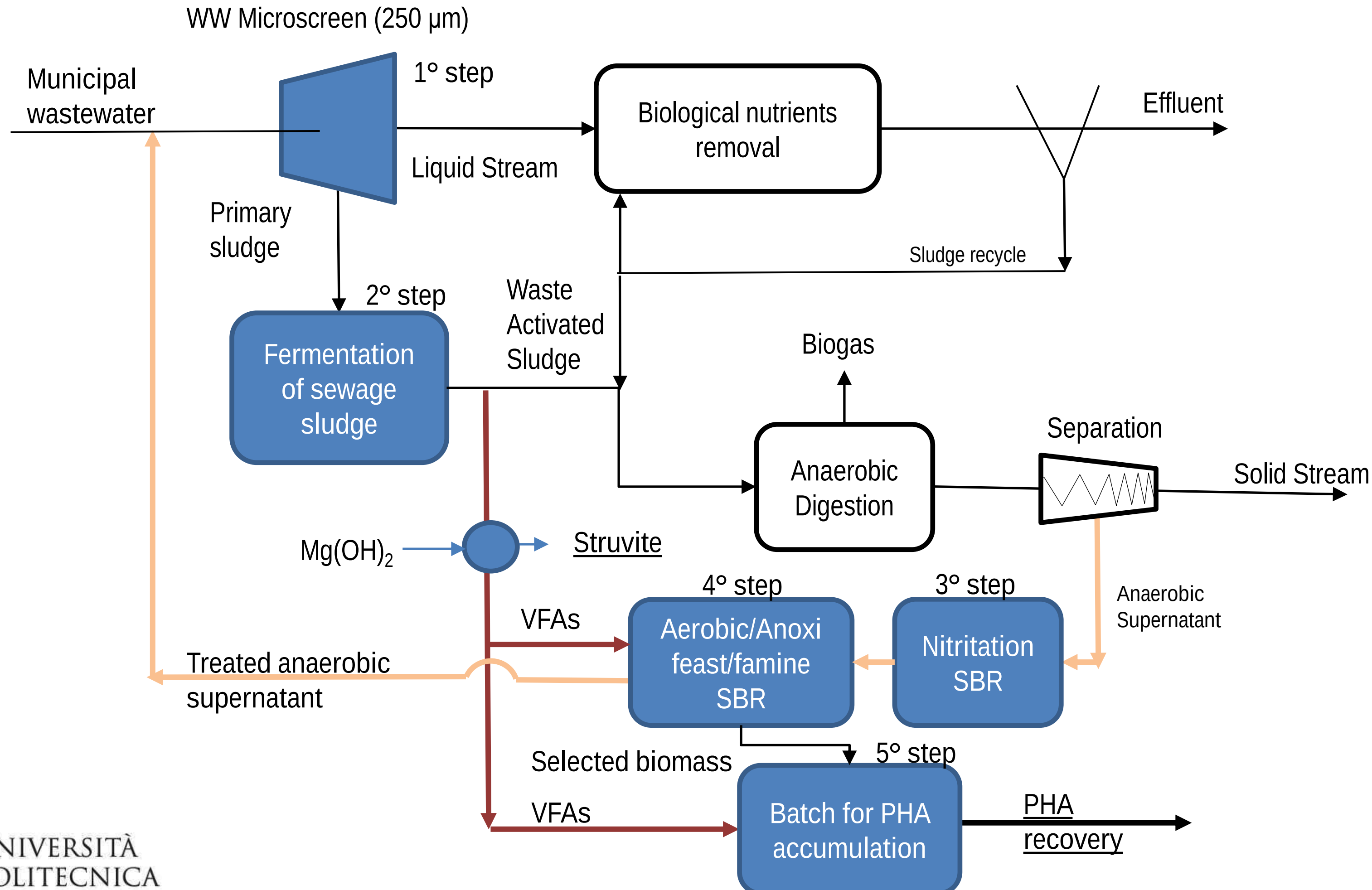
SMARTech 4a and SMARTech 5
Carbonera WWTP (Italy)

SMARTech 4b - Psyttalia WWTP

Sidestream S.C.E.P.P.H.A.R.: Short-Cut Enhanced Phosphorus and PHA recovery (Smartech 5)

Supported by the Horizon 2020 Framework Programme of the European Union

www.smart-plant.eu



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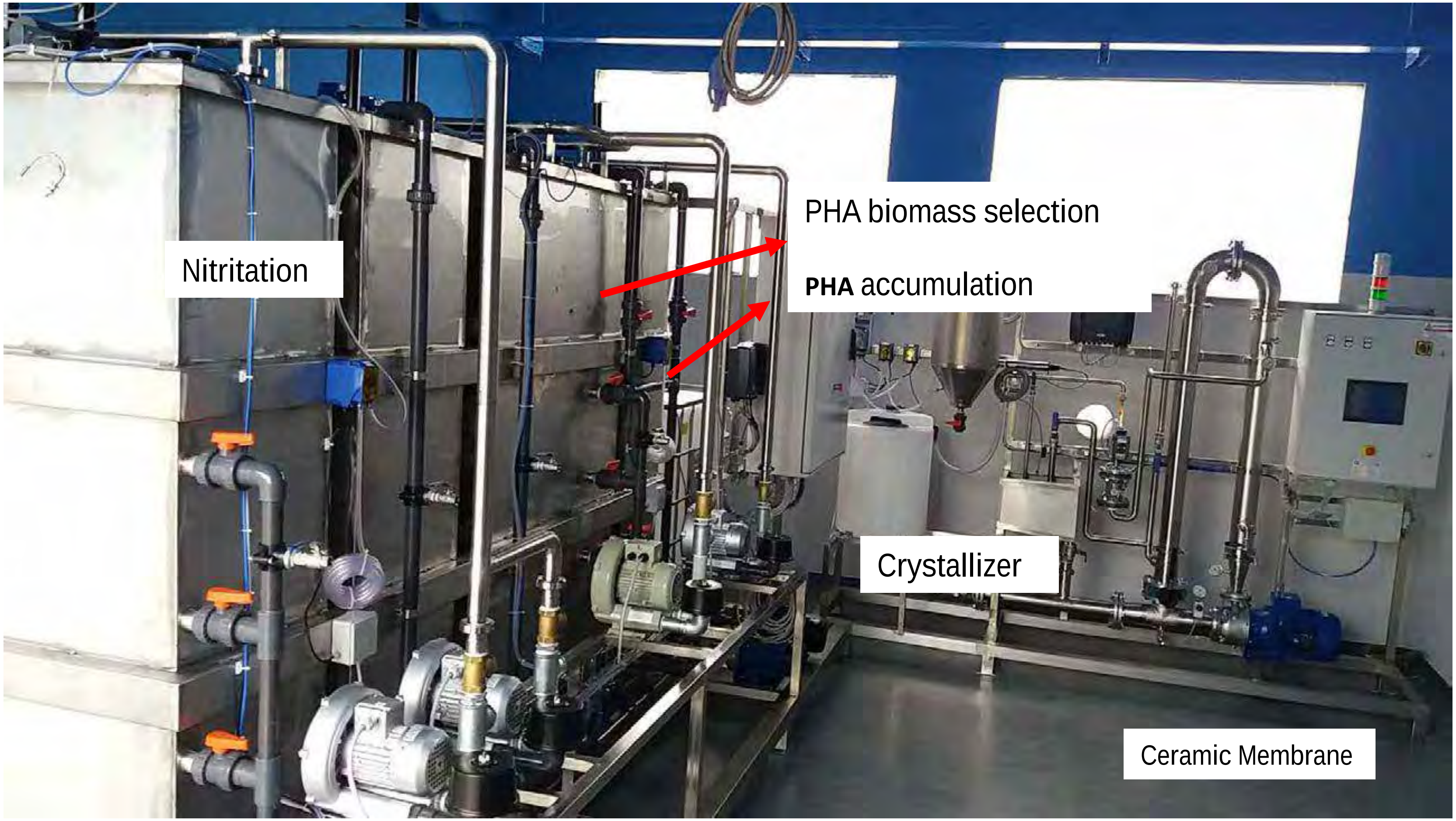
Conca et al. Long-term validation of polyhydroxyalkanoates production potential from the sidestream of municipal wastewater treatment plant at pilot scale
Chemical Engineering Journal, 390, 124627, 2020, https://doi.org/10.1016/j.cej.2020.124627

Sidestream SCEPPHAR pilot scale (Smartech 5): TRL 5



Pilot plant potential recoveries: 0.7-0.8 kgPHA/day; up to 300 gStruvite/day)

Full scale final projection: PHA 1-1,2 kg per PE per YearStruvite 0,2-0,4 kg PE per Year

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Supported by the Horizon 2020 Framework Programme of the European Union

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RESources from **UR**ban **BI**o-wa**S**te

RES URBIS

EN Horizon 2020 Work Programme 2016 - 2017

CIRC-05-2016: Unlocking the potential of urban organic waste

Research and Innovation Actions (RIA)

3-year project, Jan 2017 – Dec 2019

20 partners, 8 countries

around 3 M€ EU support

Project coordinator: M. Majone

Research Centre for Protection of Environment and Cultural Heritage

University of Rome “La Sapienza”, Italy

Website: www.resurbis.eu

CIRC-05-2016: Unlocking the potential of urban organic waste

In a Circular Economy perspective, turning waste into a resource is an essential part of increasing resource efficiency and closing the loop

More than 70% of Europeans live in cities and urban areas, and produce huge amount of organic waste (**including sludge from wastewater treatment**)

Challenges from the Call which RES URBIS aims at answering to

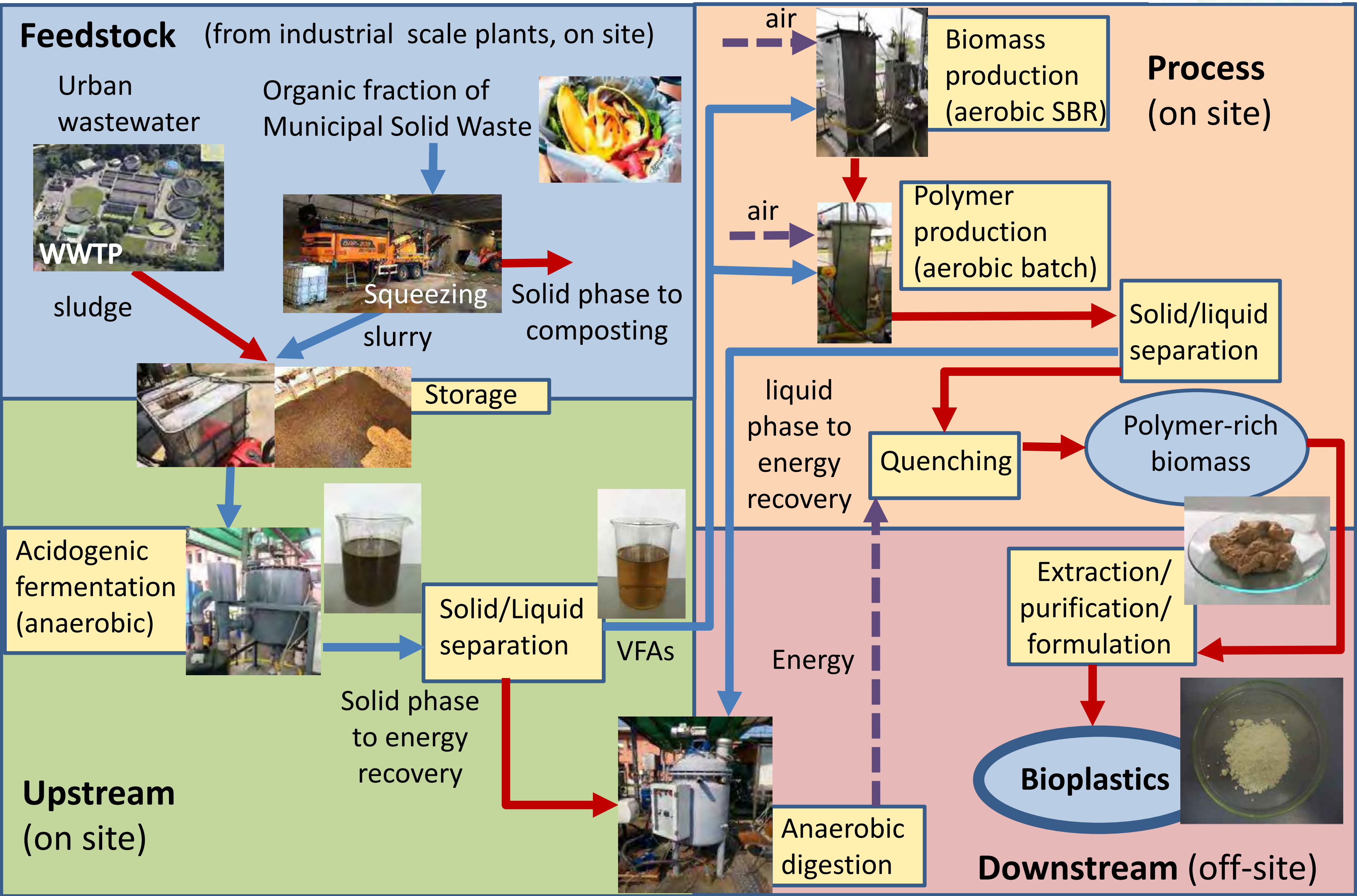
Can different organic waste streams of urban origin combined into a common valorization chain?

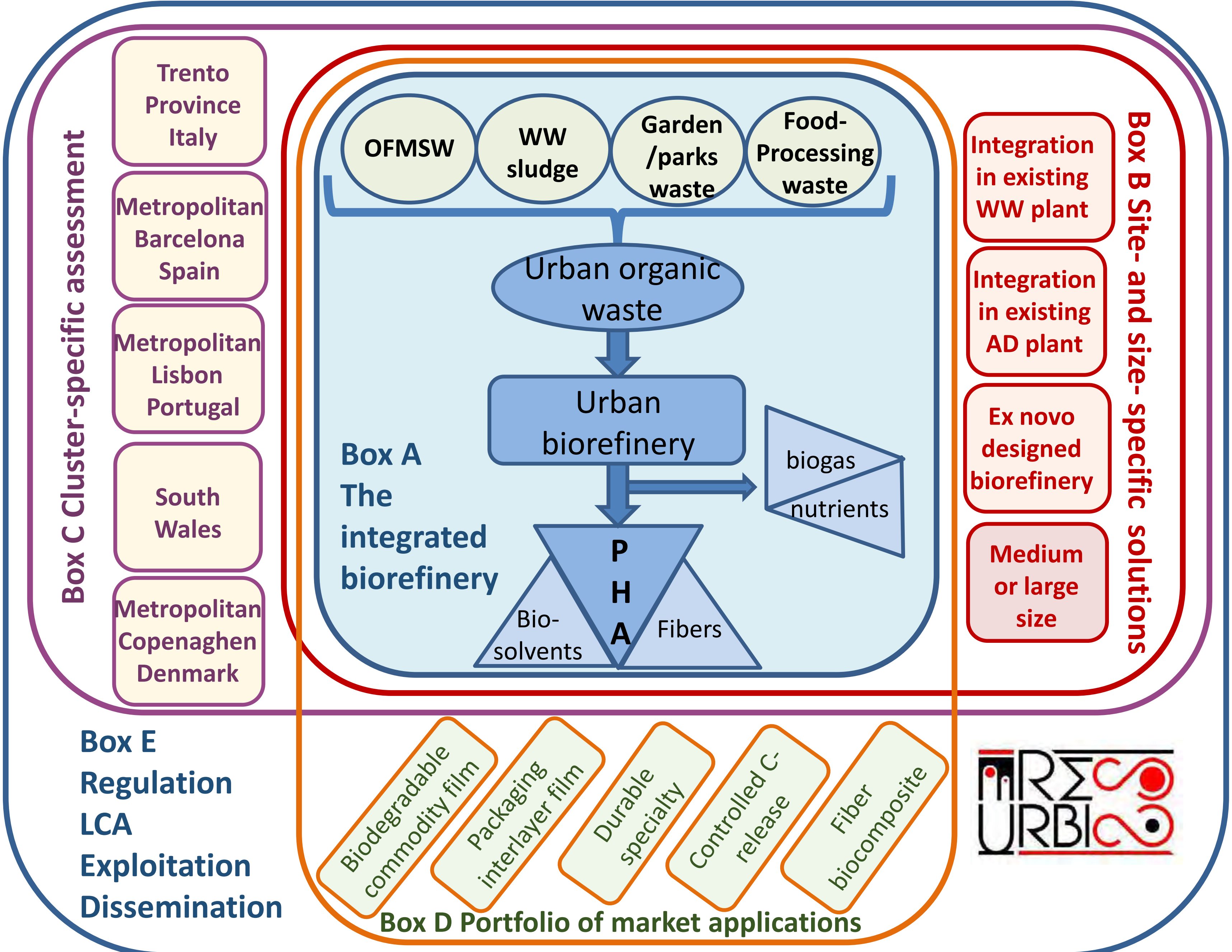
Can bio-based products be obtained from organic waste of urban origin, with a higher economic value than compost and biogas?

Can both targets be fullfilled togheter?

Can the new technological solutions be integrated in the present waste management systems

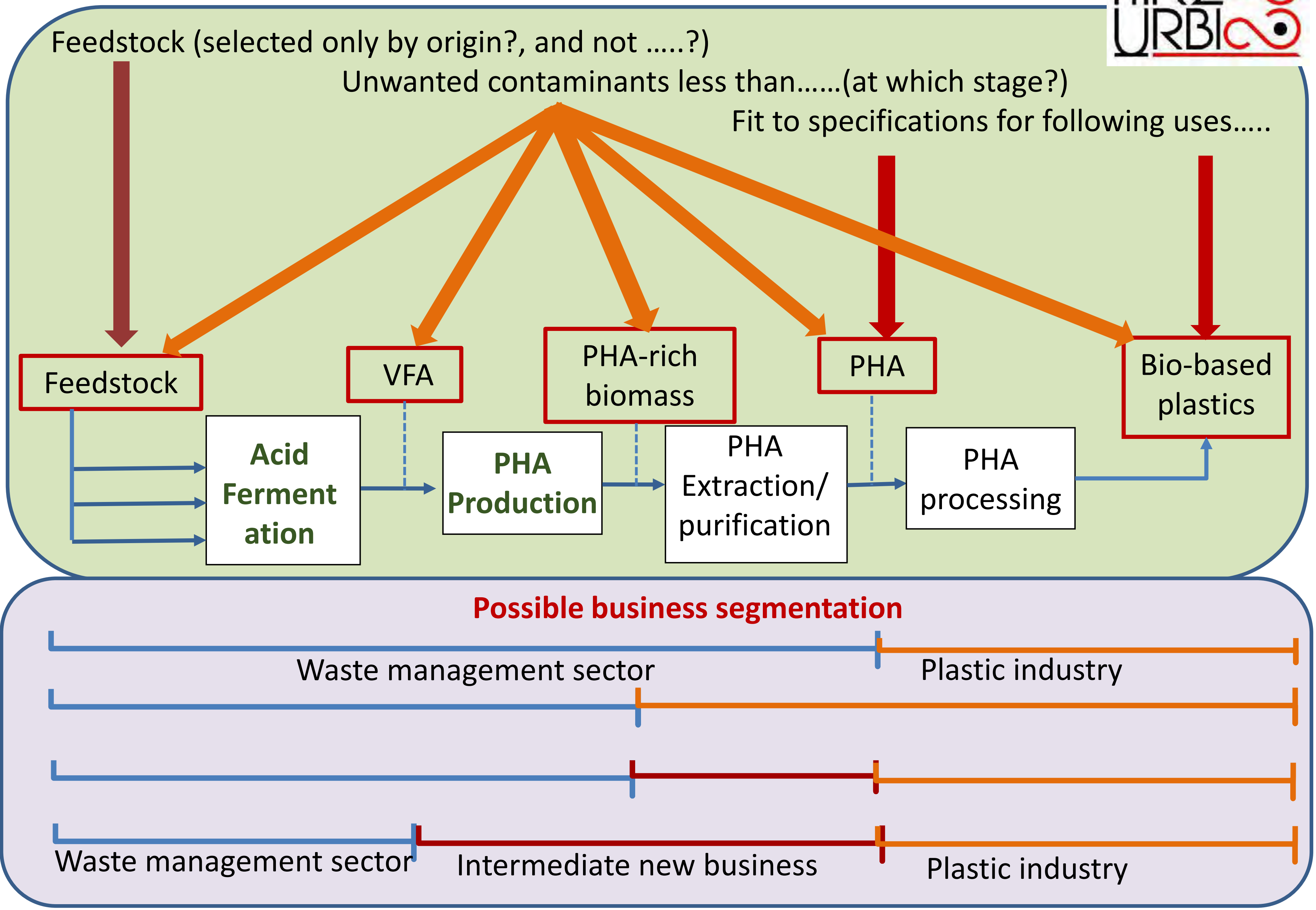
Flow-sheet of biopolymer production from urban biowaste (pilot scale plant in Treviso, Italy)





The RES URBIS box-model

“End of waste” criteria: where and how



The definition of "end of waste" criteria is a key step along any way a waste is transformed into a product

"End-of-waste" status

Article 6 of the Directive 2008/98/EC, as amended by the new Waste Directive (Brussels, 27 April 2018 (OR. en) 2015/0275 (COD) PE-CONS 11/18)

1. Member states shall take appropriate measures to ensure that waste which has undergone a recycling or other recovery operation is considered to have ceased to be waste if it complies with the following conditions:

(a) the substance or object is to be used for specific purposes;

(b) a market or demand exists for such a substance or object;

(c) the substance or object fulfils the technical requirements for the specific purposes and meets the existing legislation and standards applicable to products; and

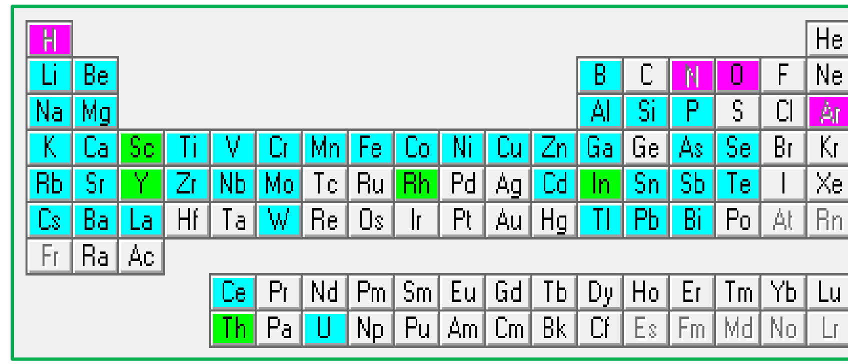
(d) the use of the substance or object will not lead to overall adverse environmental or human health impacts.

Analysis of contaminants in PHA samples

As function of:
- Feedstock
- Stabilization method
- Before/after extraction
- Extraction mehod

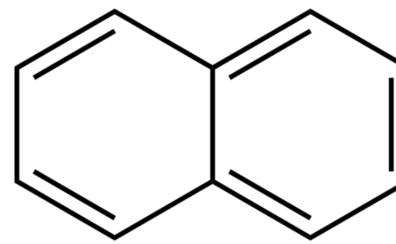
Inorganic elements, including toxic metals
>40

Astolfi ML. et al., Chemosphere, 259, 127472, 2020
https://doi.org/10.1016/j.chemosphere.2020.127472.



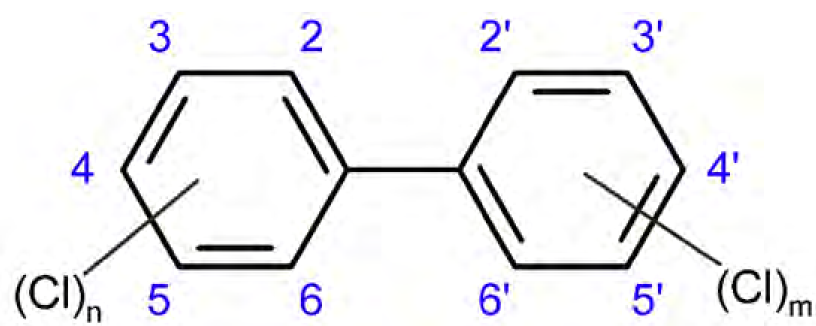
Polycyclic aromatic hydrocarbons (PAHs)
16 compounds

Cavaliere C. et al., Molecules 2021, 26, 539.
https://doi.org/10.3390/molecules26030539



Polychlorinated biphenyls (PCBs)
21 compounds

Riccardi C. et al. Polymers 2020, 12, 659.
https://doi.org/10.3390/polym12030659



Summary from analytical results

- The PHA content of contaminants is generally low, i.e in the range between ppb and a few ppm, but for alkaline and alkaline earth metals (which are of little environmental or health concern)
- The **type of feedstock** affects the contaminant contents:
  - PHA from fruit waste has lower content than PHA from the mixture of organic fraction of municipal waste and sludge from wastewater treatment.
  - commercial PHAs derived from crops have lower concentrations of heavy metals than waste-based PHA, but similar concentrations of PAH and PCB.
- **PHA extraction** also affects the contaminant contents: acid stabilization and extraction with aqueous inorganic extractants generally brings to lower contents than thermal stabilization and extraction with either hypochlorite or chloroform.
- Although a specific regulation does not exist yet, **all tested PHA types meet present regulatory standards and guidelines for similar conditions and materials** (e.g. limits for Cd and PAH in plastic materials based on REACH regulation, including toys; limits for PCB in Recycling Plastics from Shredder Residue, based on EPA guidelines).
- From reliminary results (to be confirmed) waste-based PHA slightly exceed the limits for heavy metals set by the EU Directive n. 10/2011 on PHA-based plastic materials and articles to come into contact with food. Thus, based on available results so far, **the use of waste-based PHA in direct contact with food cannot be suggested**.
- On the other hand, in migration tests, the PHA samples obtained under the best operating conditions **complied with the EU limits for the safety of toys and on plastic materials intended for contact with refrigerated or frozen food** (10/2011).

A tentative proposal for an EoW national decree on PHA

Directive 2018/851 (art 6) states that End of Waste for a given material can be determined case by case when a specific EU regulation is absent.

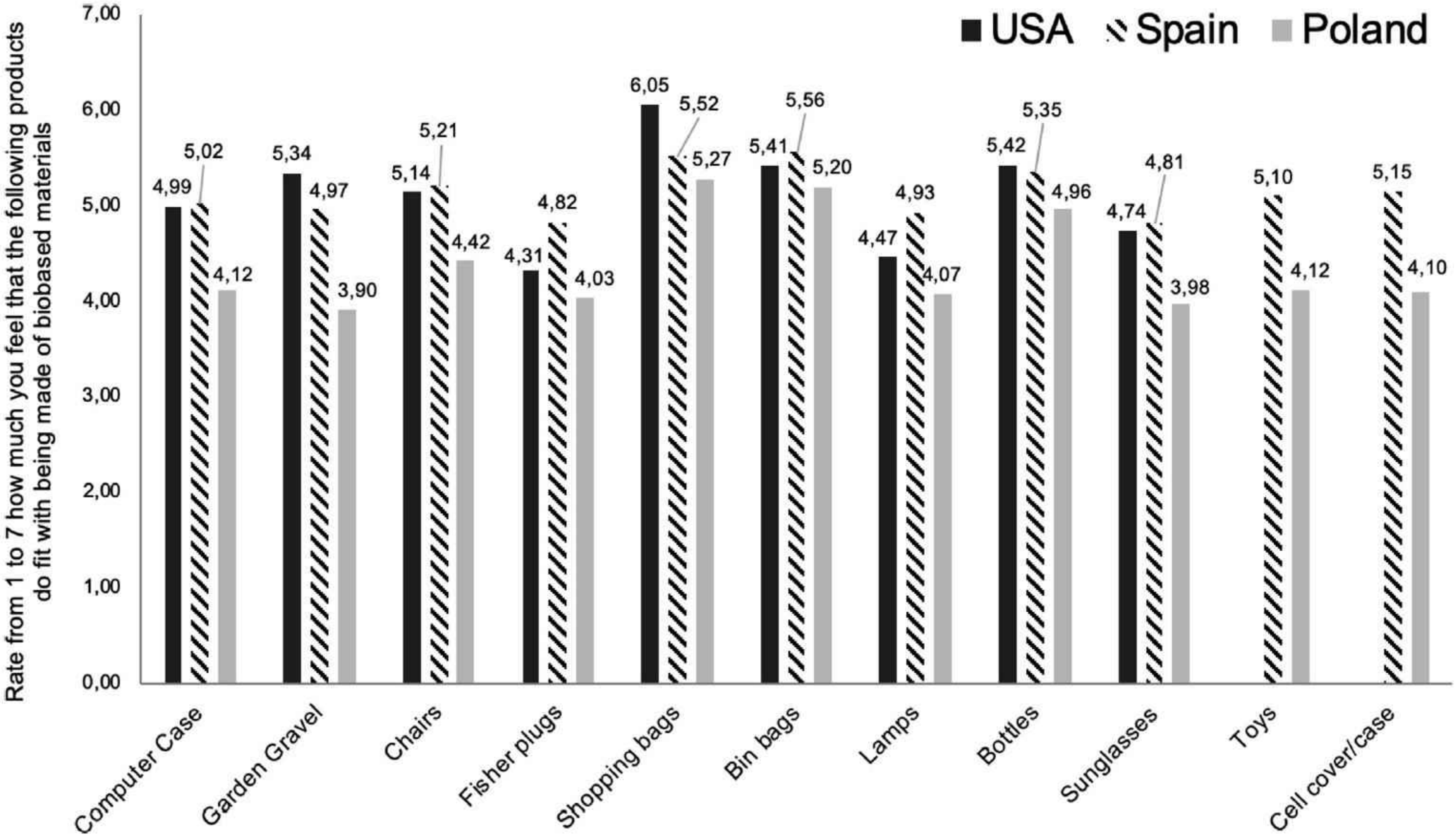
The specific Decree at National level, should be based on the following points:

1. Definition of the waste type (with indication of the European Catalogue Code) and its characteristics including the acceptability definitions/standards
2. Technical parameters in terms of characteristics and definition of limits of the resulting “new” material / substance
3. Definition of the specific use and markets for the new waste-derived material

In the case of PHA production from urban organic waste these three points can be clearly defined:

a) Proposed organic waste for PHA production are typically the **organic fraction from municipal solid waste and/or the sludge from municipal wastewater treatment**, whose quantity and characteristics are typically well defined at territorial level. Based on local conditions, food processing waste can be also included.
b) Characteristics of obtained PHA can be easily determined (**monomer composition, purity, ashes**), and PHA meet regulatory standards or guidelines for the allowable presence of relevant contaminants as well. Exemption/compliance for REACH/ECHA regulation has to be checked case by case as well as compliance with CLP regulation has to be warranted
c) There is a clear market demand for bioplastics in several sectors and a first estimation of at least 1 million ton per year worldwide can be considered. Because all market segments are well ruled, there’s a general provision that **PHA use complies with existing regulations, guidelines and technical specification for the respective sector.**

Perception and awareness of consumers towards bioplastics from waste/sludge



Thanks to Ivan Russo

G. Moretto et al. Water Research https://doi.org/10.1016/j.watres.2019.115371

A few remarks

How to transform wastewater/waste treatment plants into biorefineries as part of the development strategies of the circular bioeconomy

✓ Availability of supply of sufficient "raw material", stable, and not in competition with more noble uses.
✓Simple and robust technologies to deal with the intrinsic variability of the raw material and at the same time to guarantee the reliability of bioproducts.
✓Integration of new technologies with existing plants.

✓Rethinking and adaptation of the legislation in the light of technological developments (e.g. overcoming the dichotomy between wastewater and waste in specific cases).
✓Rapid implementation of the regulatory and authorization aspects (eg "end of waste"), starting from the early development stage of the new technologies.
✓Management of the possible contradiction between the circularity of waste and non-contaminants.

✓Bio-products with real market value
✓Adequate connection between the different industrial sectors and business models (revenues/tariffs/taxes and incentives if any)
✓Effective and proven sustainability of bioproducts (LCA, "end of life")
✓Awareness, motivation and satisfaction on a social level

Annex 7: Presentations – Digitalisation

The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

Online seminar on digitalization

A. Kleyböcker, S. Casa Garriga, F. Fantone, C. Bruni

May, 20th 2021

Ultimate (June 2020 – May 2024):

Industry water-utility symbiosis for a smarter water society

- Promotion, establishment and extension of **Water Smart Industrial Symbioses**
- Development and demonstration of **innovative technologies** for symbioses
- **Assessment** of the technologies and development of **digital „support tools“**
- Development of **new business models** towards marketability

9 Symbioses between:

Industrial sectors

- Agro-food
- Beverage
- (Petro)chemical
- Biotech

Service providers

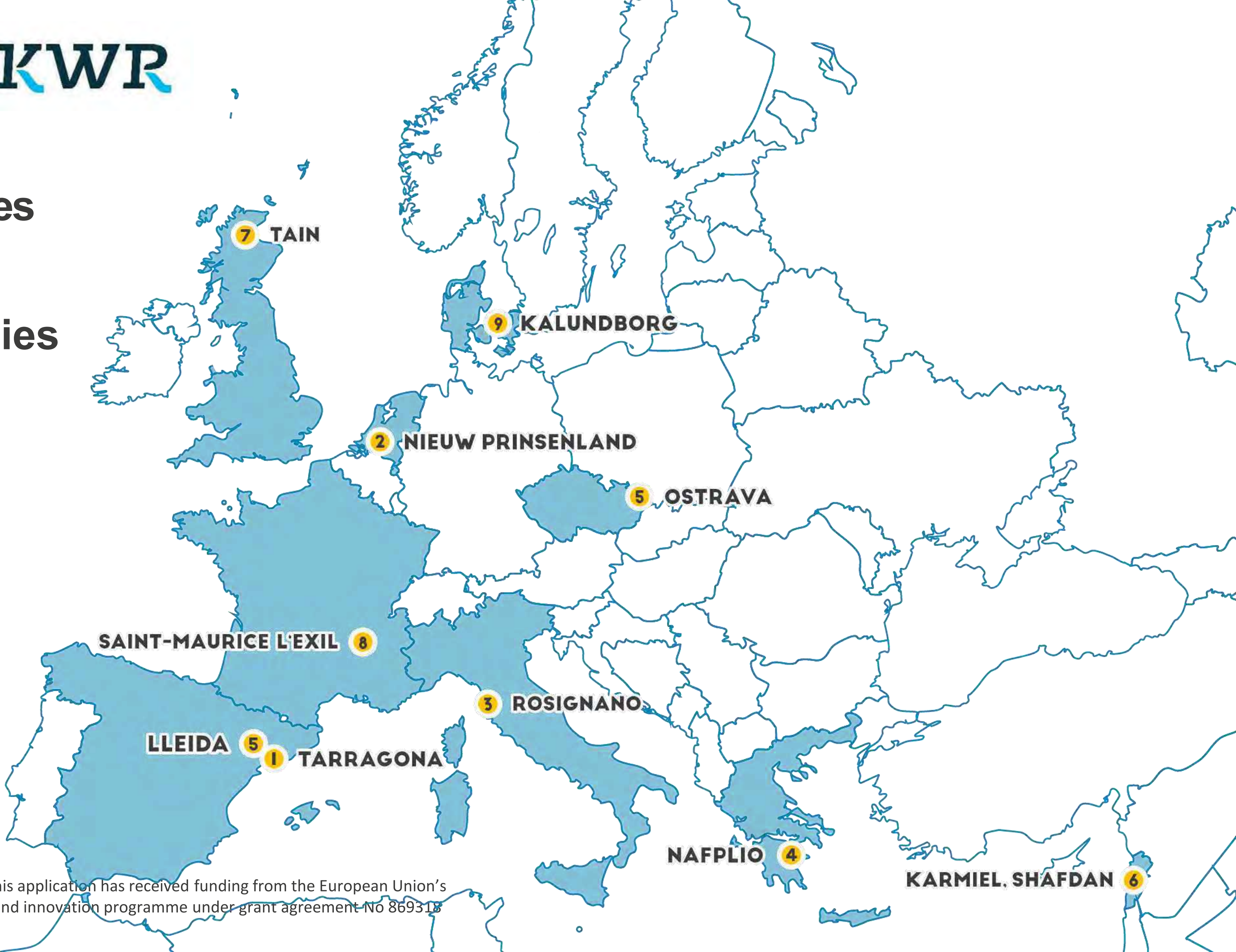
- Municipal utility
- Multi-industry utility
- Specialized SME
- Water services provider

Coordinator: KWR

9 Case Studies

27 Partners

37 Technologies



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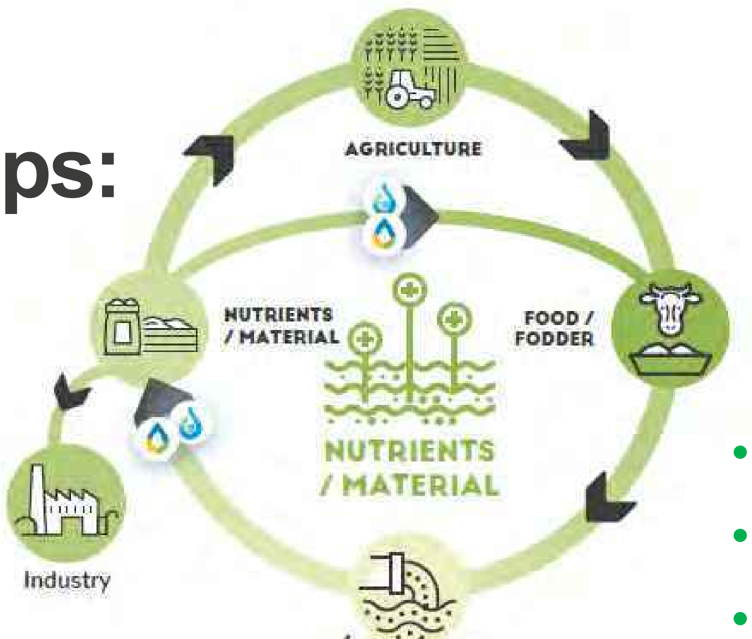
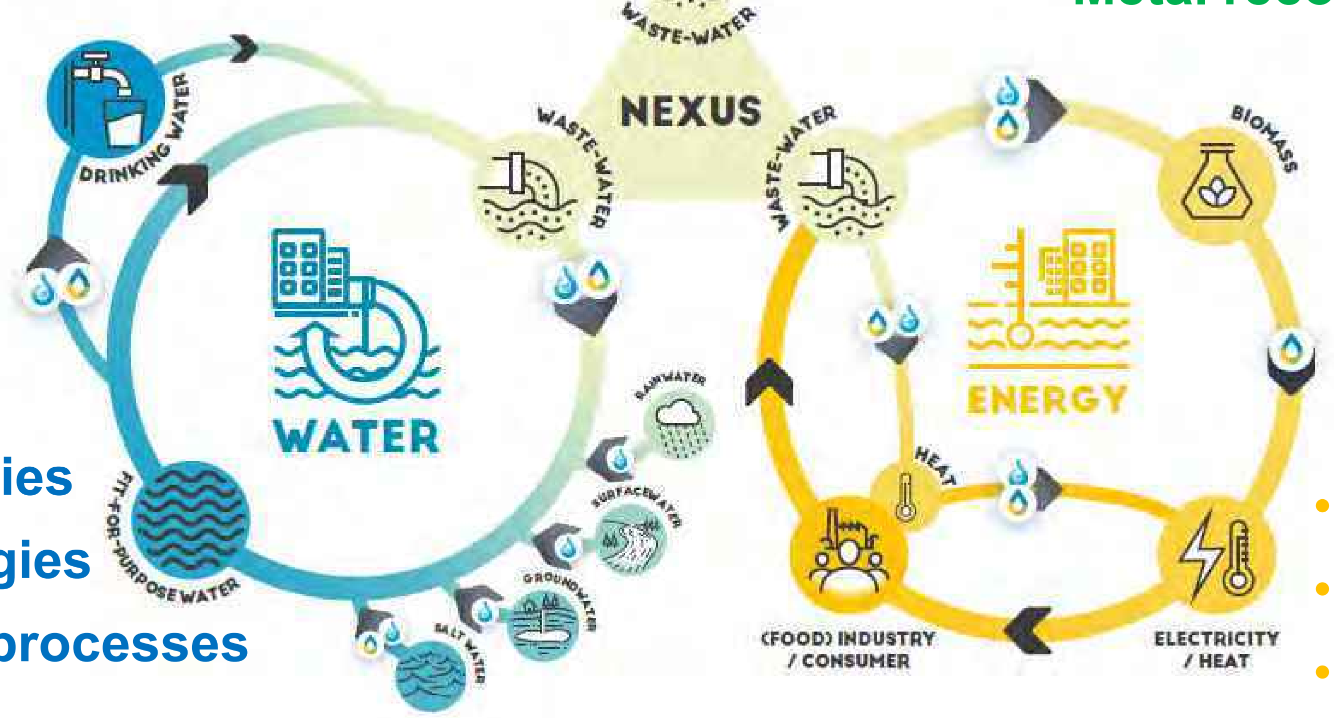
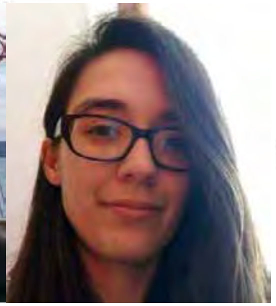
3 Cross-cutting Technology Groups: 9 Topics





F. Fatone C. Bruni

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- Nutrient recovery
- High added value products
- Metal recovery

eurecat
Centre Tecnològic de Catalunya

S. Casas

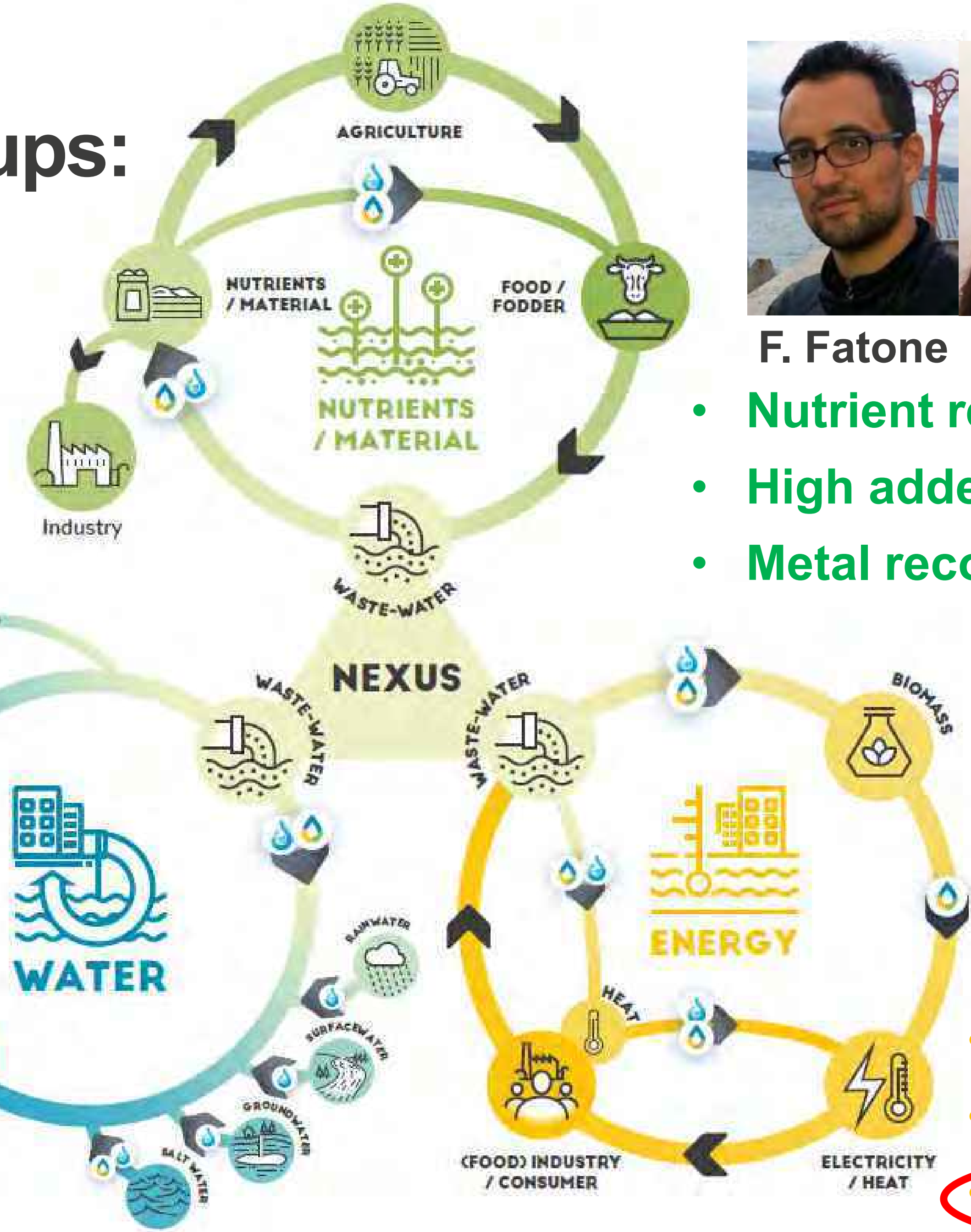
- Membrane technologies
- Adsorption technologies
- Advanced oxidation processes

A. Kleyböcker

KOMPETENZZENTRUM Wasser Berlin

- Biogas technologies
- Heat recovery
- Digitalization

3 Cross-cutting Technology Groups: 9 Topics



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- Nutrient recovery
- High added value products
- Metal recovery

eurecat
Centre Tecnològic de Catalunya

S. Casas

- Membrane technologies
- Adsorption technologies
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KOMPETENZZENTRUM WasserBerlin

A. Kleyböcker

- Biogas technologies
- Heat recovery
- Digitalization

Coordinator: KWR

9 Case Studies

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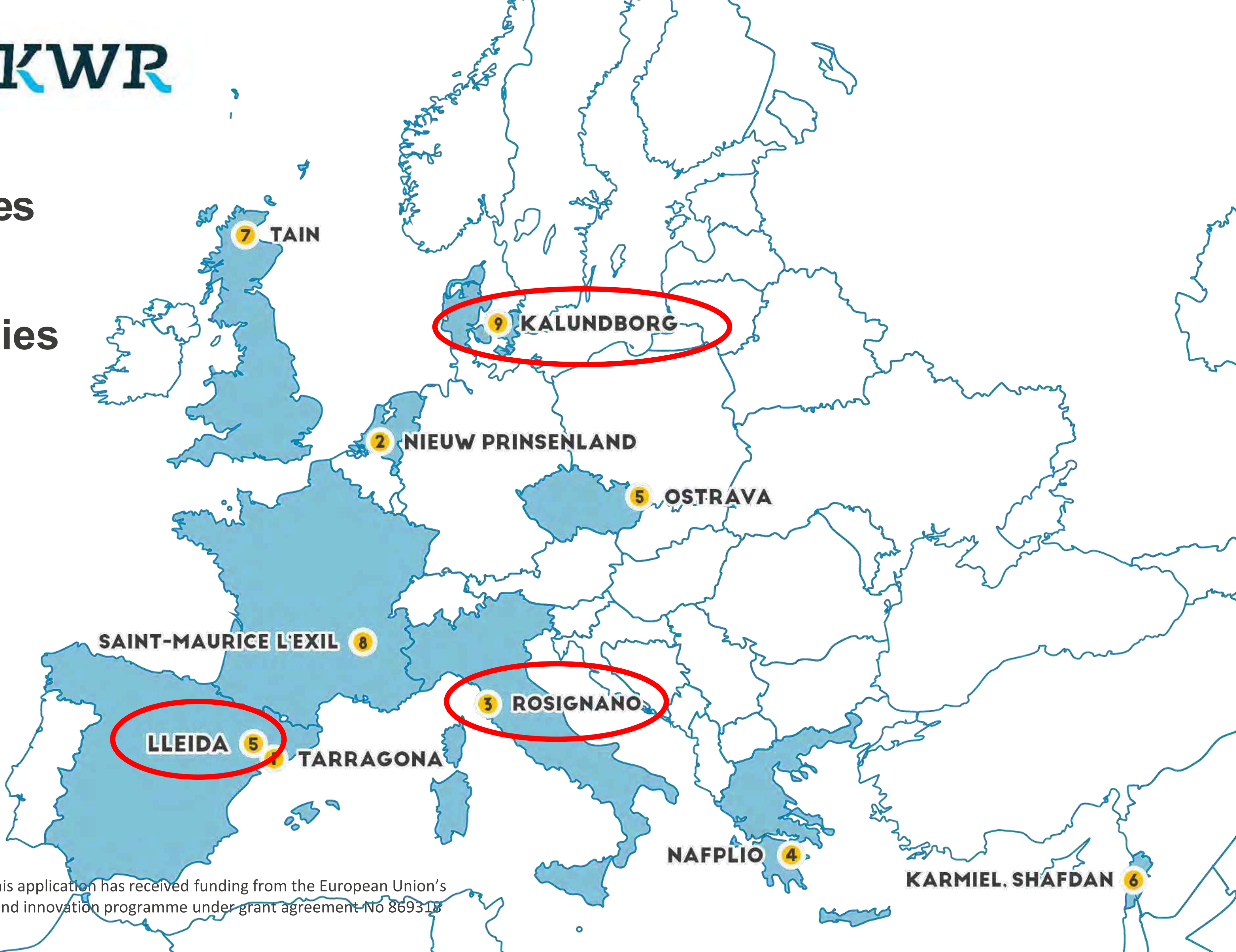
37 Technologies



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Online seminar on digitalization

14:10	**Digital Water City (DWC)**: Early warning system for bathing water quality and water reuse *Nicolas Caradot (KWB)*
14:35	**CS3 Rosignano**: Development of an early warning system for saltwater intrusion in the sewer system *Simone Neri (West) & Cecilia Bruni (UNIVPM)*
14:50	**CS5 Lleida**: Development and implementation of an early warning system for membrane fouling *Antonio Giminez Lorang (Aqualia)*
15:05	Short break
15:15	**CS9 Kalundborg**: Development of a joint control system for an industrial and a municipal wastewater treatment plant *Anne Kleyböcker (KWB) & Line Rodenkam Melchiorsen (KCR)*
15:30	**Fiware4Water**: Intelligent control wastewater treatment *Siddharth Seshan (KWR) & Alex van der Helm (Waternet)*
15:55	**End**

Please mute your microphone and use the chat to ask questions!

Presentations will be available on our webpage: **ultimatewater.eu**

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ULTIMATE

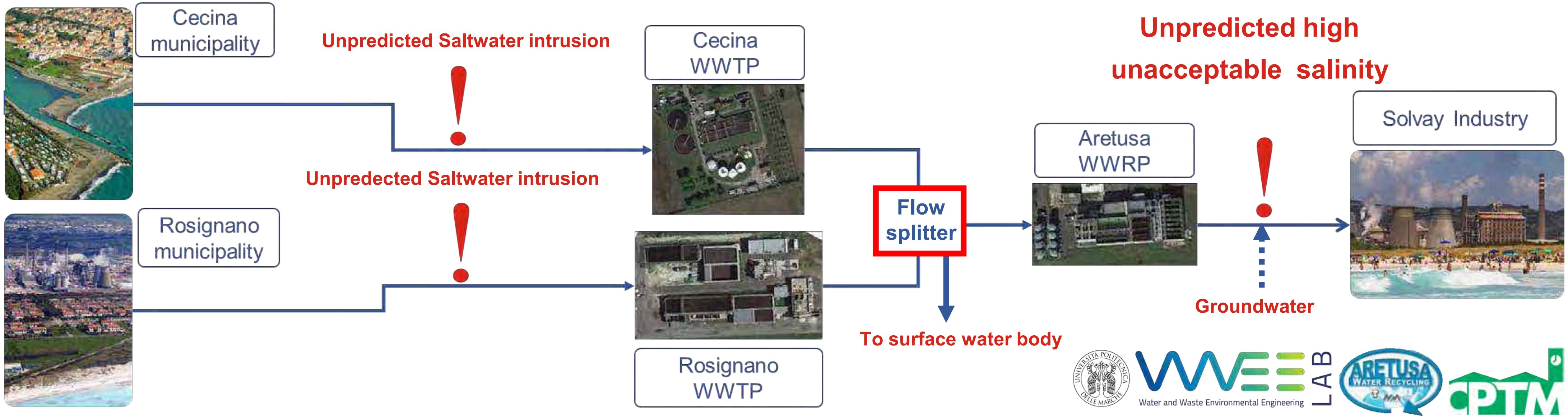
WATER SMART INDUSTRIAL SYMBIOSIS

CS3 – Development of an early warning system for saltwater intrusion in the sewer system

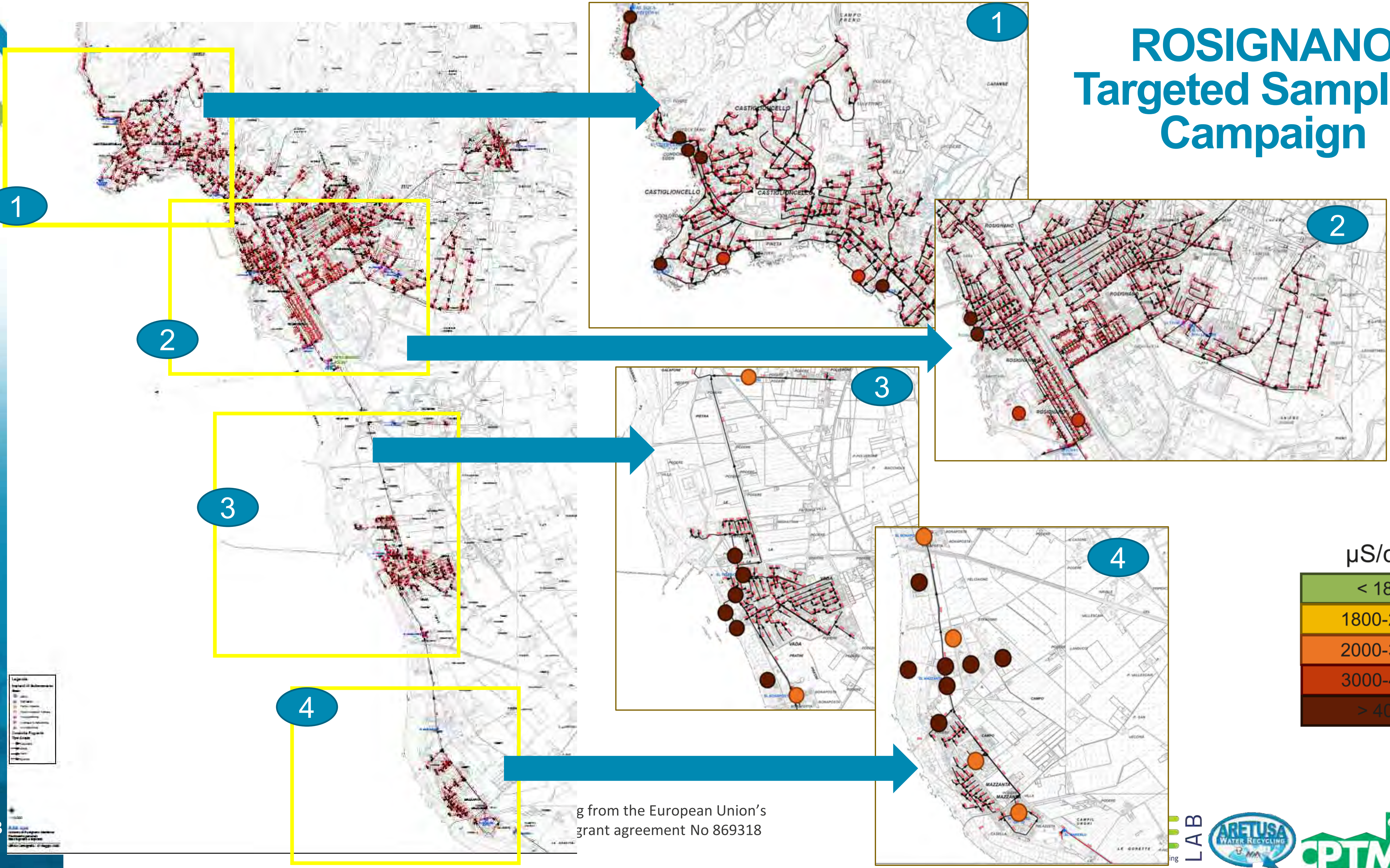
Cecilia Bruni (UNIVPM) and Simone Neri (WEST)

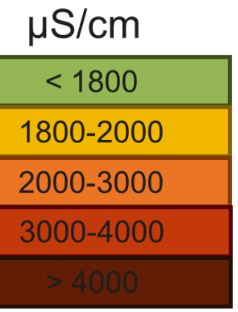
20th May 2021

ULTIMATE Project



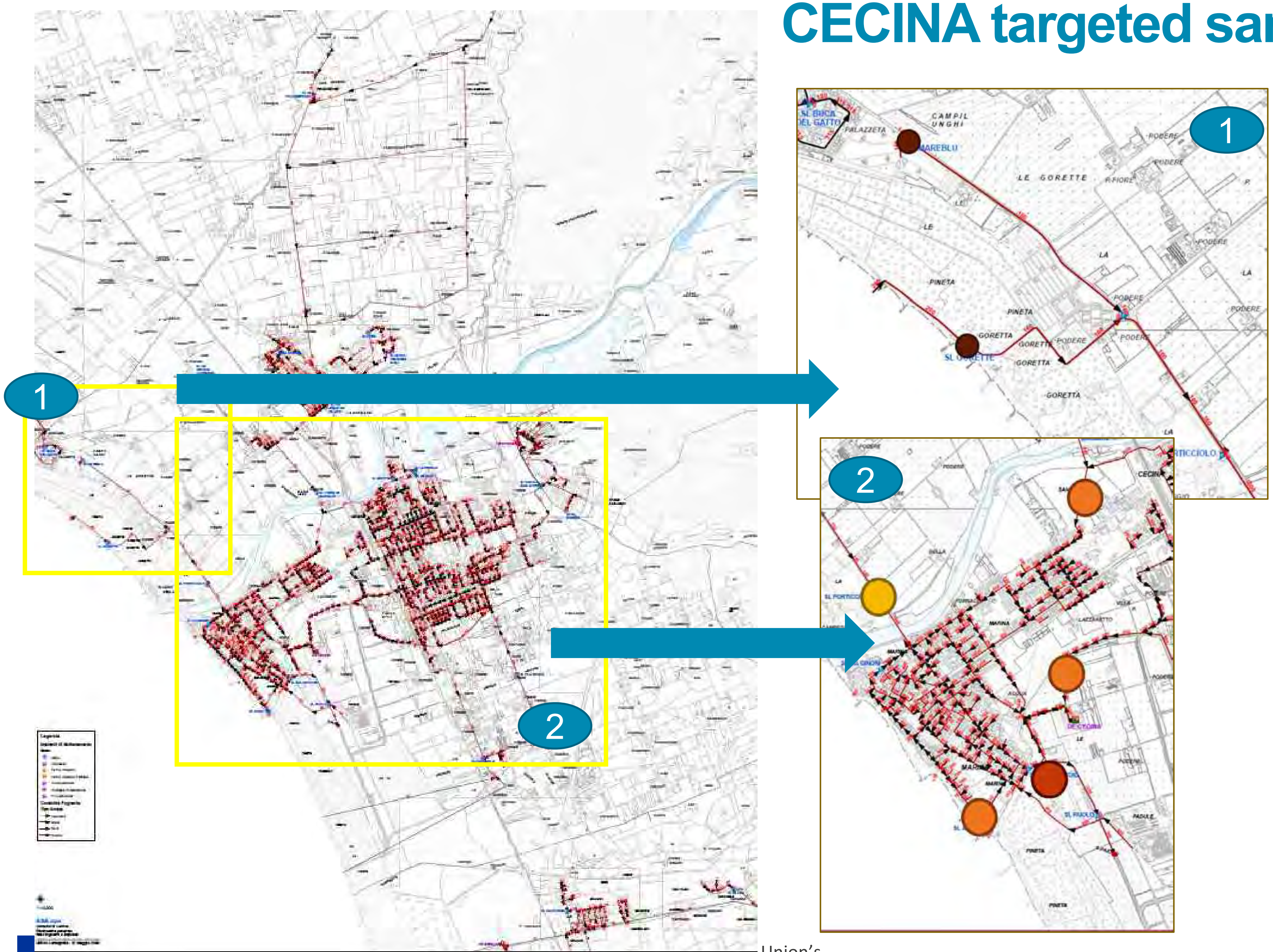
ROSIGNANO Targeted Sampling Campaign





g from the European Union's
grant agreement No 869318

CECINA targeted sampling campaign



µS/cm

< 1800
1800-2000
2000-3000
3000-4000
> 4000

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Water and Waste Environmental Engineering LAB

ARETUSA WATER RECYCLING

WEST Systems

CECINA Sensor network

- ✓ 3 conductivity sensors in Cecina sewer network
- ✓ 4 flow sensors in Cecina sewer network
- ✓ 2 conductivity sensors at Cecina WWTP

Influent

CECINA WASTEWATER TREATMENT PLANT

Effluent

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ROSIGNANO and ARETUSA Sensor network

Influent

ROSIGNANO WASTEWATER TREATMENT PLANT

Effluent

Influent

ARETUSA WASTEWATER REUSE PLANT

Effluent

- ✓ 6 conductivity sensors in Rosignano sewer network
- ✓ 6 flow sensors in Rosignano sewer network
- ✓ 2 conductivity sensors at Rosignano WWTP
- ✓ 2 conductivity sensors at Aretusa WWRP

Smart equalization before ARETUSA WWRP

Rosignano WWTP

Flow = 2458 ± 3241 m3/d
EC = 2661 ± 552 µS/cm
→ Surface water body

Flow = 9281 ± 3623 m3/d
EC = 2661 ± 552 µS/cm

Cecina WWTP

Flow = 3477 ± 2140 m3/d
EC = 1976 ± 541 µS/cm

Flow = 2893 ± 2798 m3/d
EC = 1976 ± 541 µS/cm
→ Surface water body

Aretusa WWRP

1. Equalization
2. Coagulation/flocculation
3. Sedimentation
4. Sand filtration
5. Biological activated carbon
6. Activated carbon filtration

Wastewater to Solvay

Flow = 9753 ± 1945 m3/d
EC = 2319 ± 483 µS/cm
Required EC: < 2000 µS/cm

SOLVAY

Groundwater

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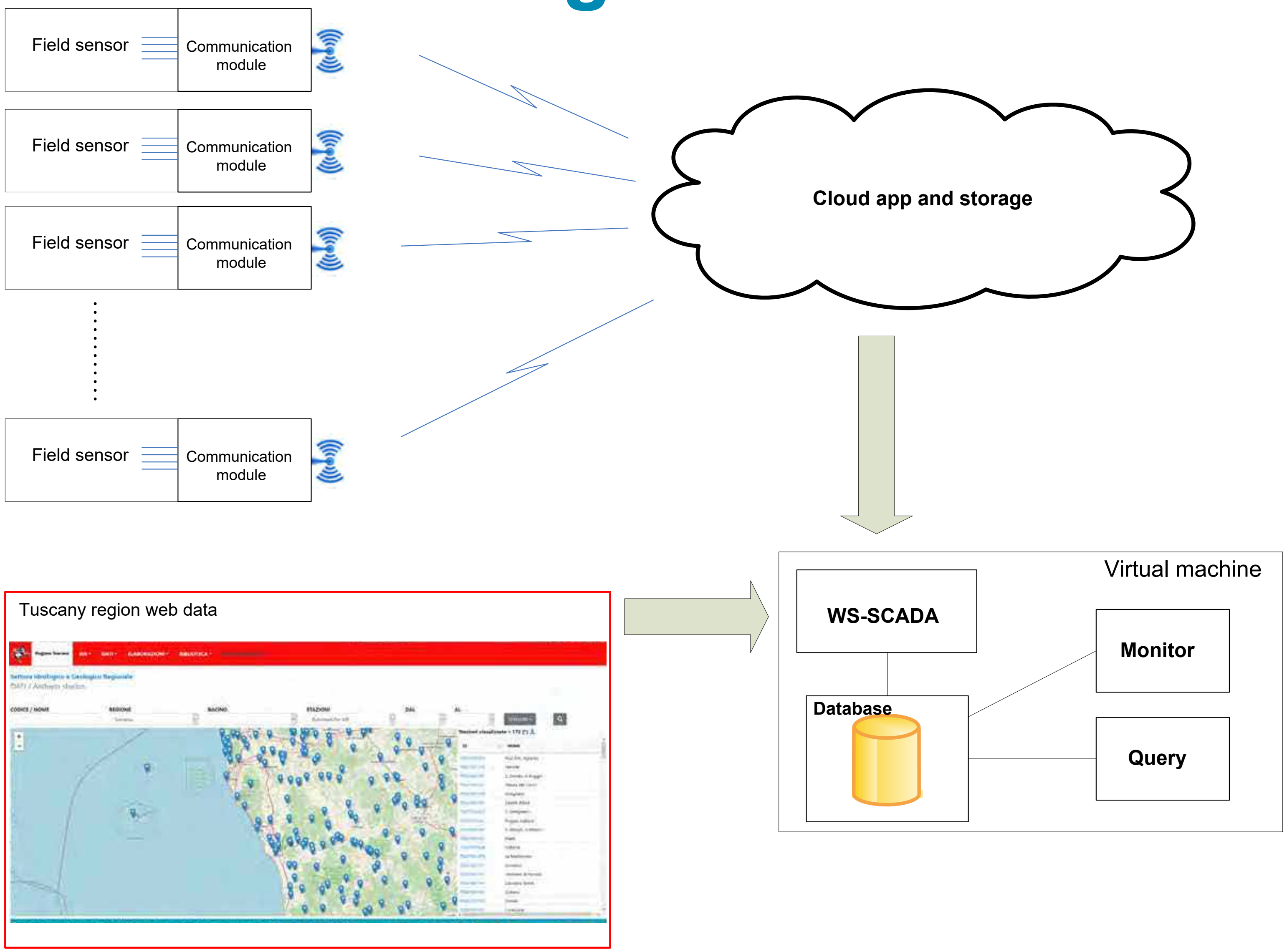
Real-time data monitoring



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Sensor

- 4 electrodes (2 graphic, 2 platinum)
- Range 0 to 200 mS/cm
- Digital sensor / **Modbus** RS-485
- Robust and Watertight

Resolution Conductivity	0,01 to 1 according the range
Accuracy Conductivity	+/- 1 % of the full range Beyond 100 mS/cm use appropriate buffer solution
Measure range salinity	5-60 g/Kg
Measure range TDS -KCl	0-133 000 ppm
Measure range Temperature	0,00 °C to + 50,00°C
Resolution Temperature	0,01 °C
Accuracy temperature	± 0,5 °C
Response time	< 5 s
Working temperature	0°C to 50°C
Temperature compensation	NTC
Stocking temperature	- 10°C to + 60°C
Signal interface	Modbus RS-485 (option SDI-12)
Maximum refreshing time	Max < 1 s
Sensor power-supply	5 to 12 volts
Electric consumption	Standby : 25 µA Average RS485 (1 measure/seconde) : 6,3 mA Average SDI12 (1 measure/seconde) : 9,2 mA Current pulse : 500 mA

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Datalogger

- 2 Analog inputs (0-20 mA, 0-5 V, 0-10 V)
- RS-485 Communication
- Cloud computing (MiDOMetSoft)
- Battery powered
- GSM/GPRS data communication

The data logger is connected to a cloud platform to upload the data recorded

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WS-SCADA software suite

WS-Scada (SCADA - *Supervisory Control And Data Acquisi*tion)

Monitor

Query

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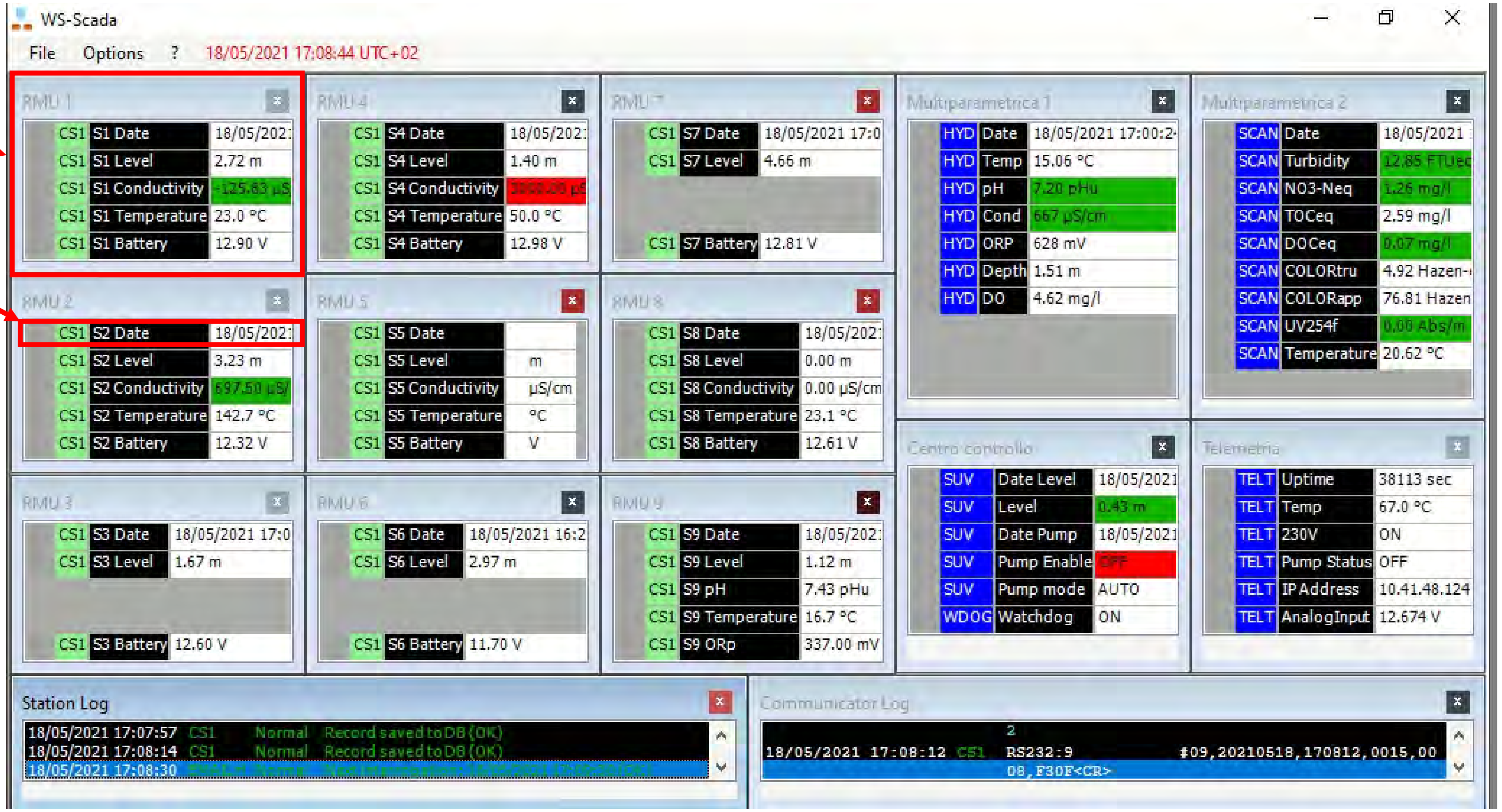
WS-SCADA software suite

WS-SCADA is able to downlaod data from different sources and save onto the database.

Parameters of each sensor/datalogger connected to the system is shown inside a box

The first line shows date and time of the last value downloaded



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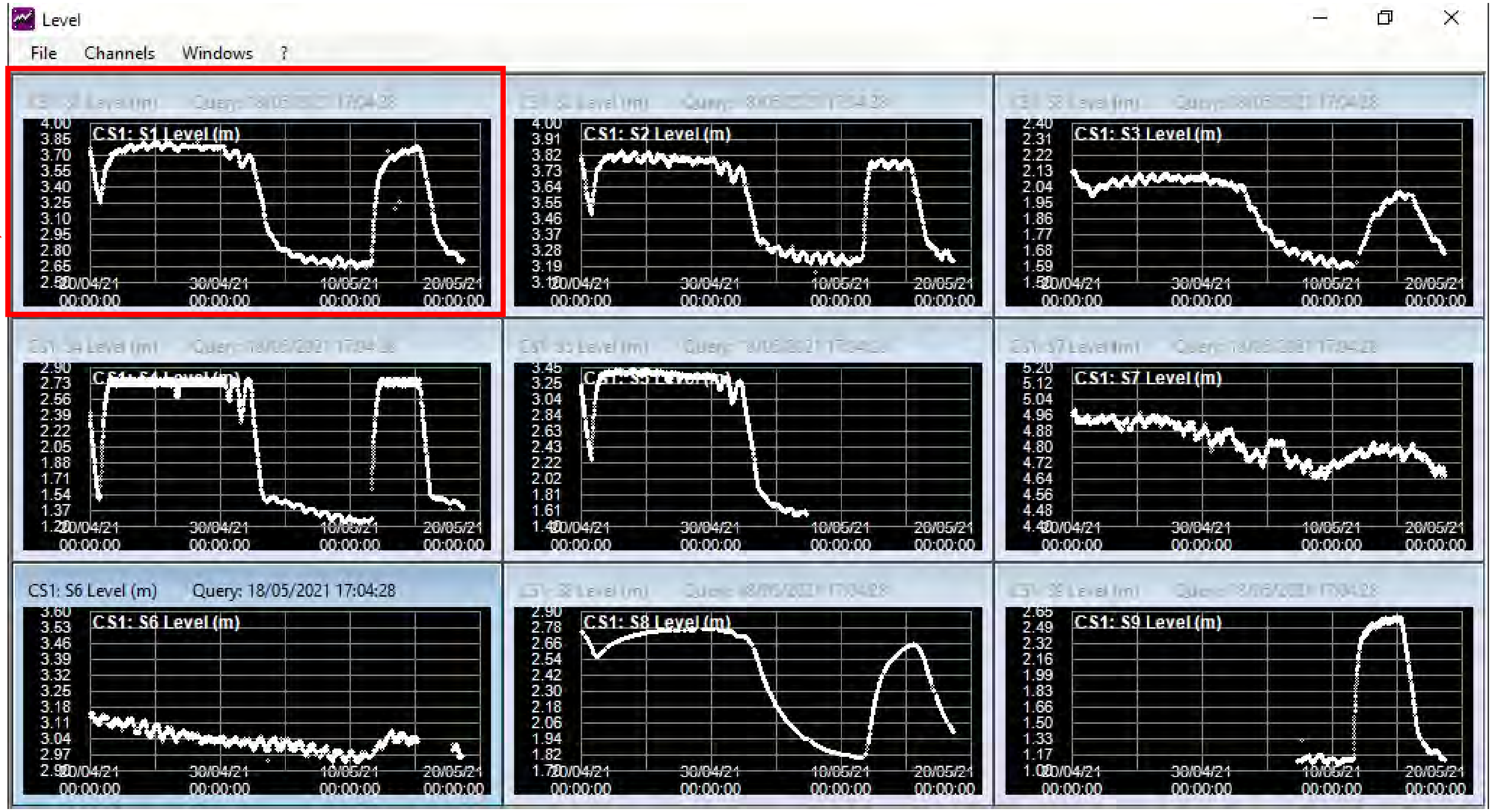
WS-SCADA monitor

Each box shows the plot of the temporal variation of a single parameter monitored

Time scale (x) and vertical scale (y) can be configured to set a different zoom



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WS-SCADA monitor

Each dot on the plot represents the value of a single measurement stored in the database

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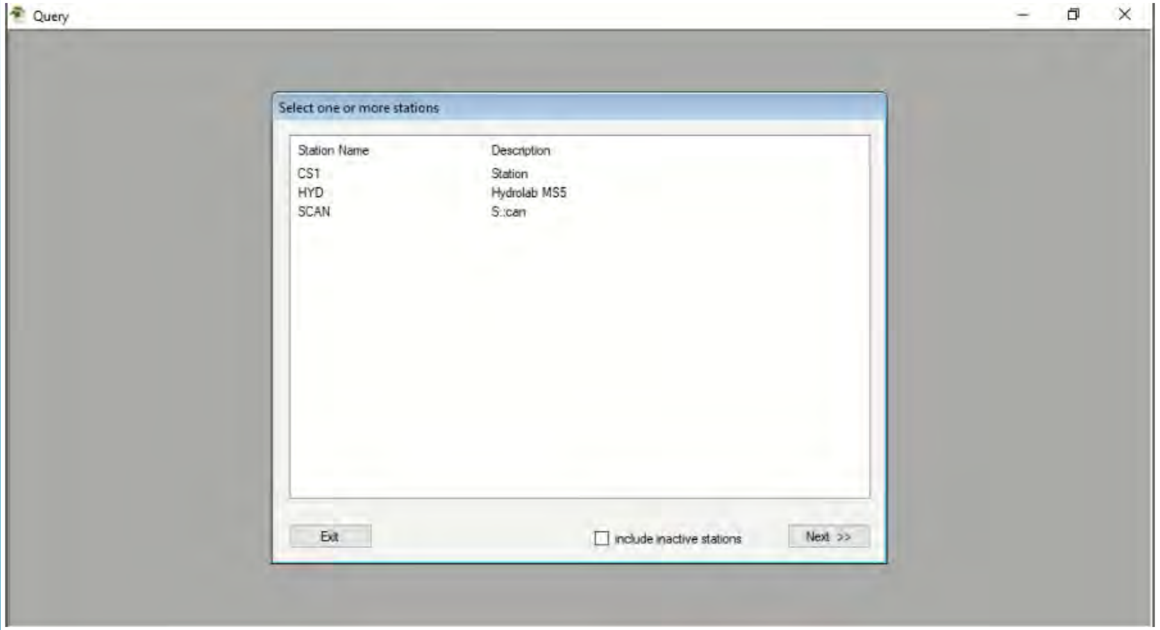
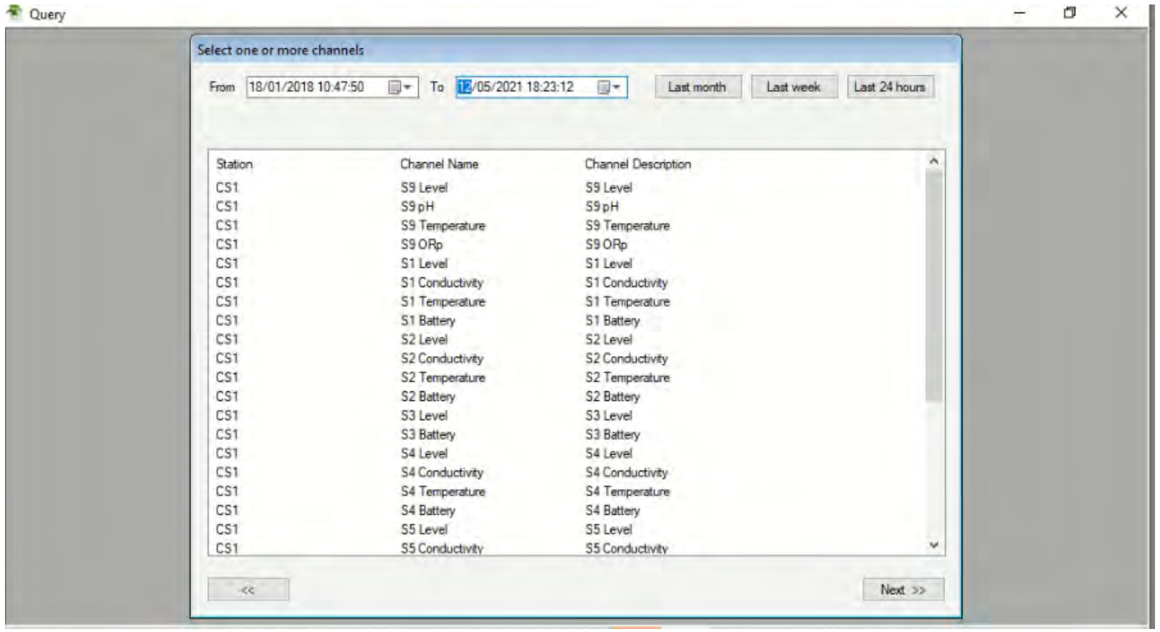
WS-SCADA query

Query

Allows to export data from the database and save them in Excel format or in Text format for data processing





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ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

Thank You!

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ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

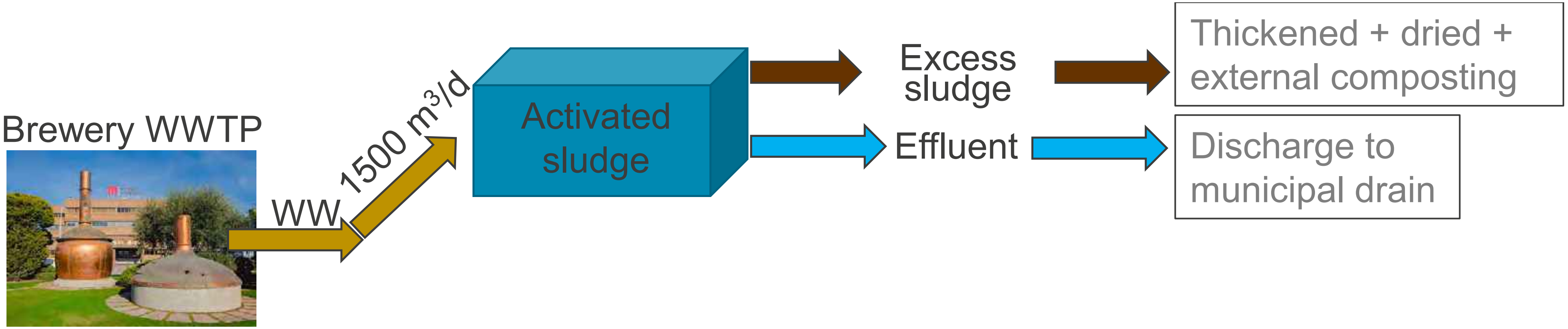
CS5 Lleida: Development and implementation of an early warning system for membrane fouling

A. Giménez-Lorang

aqualia

20.05.2021 CS meeting on “Digitalization”

Case study nr. 5: baseline conditions



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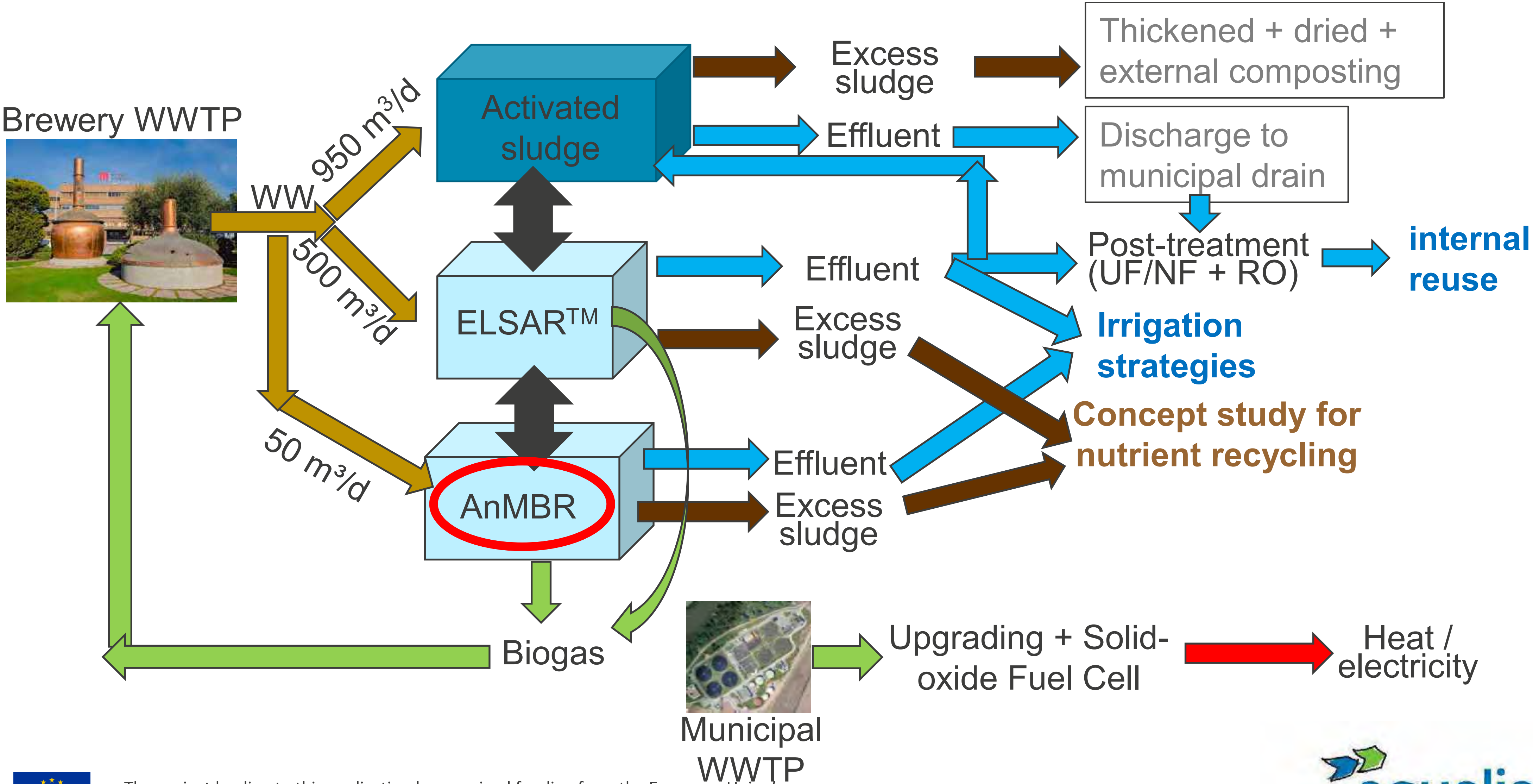
Case study nr. 5: ULTIMATE water-smart solution



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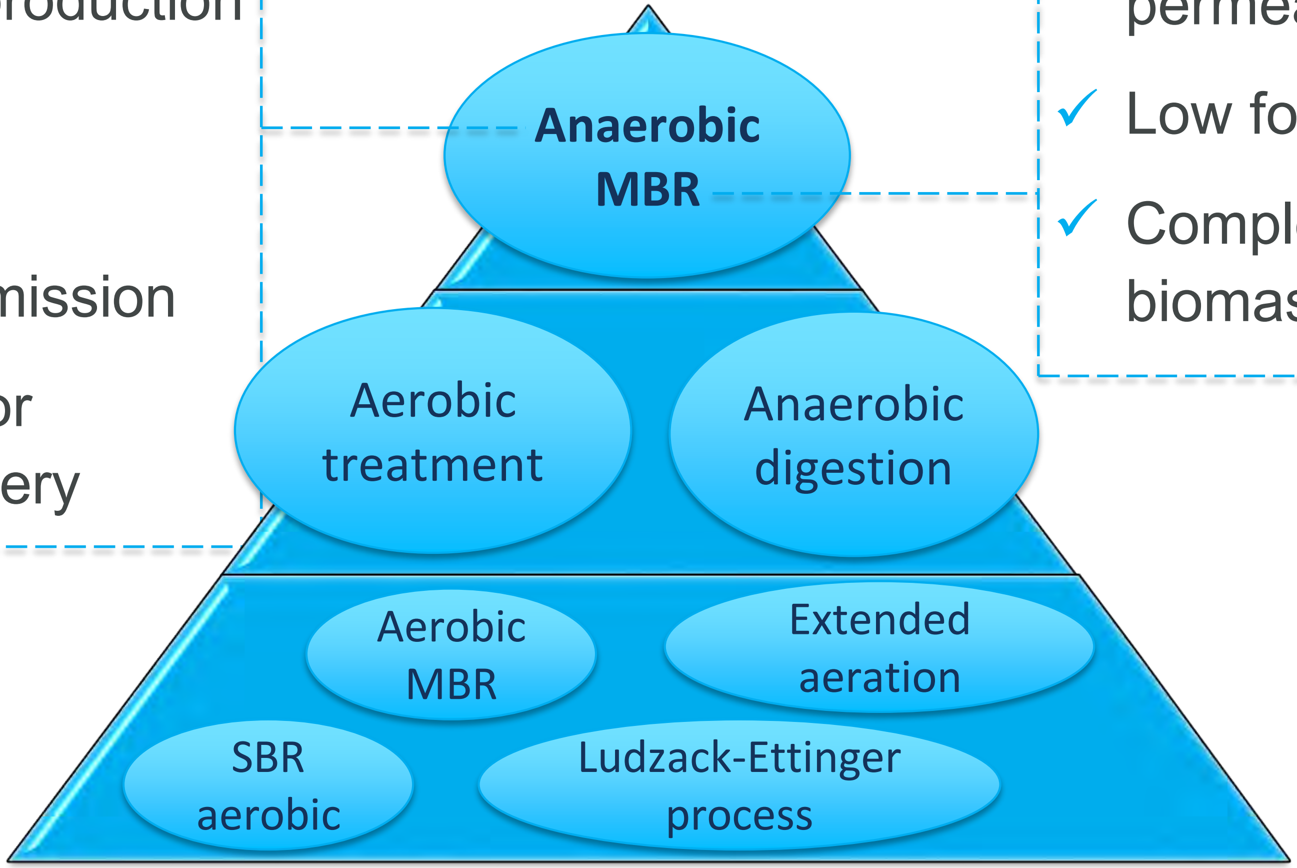
aqualia

Why AnMBR?

- ✓ Lower energy demand / net energy production
- ✓ Lower sludge production
- ✓ Lower CO_2 emission
- ✓ Opportunity for nutrient recovery



- ✓ High-quality permeate
- ✓ Low footprint
- ✓ Complete biomass retention

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R&D projects by Aqualia in the AnMBR field

Municipal | Black water | Industrial | OFMSW

www.life-methamorphosis.eu

www.life-memory.eu

http://eranetbestf.eu/call/bestf2/project-results/biowamet/

www.run4life-project.eu

The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

Scientific background of Aqualia in the MBR field

- Silva-Teira A, **Vázquez-Padín JR**, Weiler R, **Fernández-González R**, **Rogalla F**, Garrido JM. Performance of a hybrid membrane bioreactor treating a low strength and alkalinity wastewater. Process Biochemistry, Volume 66, 2018, Pages 176-182, https://doi.org/10.1016/j.procbio.2017.12.015
- Jiménez-Benítez A, Ferrer J, **Rogalla F**, **Vázquez JR**, Seco A, Robles A. 12 - Energy and environmental impact of an anaerobic membrane bioreactor (AnMBR) demonstration plant treating urban wastewater. In: Current Developments in Biotechnology and Bioengineering, Elsevier, 2020, Pages 289-310, ISBN 9780128198544, https://doi.org/10.1016/B978-0-12-819854-4.00012-5
- Silva-Teira A, **Vázquez-Padín JR**, Reif R, Arias A, Garrido JM. Assessment of a combined UASB and MBR process for treating wastewater from a seafood factory at different temperatures. 180(2020)43-54. https://doi.org/10.5004/dwt.2020.25076
- Robles A, **Durán F**, Giménez JB, **Jiménez E**, Ribes J, Serralta J, Seco A, Ferrer J, **Rogalla F**. Anaerobic membrane bioreactors (AnMBR) treating urban wastewater in mild climates. Bioresource Technology, Volume 314, 2020. https://doi.org/10.1016/j.biortech.2020.123763
- Odriozola M, **Morales N, Vázquez-Padín JR**, Lousada-Ferreira M, Spanjers H, van Lier JB. Fouling Mitigation by Cationic Polymer Addition into a Pilot-Scale Anaerobic Membrane Bioreactor Fed with Blackwater. Polymers. 2020; 12(10):2383. https://doi.org/10.3390/polym12102383
- **Giménez-Lorang A**, **Vázquez-Padín JR**, **Dorado-Barragán C**, Sánchez-Santos G, Vila-Armadas S, Flotats-Ripoll X. Treatment of the Supernatant of Anaerobically Digested Organic Fraction of Municipal Solid Waste in a Demo-Scale Mesophilic External Anaerobic Membrane Bioreactor. Front Bioeng Biotechnol. 2021 Apr 12;9:642747. https://doi.org/10.3389/fbioe.2021.642747
- Sanchis-Perucho P, Robles Á, **Durán F, Rogalla F,** Ferrer J, Seco A. Widening the applicability of AnMBR for urban wastewater treatment through PDMS membranes for dissolved methane capture: Effect of temperature and hydrodynamics. J Environ Manage. 2021 Jun 1;287:112344. https://doi.org/10.1016/j.jenvman.2021.112344. Epub 2021 Mar 19.

EP16382140.8:
Anaerobic process with filtration procedure for treating wastewater at room temperature.
FCC Aqualia, S.A., Universitat Politècnica De València, Universitat De València

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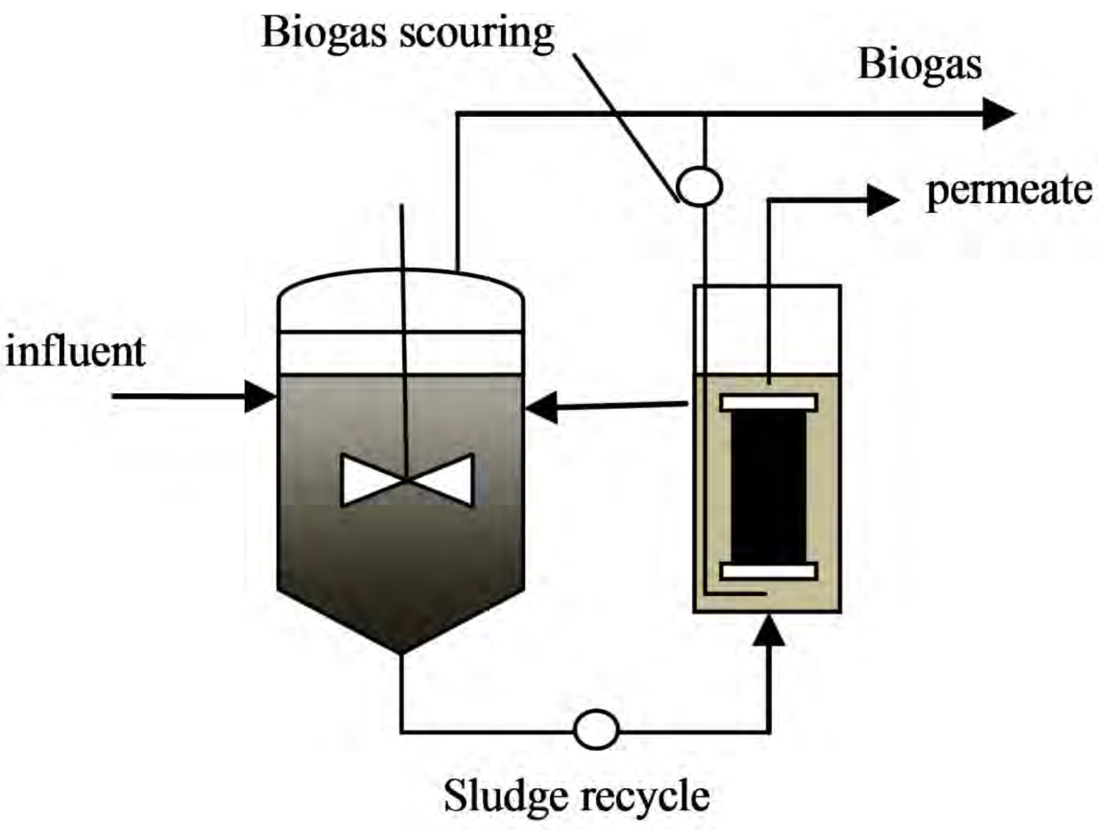
What we know from fouling… in a few words

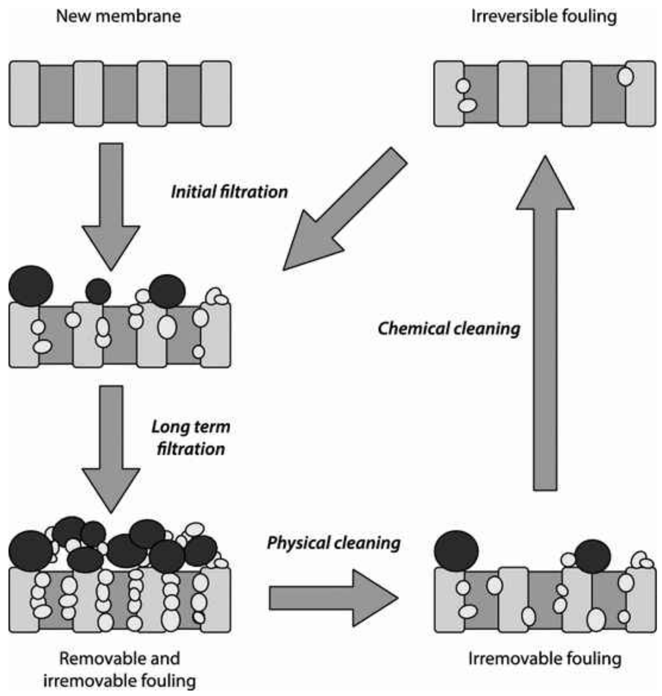


Advances in Chemical Engineering and Science
Vol.4 No.1(2014), Article ID:42423,6 pages DOI:10.4236/aces.2014.41008

WHAT IS FOULING?

- Process leading to deterioration of flux due to the surface or internal blockage of the membranes (Judd 2006).

Judd, S. (2006) *The MBR Book: Principles and Applications of Membrane Bioreactors in Water and Wastewater Treatment*. Elsevier, Amsterdam.



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What's important about fouling (I)

WHAT IS FOULING?

- Process leading to deterioration of flux due to the surface or internal blockage of the membranes (Judd 2006).

Judd, S. (2006) *The MBR Book: Principles and Applications of Membrane Bioreactors in Water and Wastewater Treatment*. Elsevier, Amsterdam.

- It's a **complex process**, with several causes that can be interlinked and **not always well understood**.

"There is no unified statement about the mechanisms of membrane fouling"

Du X, Shi Y, Jegatheesan V, Haq IU. A Review on the Mechanism, Impacts and Control Methods of Membrane Fouling in MBR System. Membranes. 2020; 10(2):24. https://doi.org/10.3390/membranes10020024

Modified from Flavita Banana

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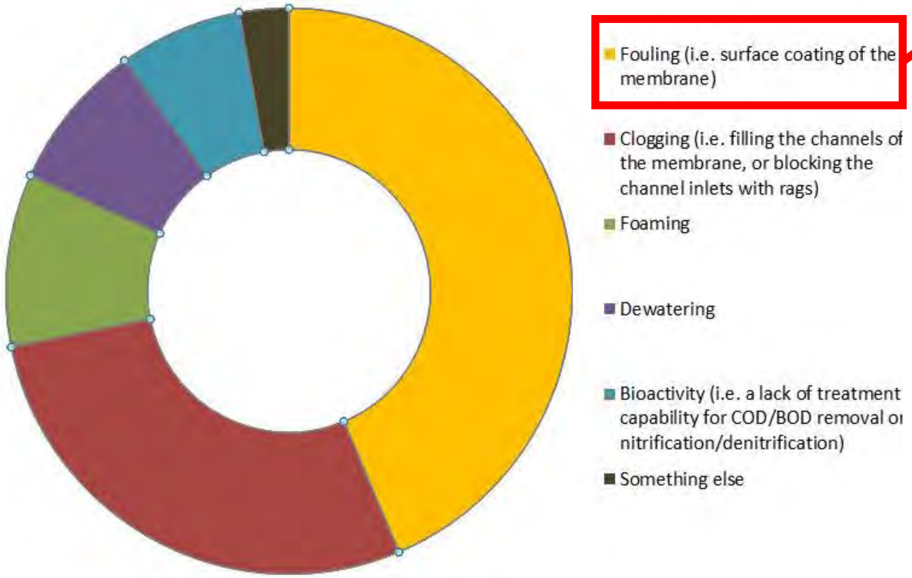
What's important about fouling (II)

- **It matters** to scientists and to operators.



Responses to the question: In your experience, what is the biggest challenge posed by MBR sludge?. Extracted from: https://www.thembrsite.com/features/the-2016-mbr-survey-results/

Another consequence of fouling

- Responsible for 40-50% of total specific energy consumed in submerged AeMBRs (Lousada-Ferreira, 2014).

Lousada-Ferreira M, Krzeminski P, Geilvoet S, Moreau A, Gil JA, Evenblij H, Van Lier JB, Van der Graaf JHJM. Filtration Characterization Method as Tool to Assess Membrane Bioreactor Sludge Filterability—The Delft Experience. Membranes. 2014; 4(2):227-242. https://doi.org/10.3390/membranes4020227

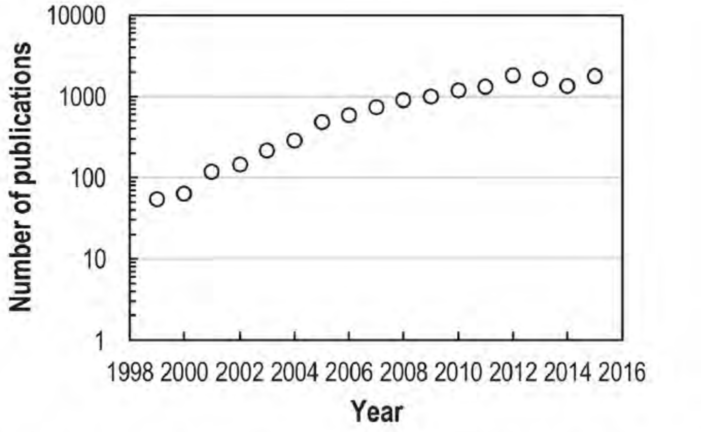


Fig. 1. The annual publications on MBR fouling (google scholar as literature database).

Cramer M, Kloth S, Tränckner J. Optimization and fouling mechanism of a thermophile submerged MBR (TSMBR) pilot plant for wastewater treatment in a paper mill, Journal of Water Process Engineering, Volume 17, 2017, Pages 110-116, https://doi.org/10.1016/j.jwpe.2017.02.008.

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Fouling indicators (I)

FOULING INDICATORS

- Other bulk classic parameters (OCR, SSV, SVI, CST, TTF…) or dead-end are debatable.
- **Sludge filterability** aims to represent the fouling propensity of sludge.

From: Lousada-Ferreira, M. Filterability and Sludge Concentration in Membrane Bioreactors; Technical University of Delft: Delft, The Netherlands, 2011.

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Fouling indicators (II)

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WATER SMART INDUSTRIAL SYMBIOSIS

Filtration test cells	**Delft Filtration Characterization Method (DFCm)**	ΔR_{20}	m^{-1}	Evenblij *et al.*(2006) Moreau *et al.* (2009)
	Berlin Filtration Method (BFM)	Critical flux	$L/(m^2h)$	de la Torre *et al.* (2009a; 2010) (this study)
	VITO Fouling Measurement (MBR-VFM)	VFM_{rev}	%	Huyskens *et al.* (2008; 2010)
	***Ex situ* test cell**	Critical flux	$L/(m^2h)$	Rosenberger *et al.* (2002) Schaller *et al.* (2006)
		Filtration resistance R	m^{-1}	

From: De la Torre T. The Quest for a Universal Indicator for MBR Fouling. Technischen Universität Berlin; Berlin, Germany: 2013

	$\Delta R_{20}[\times 10^{12} m^{-1}]$
Good	< 0.1
Moderate	0.1-1
Poor	>1

Table. ΔR_{20} values and corresponding MBR activated sludge filterability-for standard DFCm measuring protocol.

From: Geilvoet, S. The Delft Filtration Characterisation Method, Assessing Membrane Bioreactor Activated Sludge Filterability; Technical University of Delft: Delft, The Netherlands, 2010.

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Advantages of monitoring sludge filterability (I)

INTEREST FOR OPERATORS

- Optimization of operation (filtration, relaxation/backwash, gas or velocity demands…).
  - F.ex. During good filterability periods

  → prolong the filtration protocol
  → decrease SGDm
  → increase hydraulic performance
  → improve the energy efficiency.

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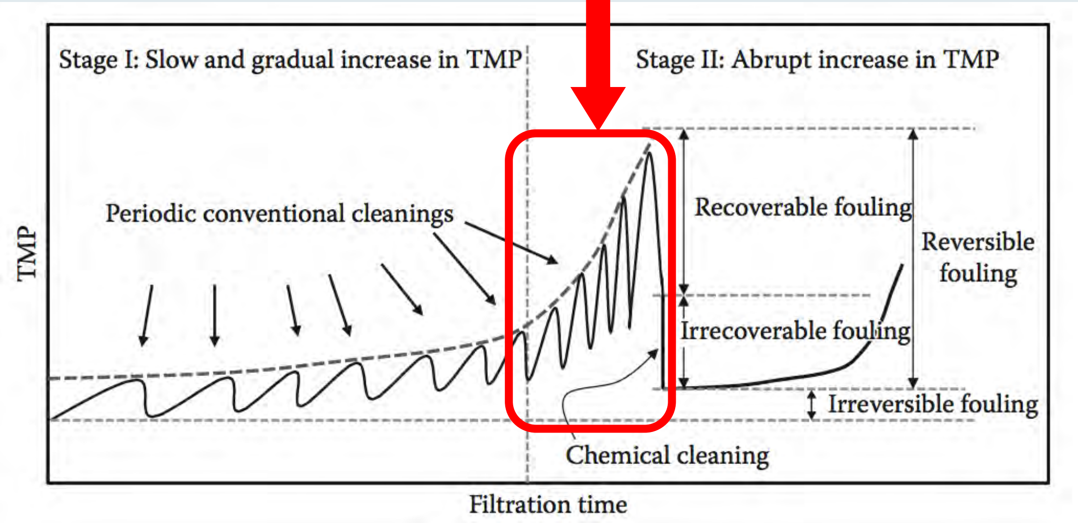
Advantages of monitoring sludge filterability (II)

INTEREST FOR OPERATORS

- Optimization of operation (filtration, relaxation/backwash, gas or velocity demands…).
- Identify the need of physical or chemical cleanings (= only when necessary) → minimize chemical consumption and exposure to membranes
- Early warning system for operators in case of bad sludge filterability
  → change in operation conditions in order to avoid excessive fouling.
  → look for causes / check disruptions (overload, bad mixing, presence of inhibitors…).



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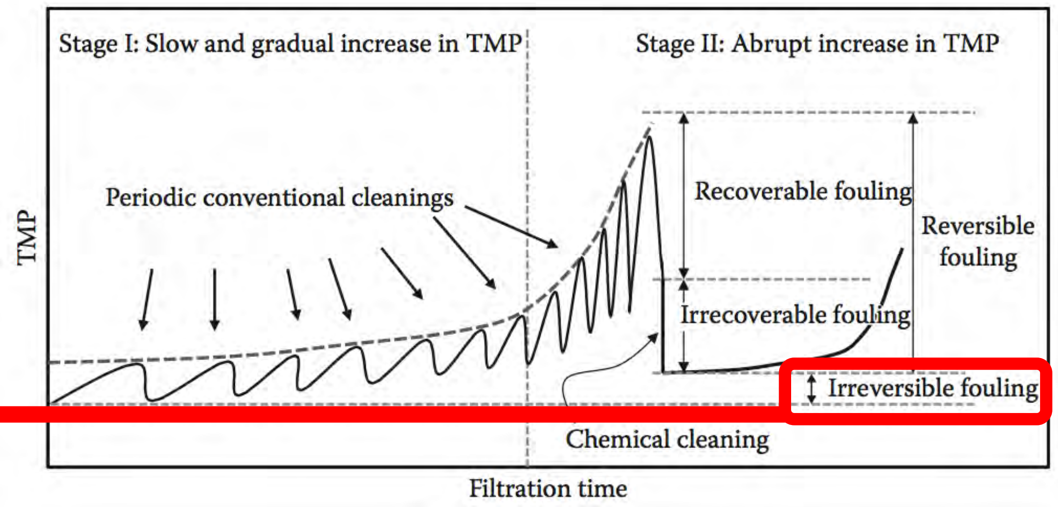
Advantages of monitoring sludge filterability (III)

INTEREST FOR OPERATORS

- Optimization of operation (filtration, relaxation/backwash, gas or velocity demands…).
- Identify the need of physical or chemical cleanings (= only when necessary) → minimize chemical consumption and exposure to membranes
- Early warning system for operators in case of bad sludge filterability
  → change in operation conditions in order to avoid excessive fouling.
  → look for causes / check disruptions (overload, bad mixing, presence of inhibitors…).
- Irreversible fouling can be estimated.



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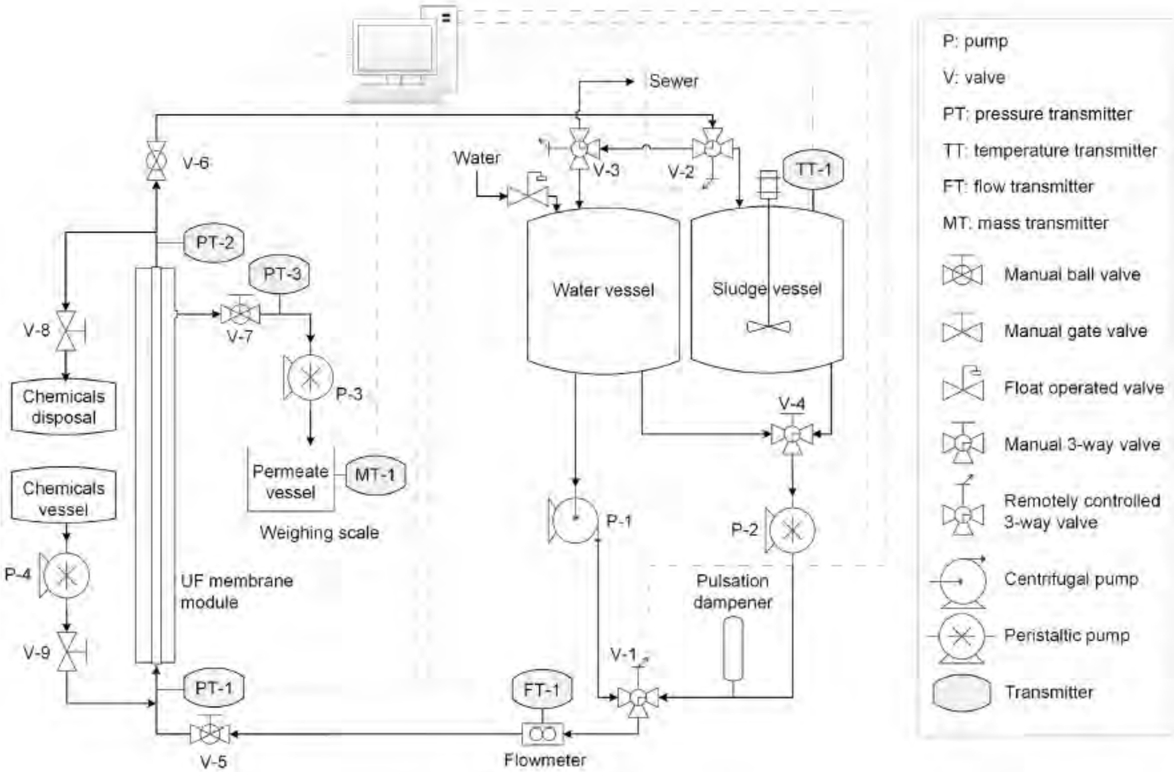
How we will do that? (I)

- Build & commissioning of the plant
  - Mobile (ex-situ), plug&play
  - Automatic
  - Integrable to SCADA



Odriozola M, Lousada-Ferreira M, Spanjers H, van Lier JB (2021). Effect of sludge characteristics on optimal required dosage of flux enhancer in anaerobic membrane bioreactors. Journal of Membrane Science 619 (2021) 118776

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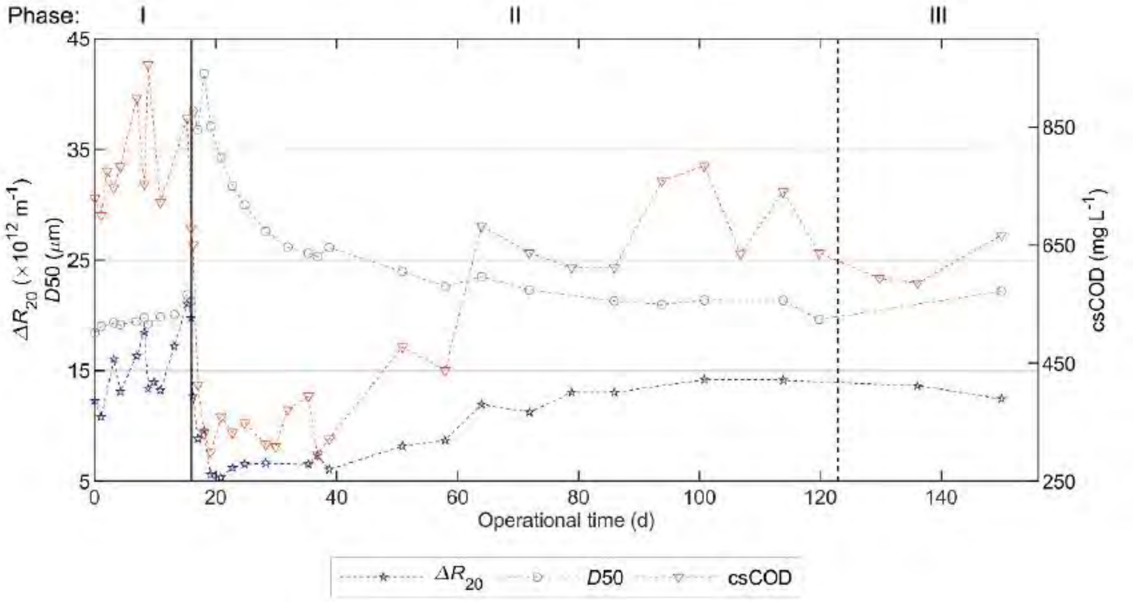
How we will do that? (II)

- Build & commissioning of the plant
    - Mobile (ex-situ), plug&play
    - Automatic
    - Integrable to SCADA
- Measure of ΔR_{20} in AnMBR in CS5
    - Correlate to permeability (K_{20}), SGD_m and other operating & analytical parameters
    - Compare with / without MB-MBR configuration
    - Procedures for operation optimization. Adapt to functioning logic.
    - Membrane screening / autopsy



Odriozola M, Morales N, Vázquez-Padín JR, Lousada-Ferreira M, Spanjers H, van Lier JB. Fouling Mitigation by Cationic Polymer Addition into a Pilot-Scale Anaerobic Membrane Bioreactor Fed with Blackwater. Polymers. 2020; 12(10):2383. https://doi.org/10.3390/polym12102383

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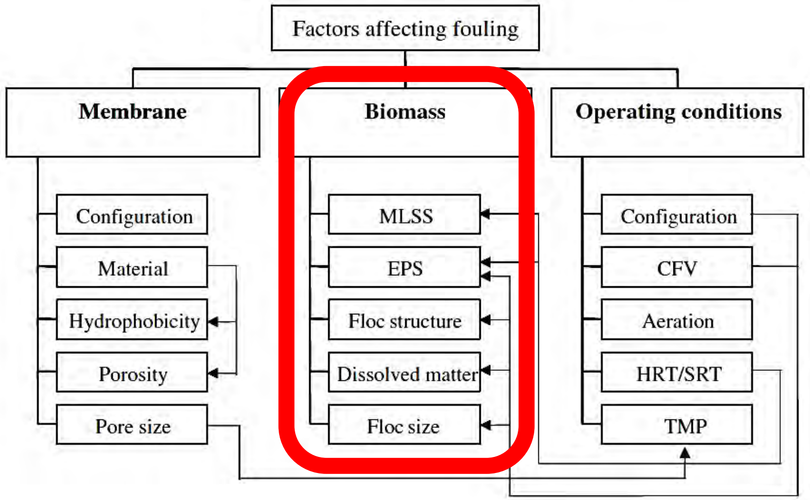
MBR + adsorbents → better filterability (I)

A way to improve biomass characteristics: add adsorbents, like activated carbon or biochar

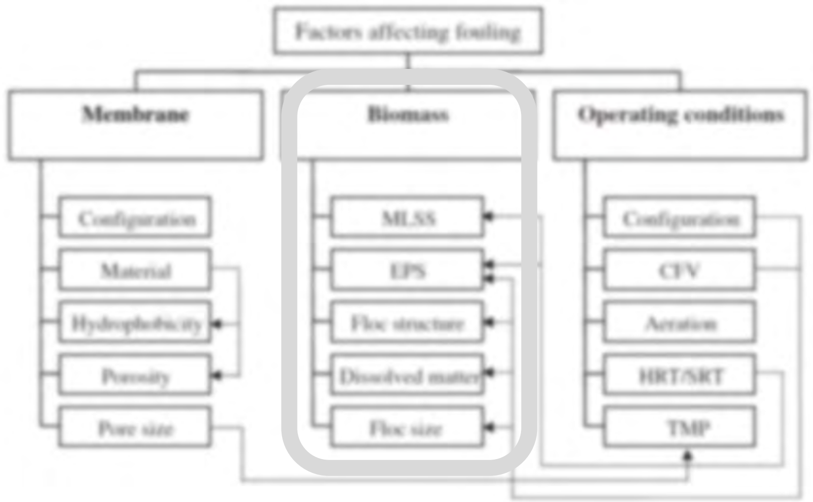


Chang, I.S., Le-Clech, P., Jefferson, B. and Judd, S.J. (2002). Membrane fouling in membrane bioreactors for wastewater treatment, Environ. Eng. Sci., 128(11), 1018-1029)

The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

MBR + adsorbents → better filterability (II)

A way to improve biomass characteristics: add adsorbents, like activated carbon or biochar

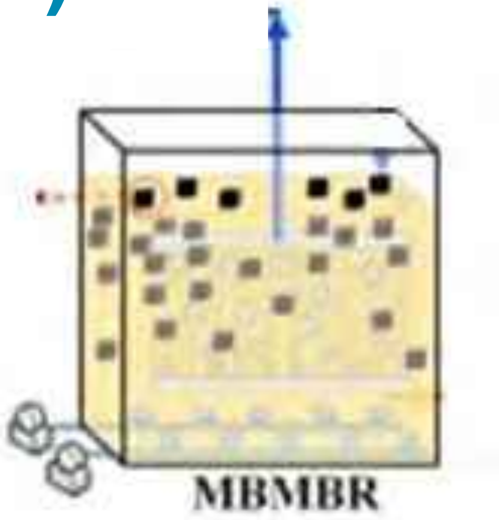


WHY ADD ACTIVATED CARBON IN A MBR?

- Floc size increase
- Adsorption of soluble microbial products
- Micro-pollutant adsorption

EXPECTED RESULTS:

- Increase process stability
- Improvement of filterability
- Decrease of fouling propensity
- Increased filtration capacity
- Decrease of aeration needs
- Decrease of chemical cleanings
- Increase of membrane lifetime
- Decrease of membrane replacement
- Decrease energy expenditure



MBMBR =
Moving Bed Membrane Bioreactor.

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Valorastur project: tested MBR + biochar

AeMBR configuration vs. **MB-AeMBR configuration**

AeMBR configuration	MB-AeMBR configuration
Mean permeated volume between CIPs: **9900 L**	Mean permeated volume between CIPs: **12375 L**
Consumed NaClO: 0.23 $g \cdot m^2_{membrane} \cdot$ treated m^{-3}	Consumed NaClO: 0.19 $g \cdot m^2_{membrane} \cdot$ treated m^{-3}

→ 25 % more permeated volume between CIPs

→ 17% less NaClO consump-tion

Conditions:

- Set-point TMP 250 mbarg
- $[NaClO]_{CIP}$ = 0.5 $g \cdot L^{-1}$

VALORASTUR

On behalf of the Programa RIS3-Empresa. Co-financed by:

PCTI ASTURIAS

Gobierno del Principado de Asturias

IDEPA Instituto de Desarrollo Económico del Principado de Asturias

Unión Europea
Fondo Europeo de Desarrollo Regional

More Info about Valorastur: https://www.aqualia.com/documents/14152670/14224452/6.+Ongoing+projects+-+Valorastur.pdf/eff63070-60f5-7f16-812c-ca3632f1aec1?t=1545234235000

The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

CS5 Lleida: Development and implementation of an early warning system for membrane fouling

A. Giménez-Lorang

aqualia

20.05.2021 CS meeting on “Digitalization”

CS9: Development of a joint control system for an industrial and a municipal WWTP

A. Kleyböcker, L. Rodenkam Melchiorsen, J. Schütz, L. Lundgaard, S. Bendix Larsen

CS9 in Kalundborg (Denmark)

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Horizon 2020 research and innovation programme under grant agreement No 869318

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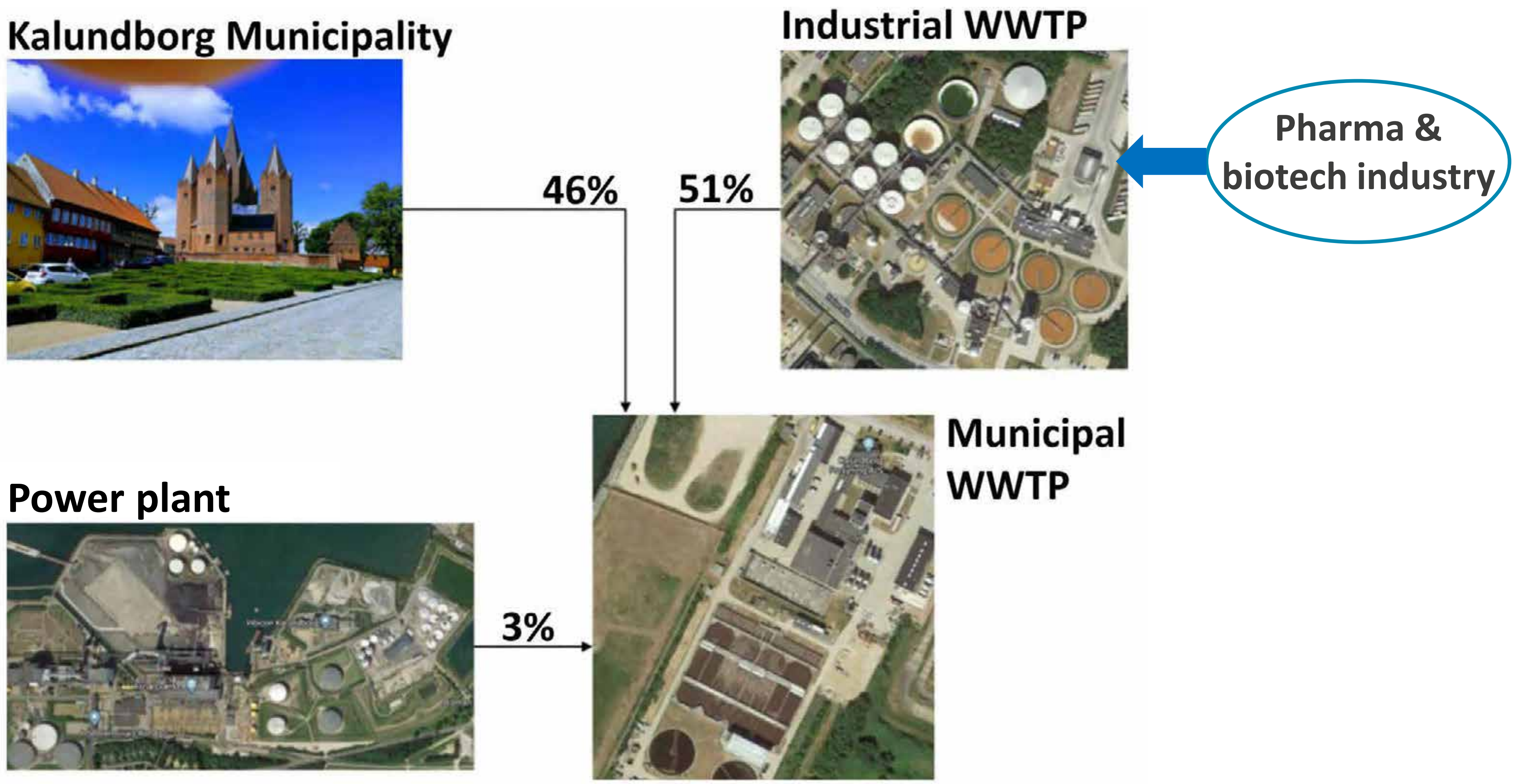
Situation at the start of Ultimate



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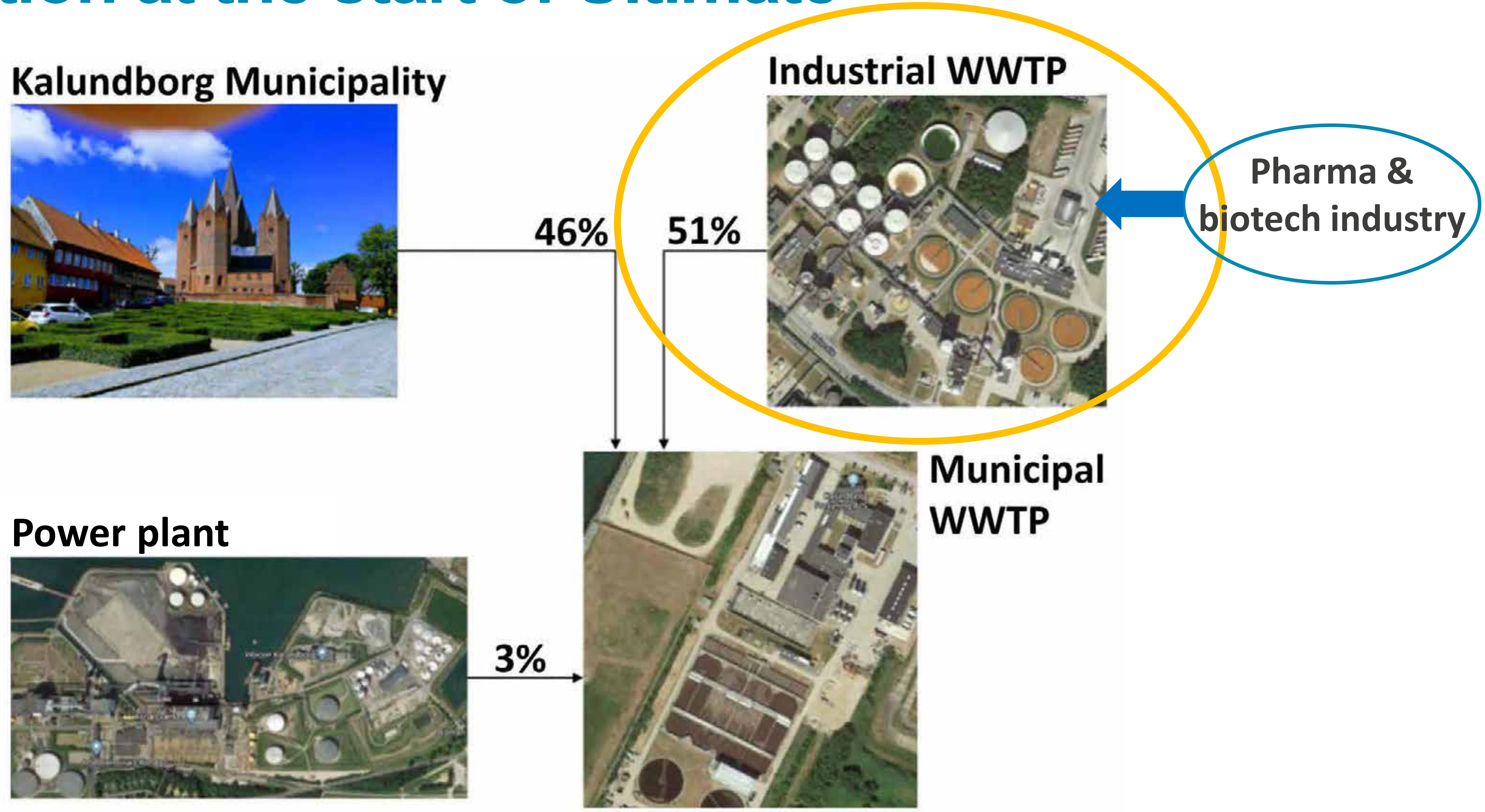
Situation at the start of Ultimate



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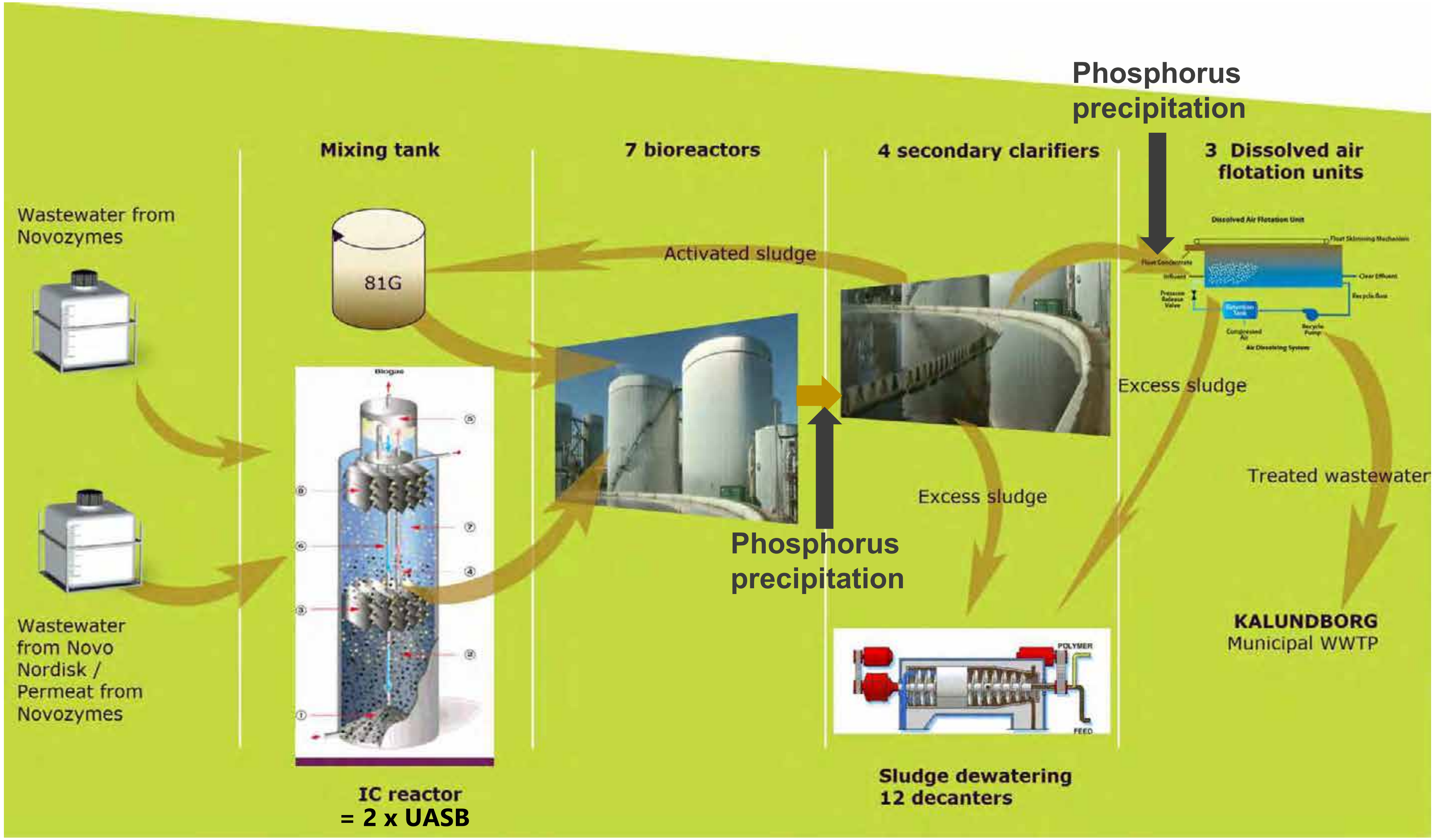
Industrial wastewater treatment plant:
own control system & chemical phosphorus removal



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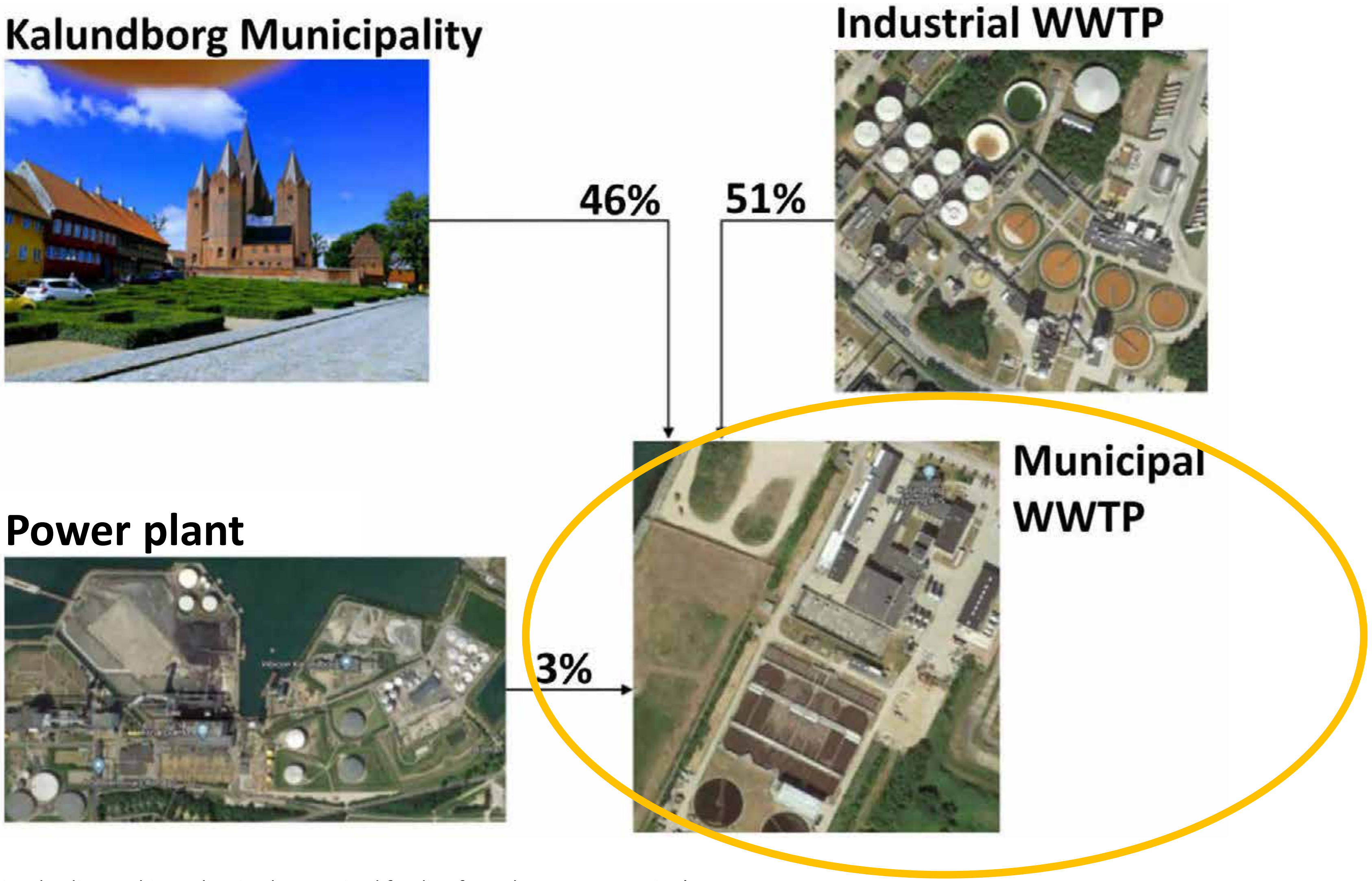

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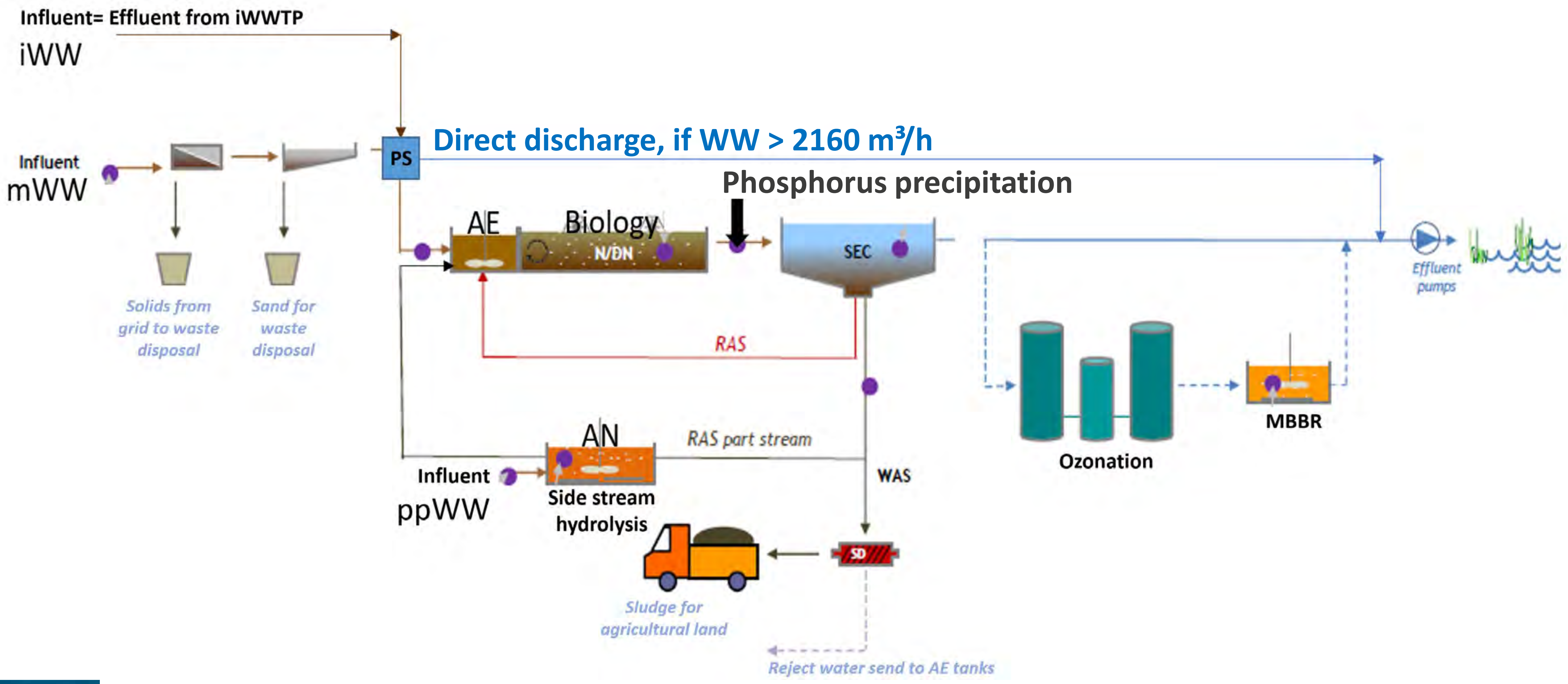
Municipal wastewater treatment plant:
own control system & chemical phosphorus removal



Joint Control System

Objective:

Reduce energy consumption

→ Predictive controlled nitrogen elimination (O_2 concentration as low as possible via predicting NH_4, NO_3, TN and COD loads to the municipal WWTP)

Options:

Reduce chemicals consumption for phosphorus elimination

→ Change to enhanced biological phosphorus removal

Reduce direct discharges to recipient

→ iWWTP = hydraulic buffer during high loading situations

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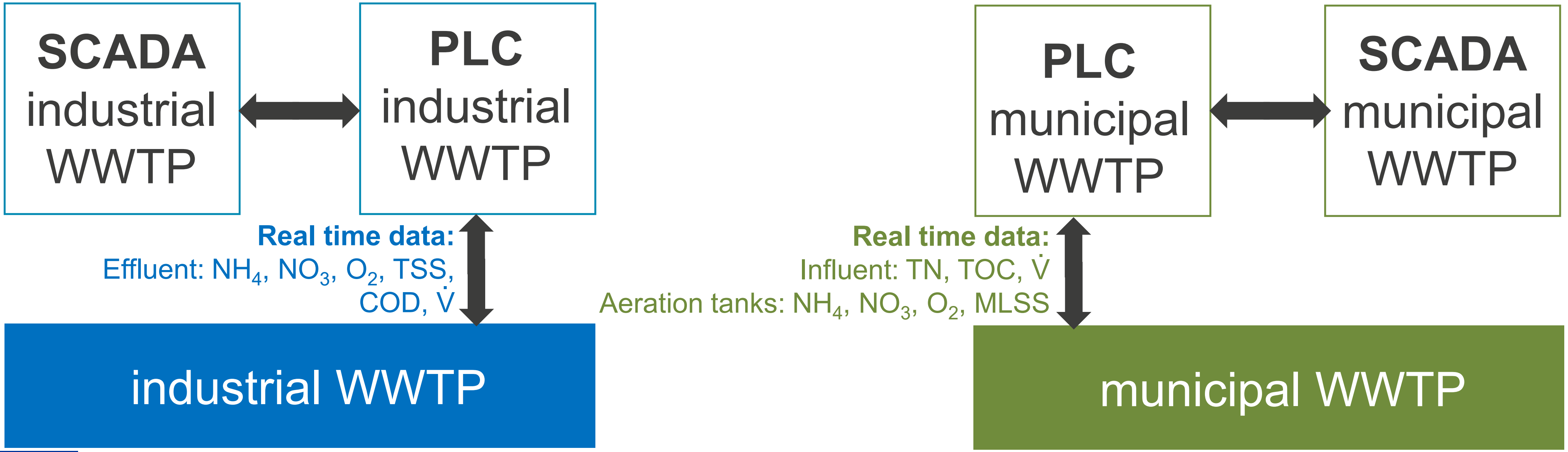
Joint Control System

SCADA	**Supervisory Control and Data Acquisition**
RTU	**Remote Terminal Unit**
PLC	**Programmable Logic Controller**
WWTP	**Wastewater Treatment Plant**



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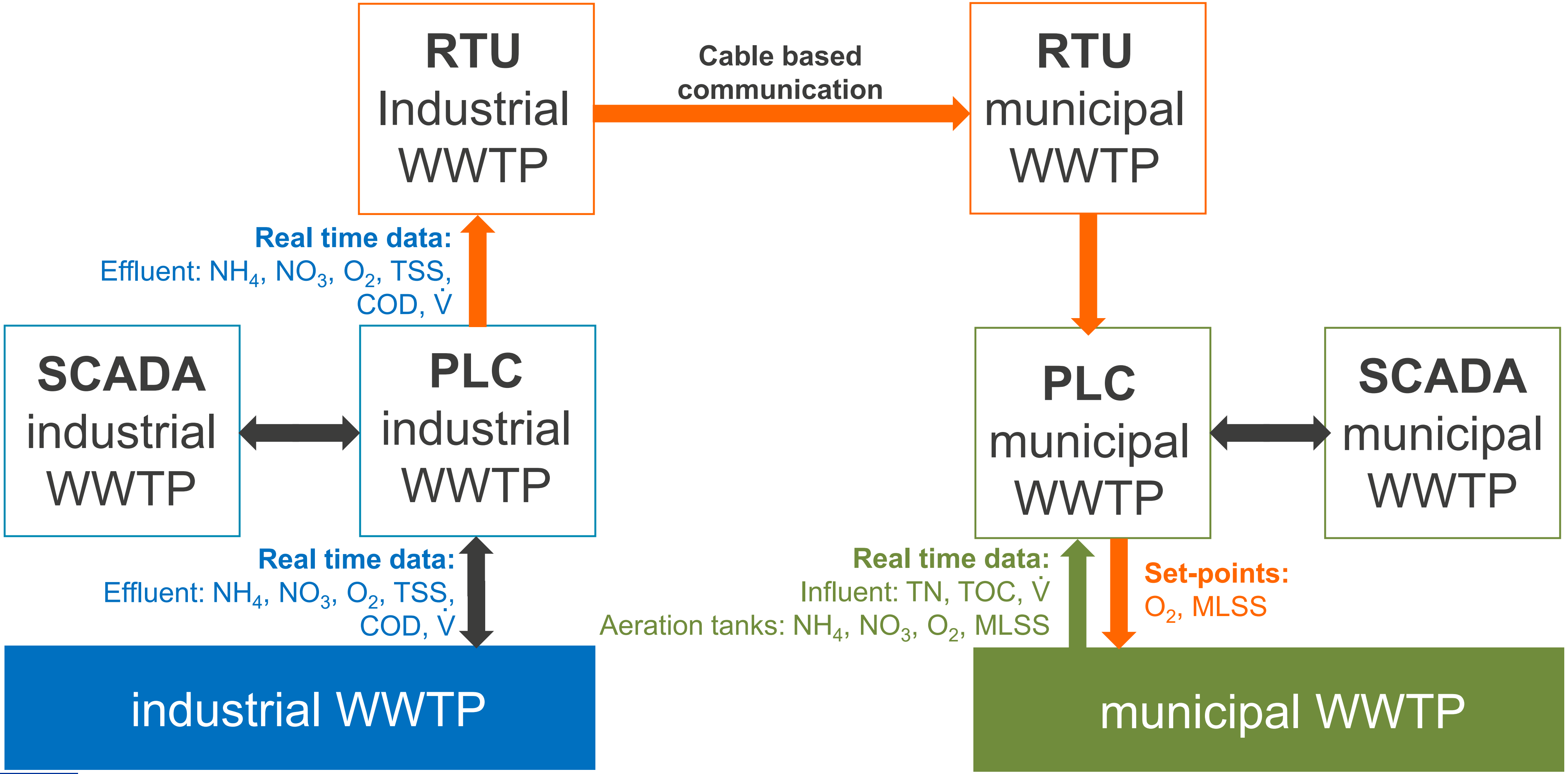

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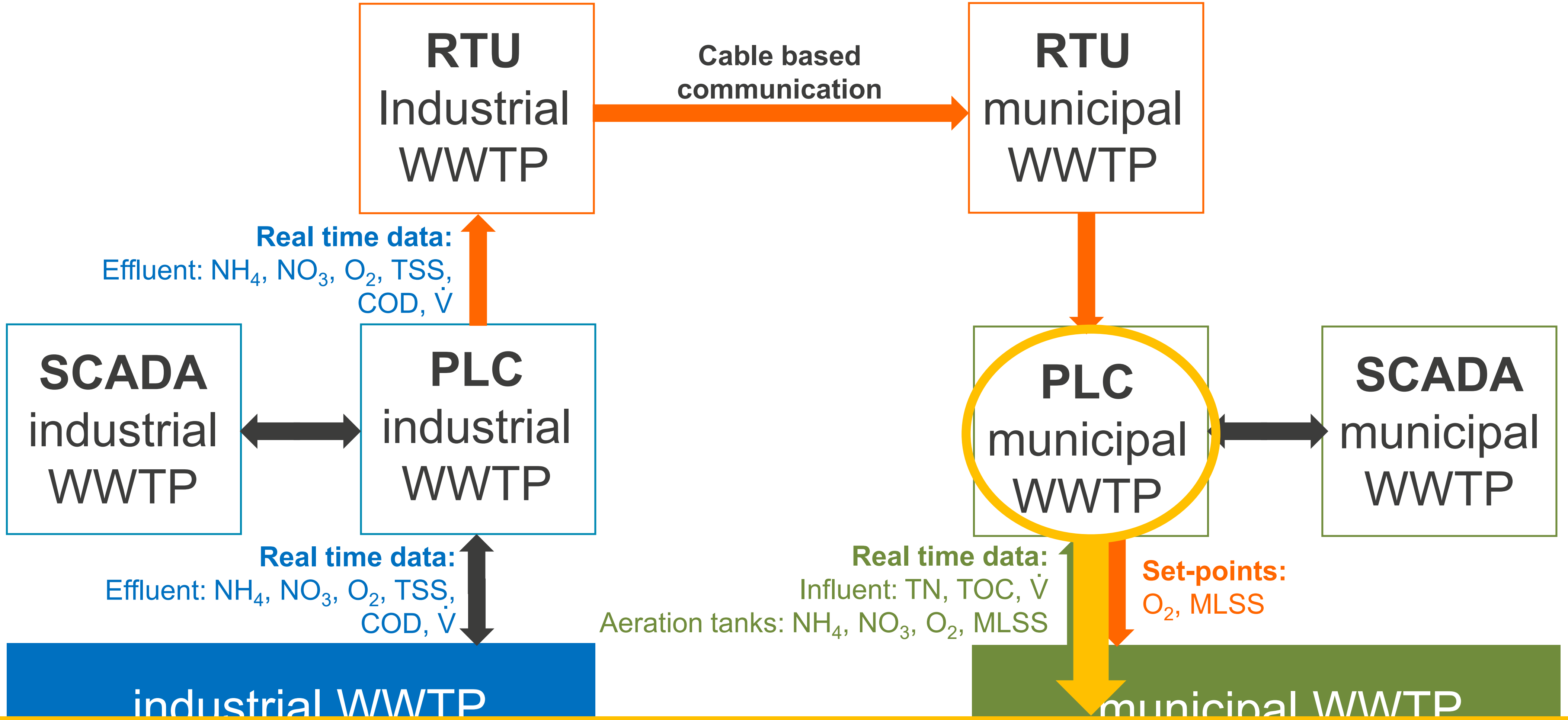

Which functions have to be implemented to generate the right set-points?

Development of functions and test via digital twin

via software:

→ Challenge: wastewater results not only from municipality, but also from industry
→Functions for modelling have to adapted

The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

Development of digital twin:

High quality data required to gain reliable results from modelling

Fractioning

- Influent mWW ✓
- Influent iWW ✓
- Influent mixed WW ✓

Steady state modelling with standard blocks

- Variation: different set-ups ✗
- Balancing of COD, TSS, ✓
- Balancing of N and P ✗
- Comparison between model results and measurement ✓
- Simple aeration model ✓
- Simple precipitation model ✓
- Calibration of the model ✗
- Validation of the model ✗

Improved model

- Dynamic model
- Improved aeration model
- Improved precipitation model
- Improved control-concept
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Digital twin

- Final set-up
- Improved model

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Data generation and management

- Evaluation of historical process data (online & routine measurements)

ADDITIONAL:

- Measuring campaigns to determine diurnal variations (influents to the mWWTP, to the conventional activated sludge dichtes and effluent of mWWTP)
- Phosphate release experiments
- Installation of new multi-sensors for real time data

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Measuring campaign to determine the diurnal variation

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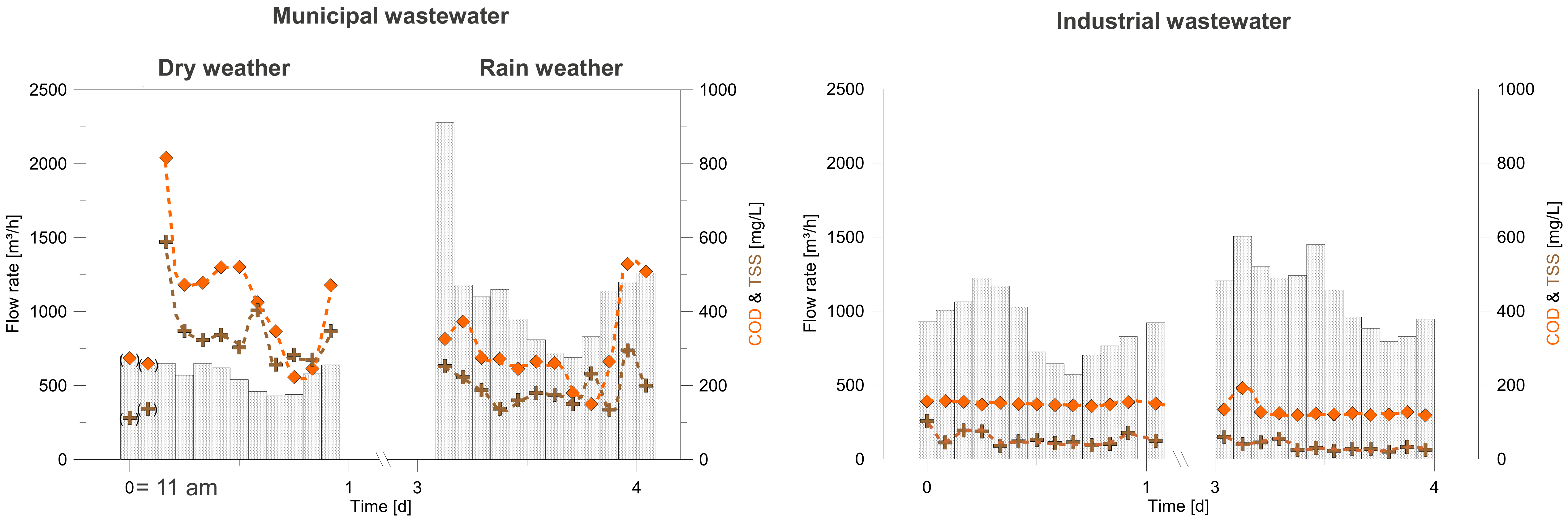
Measuring campaign to determine the diurnal variation
Chemical oxygen demand & Total suspended solids



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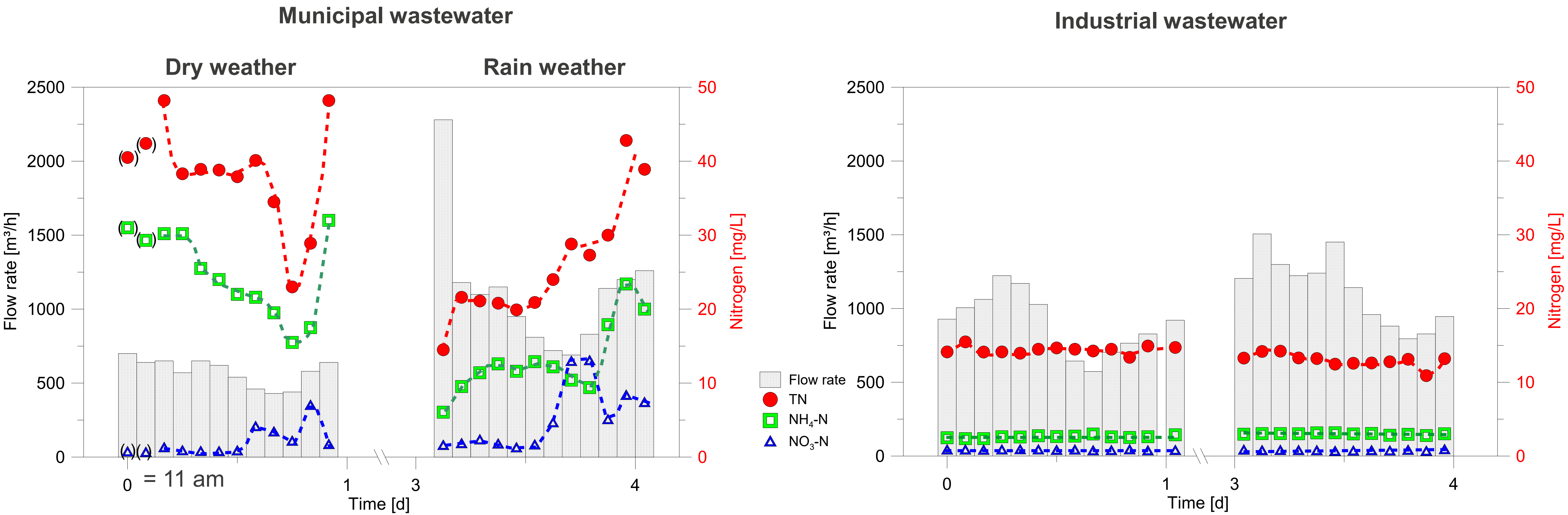
Measuring campaign to determine the diurnal variation
Total nitrogen, Ammonium, Nitrate



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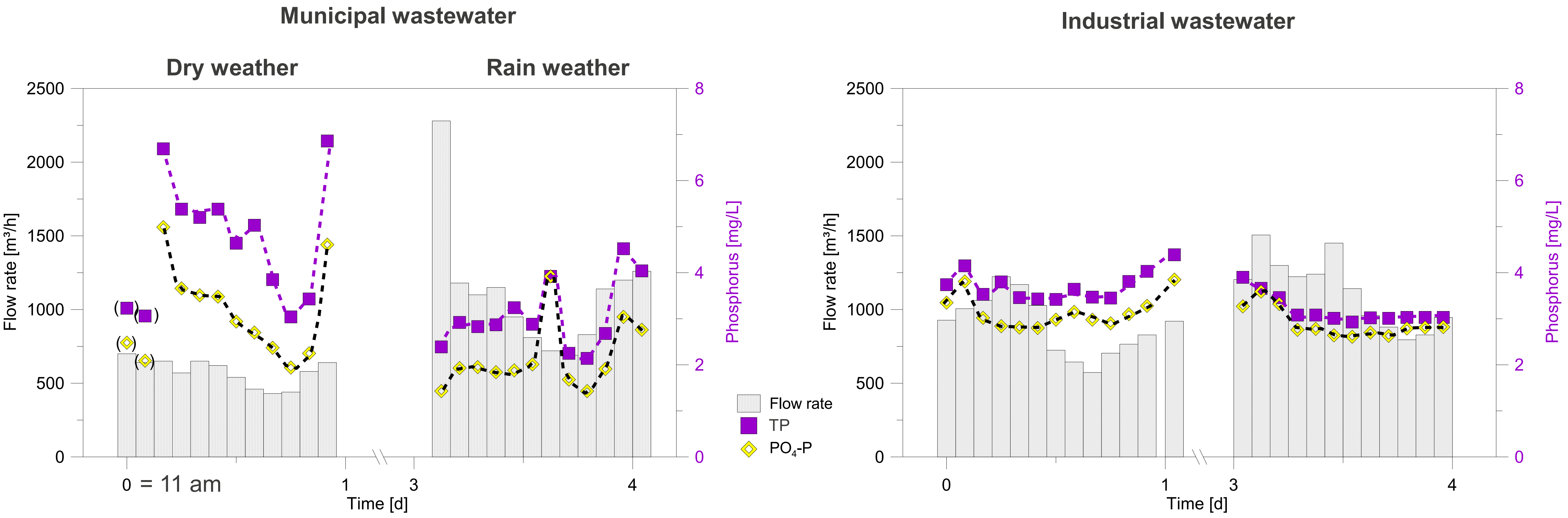
Measuring campaign to determine the diurnal variation
Total phosphorus & Phosphate



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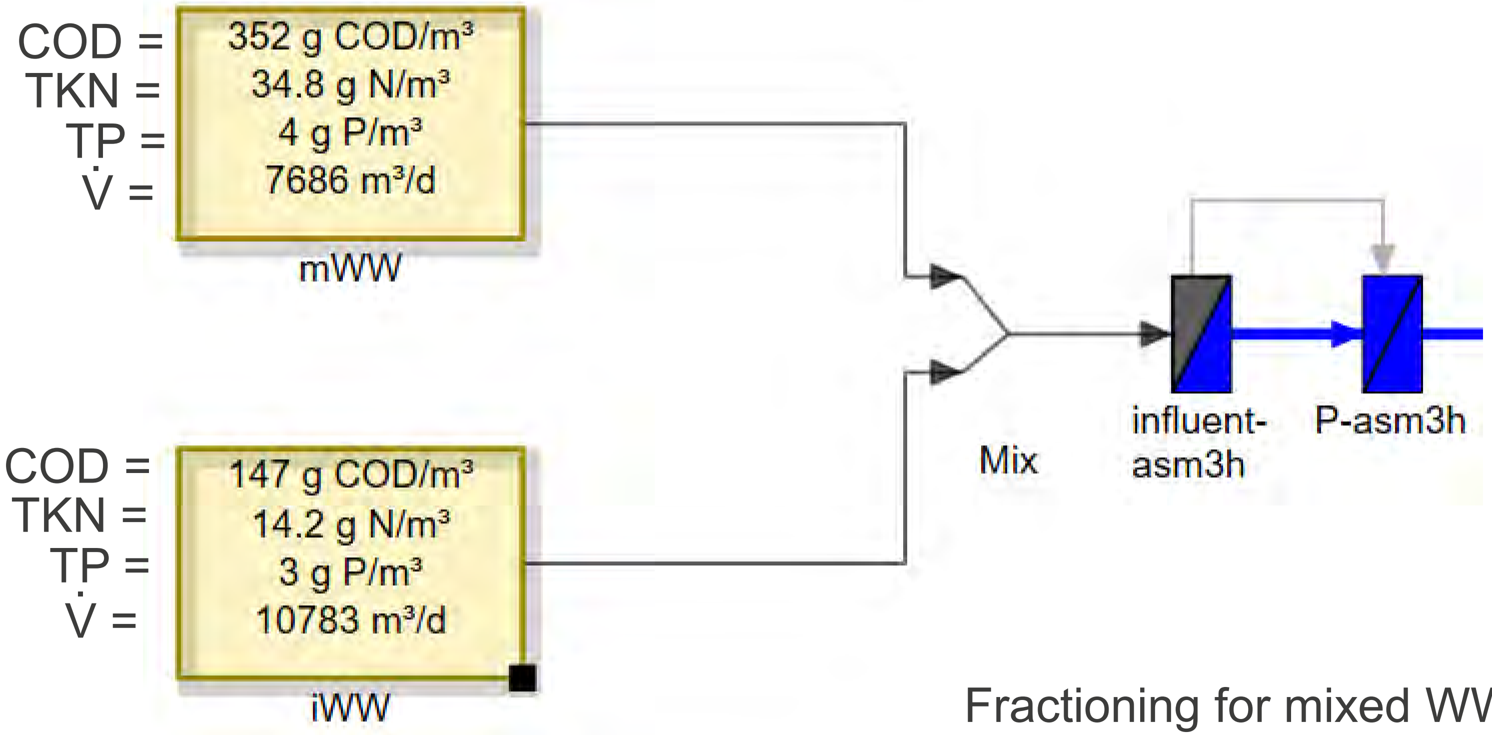
Modelling: Fractioning parameter



Symbol	Calc.
C_{COD}	= 232 mg/l
X_{SS}	= 132 mg/l
$S_{COD,inert}$	= 50 mg/l
$X_{anorgSS}$	= 35 mg/l
X_{COD}	= 151 mg/l
S_{COD}	= 81 mg/l
$X_{COD,inert}$	= 106 mg/l
C_{BOD}	= 76 mg/l

Fractioning for mixed WW:

$\boldsymbol{f_S}$ **= 0.215**

$\boldsymbol{f_B}$ **= 0.265**

$\boldsymbol{f_A}$ **= 0.70**

ratio of COD to VSS = **1.56** g COD /(g TSS)

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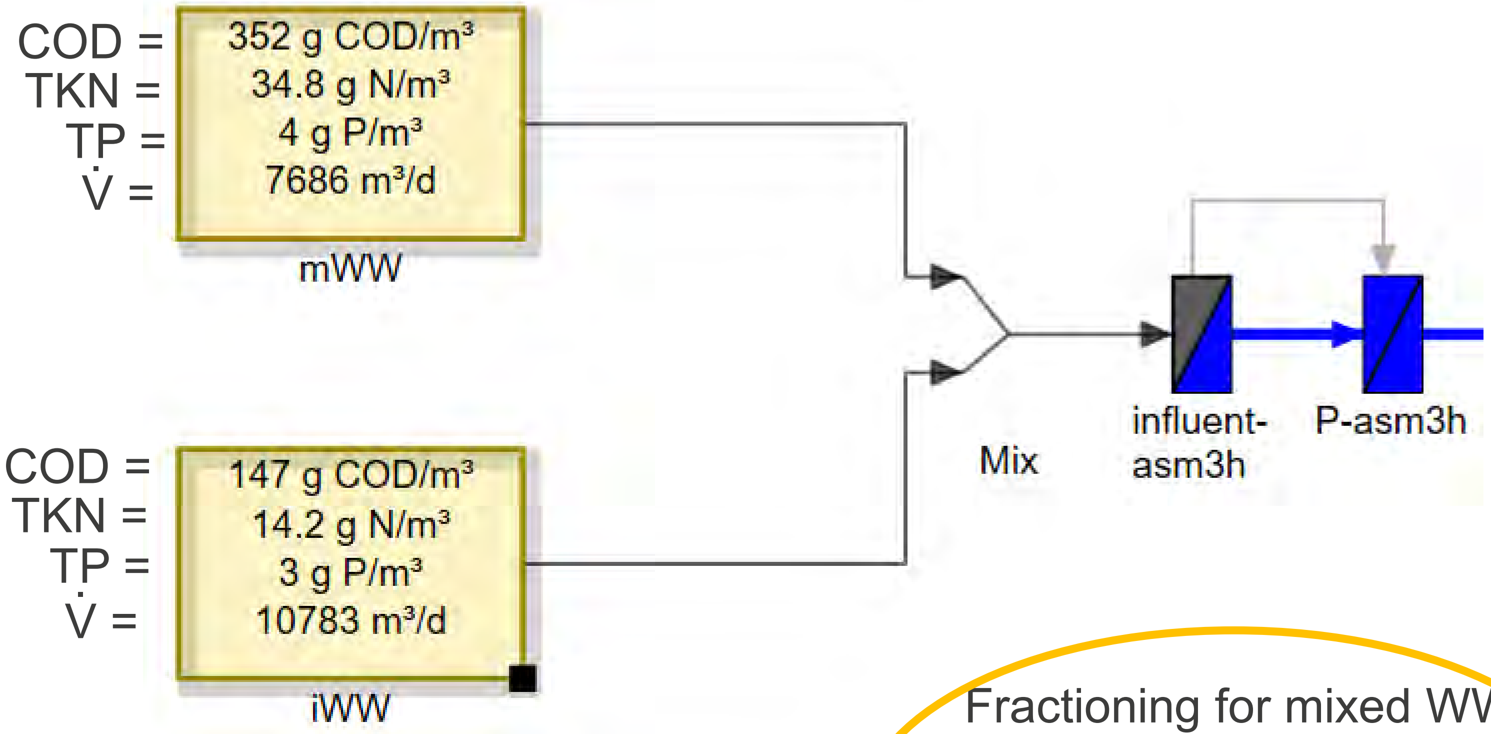

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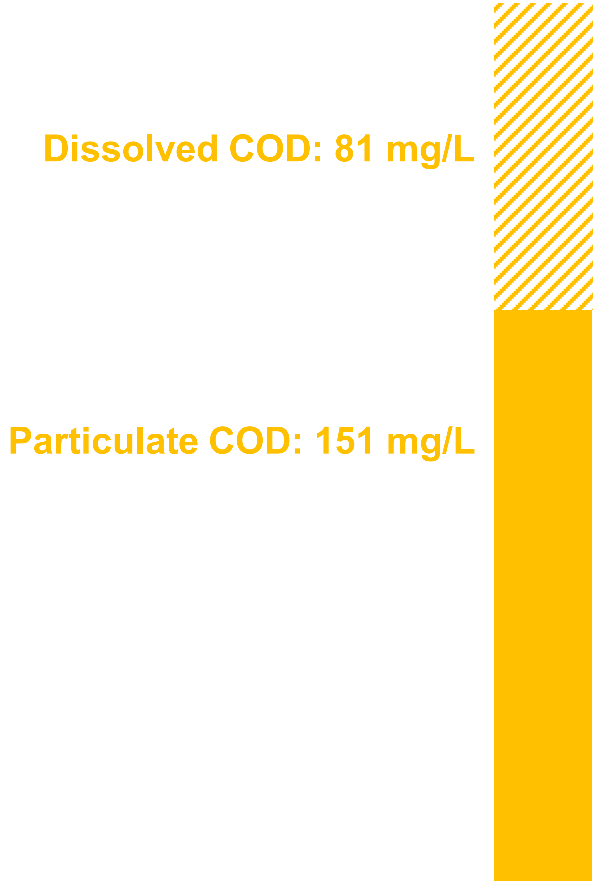
Fractioning of the influent mix: municipal & industrial WW

What do those factors mean?

f_S = **0.215**
f_B = **0.265**
f_A = **0.70**



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25

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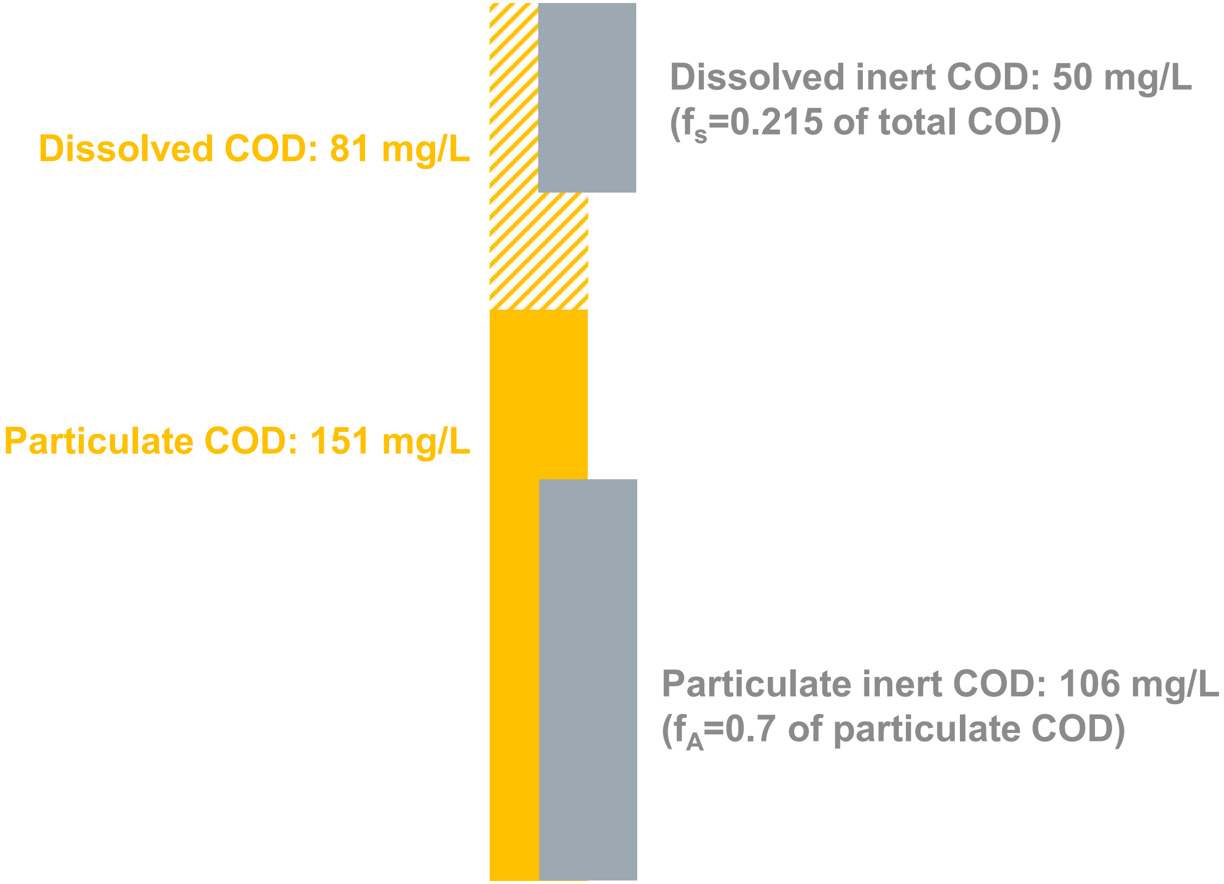

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26

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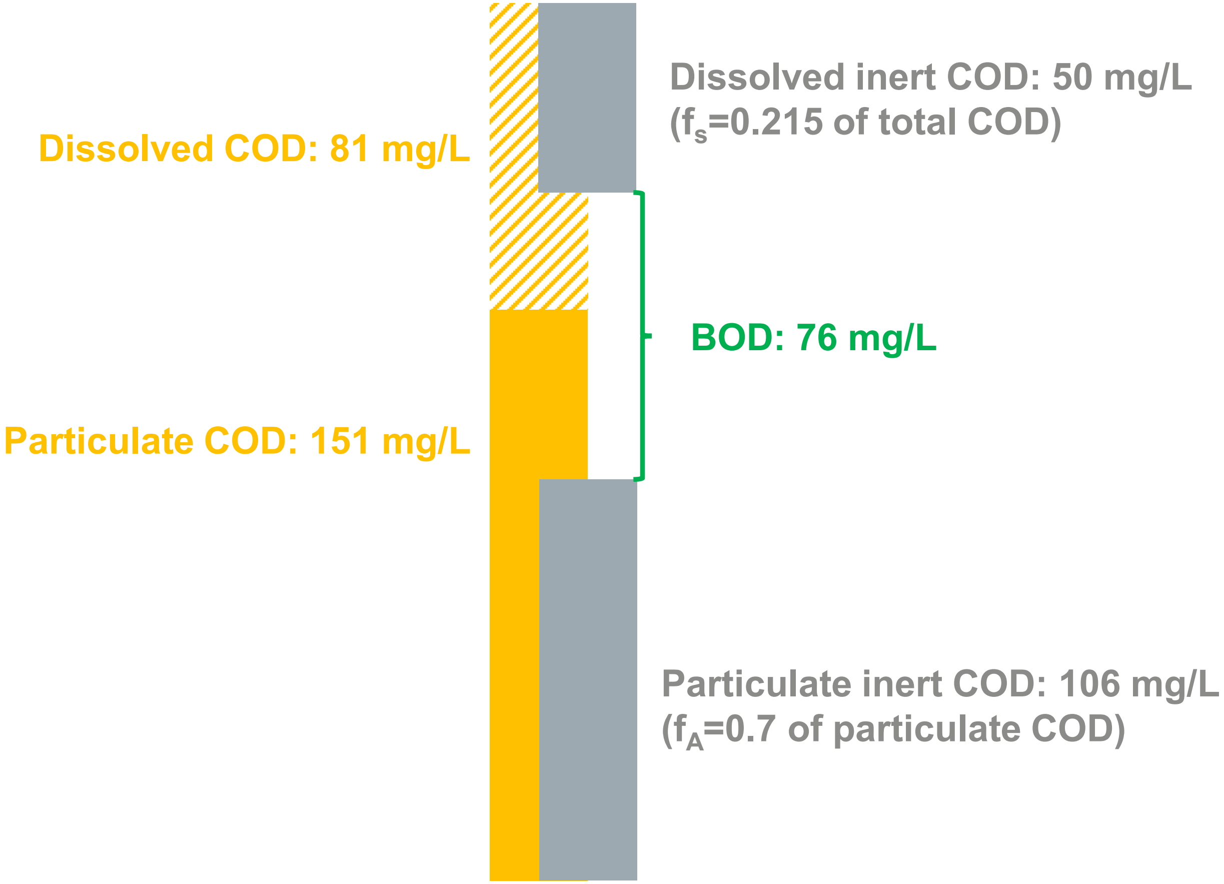

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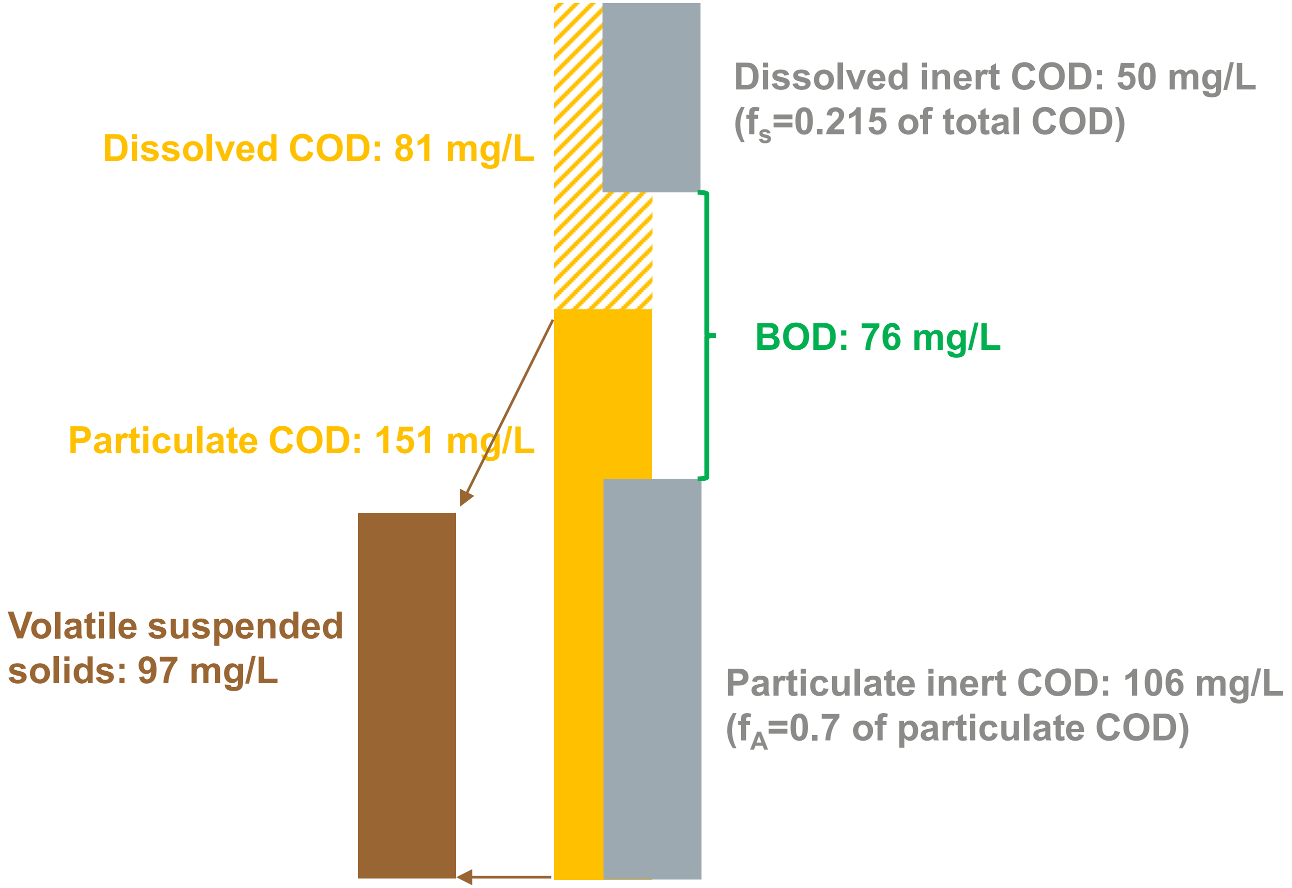

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28

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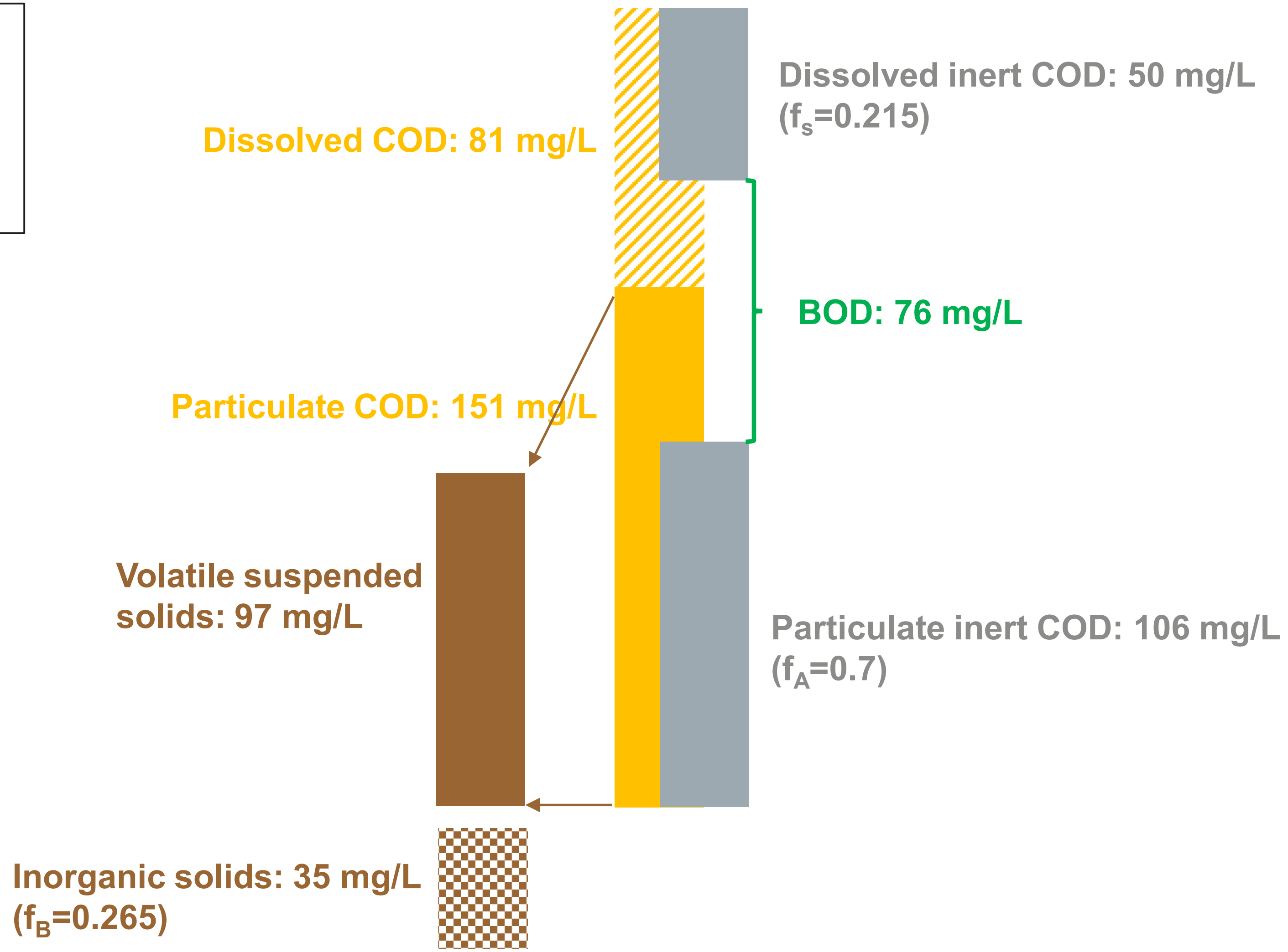

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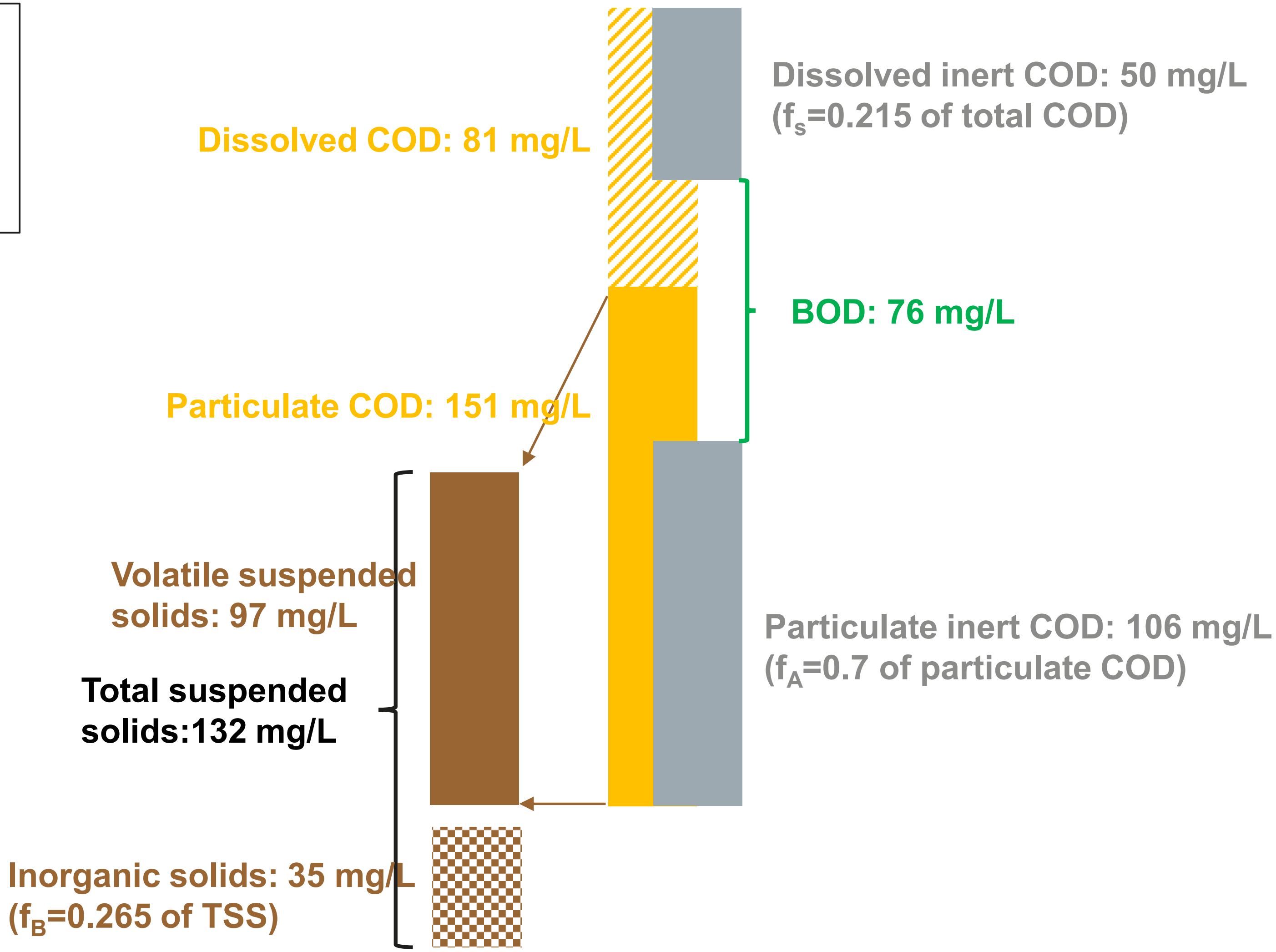

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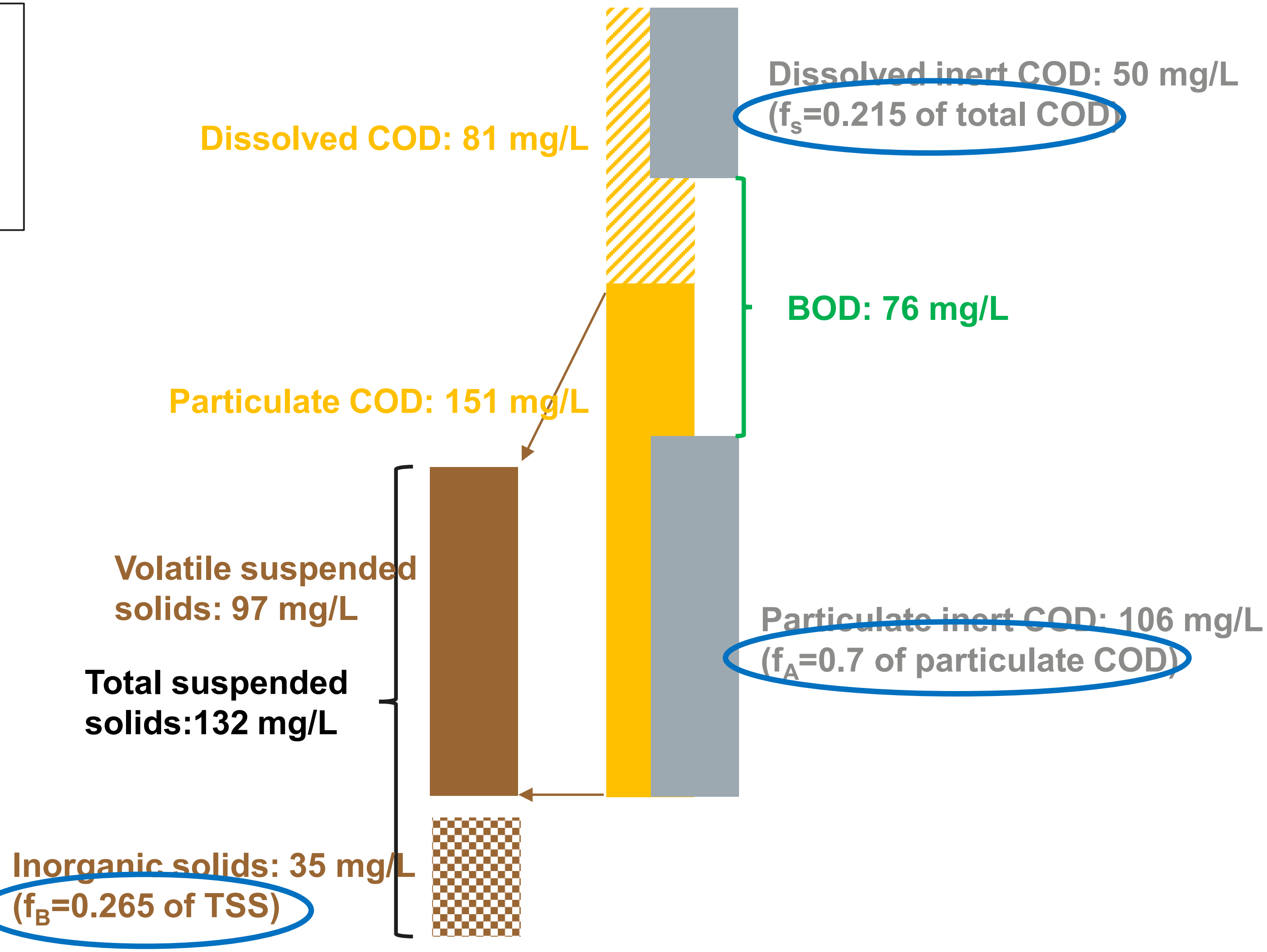

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31

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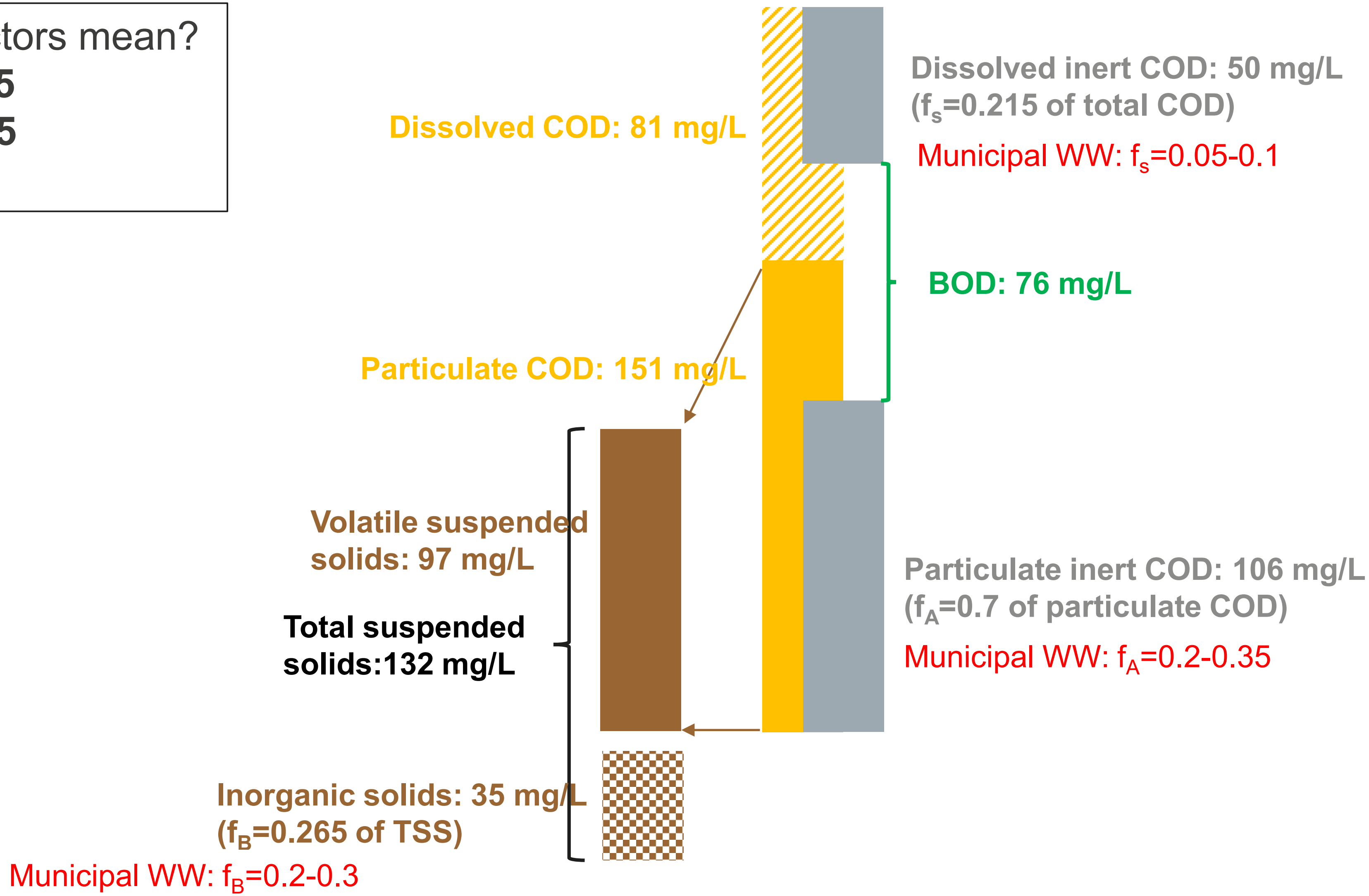

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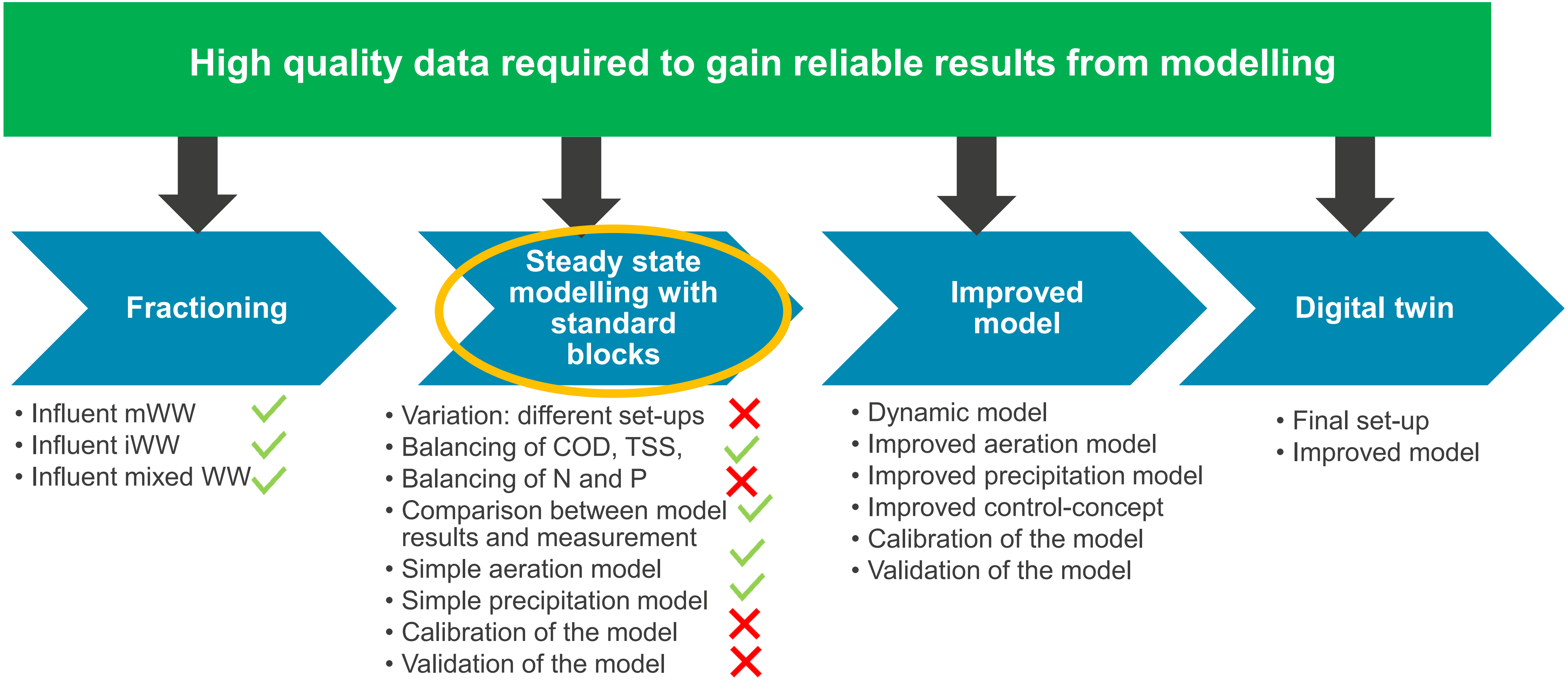
32

Development of digital twin:



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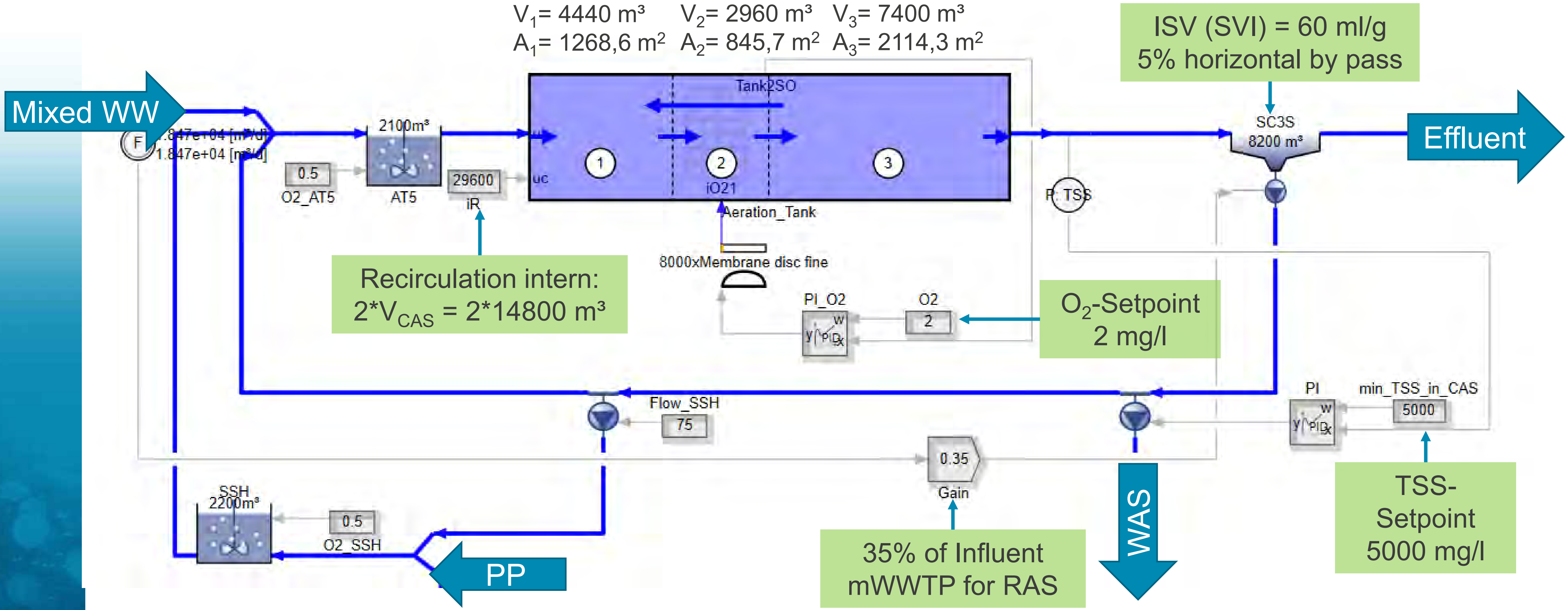
Modelling: #SIMBA Model-Overview Basic Set-UP 1



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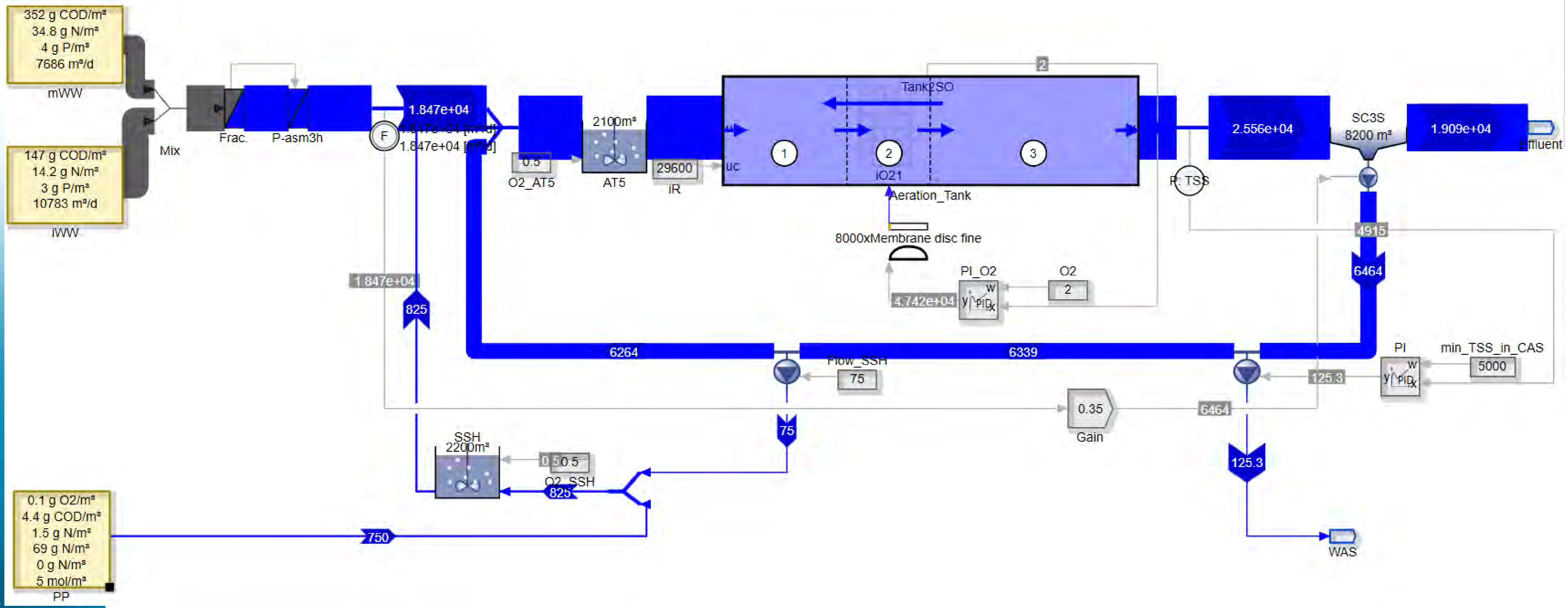
Modelling: #SIMBA - Flow [m³/d]



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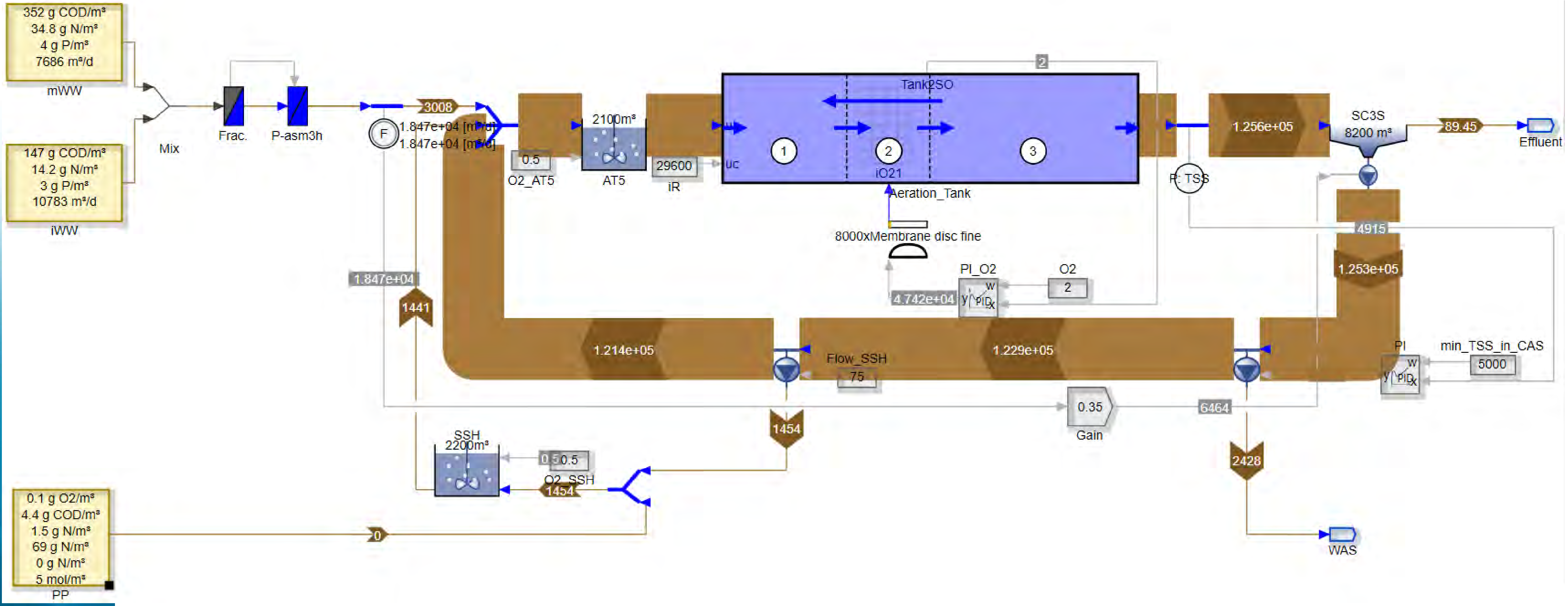
Modelling: #SIMBA - Total suspended solids [g/d]



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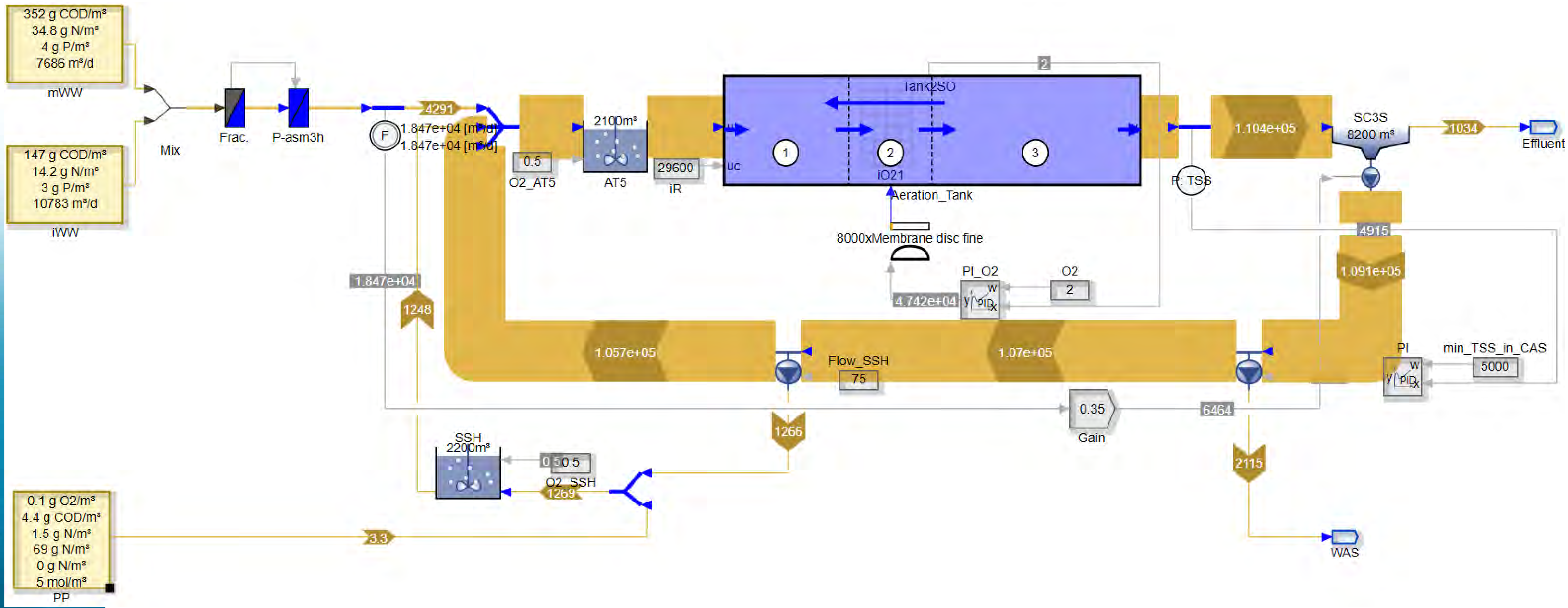
Modelling: #SIMBA – Chemical oxygen demand [g/d]



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Digital twin

- Final set-up
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Thank you for your attention!

Contact:

Anne Kleyböcker <anne.kleyboecker@kompetenz-wasser.de>

Line Rodenkam Melchiorsen <lirm@kalfor.dk>

Lars Lundgaard <lalu@kalfor.dk>

Sille Bendix Larsen <SBXL@novozymes.dk>

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digital-water.city

Leading urban water management to its digital future

H2020 innovation action | 5 M€ funding

2019-2022

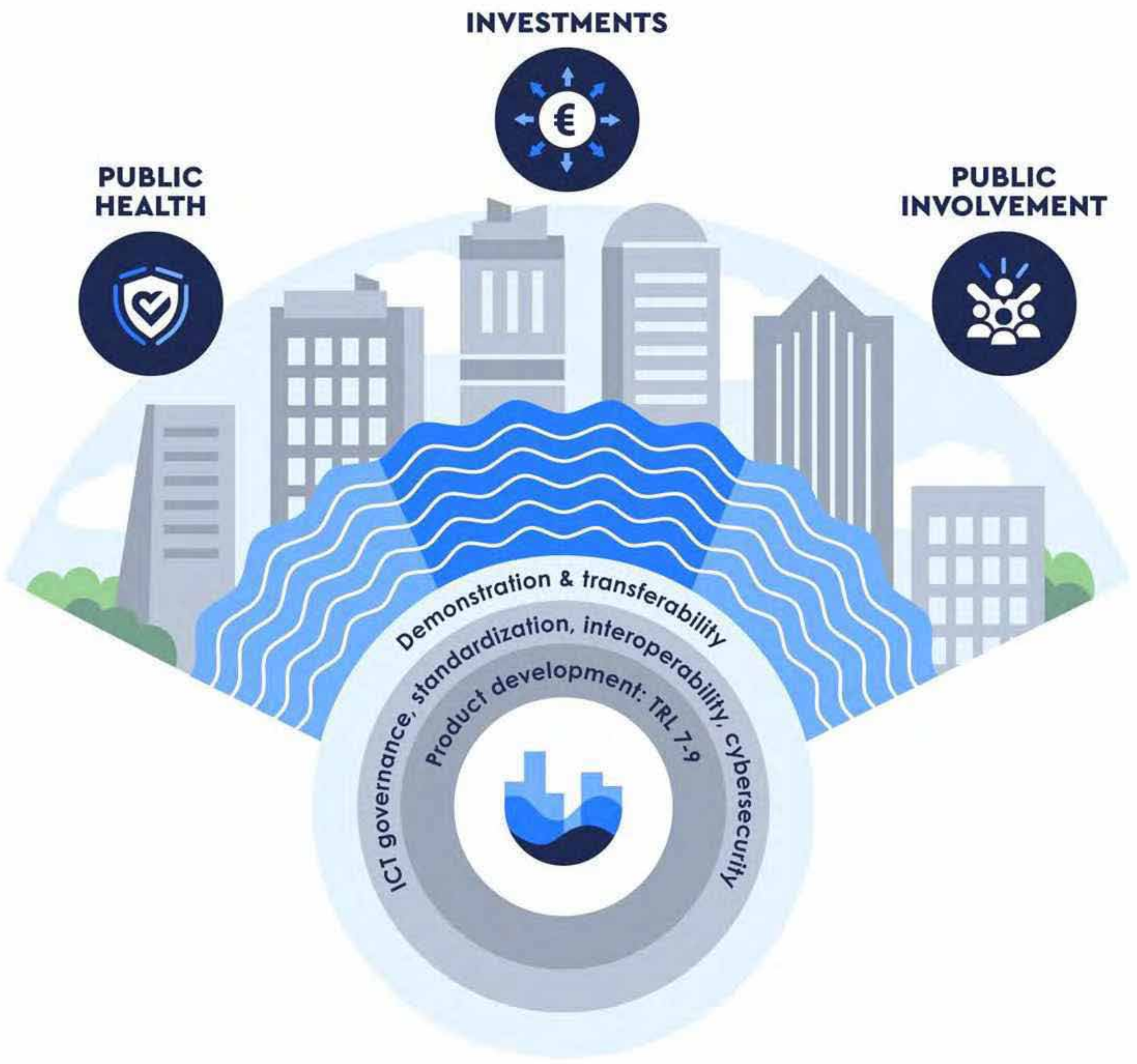
Nico Caradot

Kompetenzzentrum Wasser Berlin

digital-water.city has received funding from the European Union's H2020 Research and Innovation Programme under Grant Agreement No. 820954.

Objective

Develop and demonstrate **15 advanced digital solutions** to address water-related challenges



24 partners

KOMPETENZZENTRUM Wasser Berlin

Digital Water .City

Utilities	R&D	Companies and SME
Berliner Wasserbetriebe	Università Politecnica delle Marche	ICRA
Sofiyska Voda	Università degli Studi di Milano	PARTNERS4URBANWATER
SIAAP	SINTEF	IPEK
Gruppo CAP	irstea	ICATALIST
BIOFOS	Sorbonne Université	fluidion
	DHI	Gimeno grupo
	ecologic	kando
	Istituto Superiore di Sanità	Vragments
		Strane Innovation
		Arctik

digital-water.city has received funding from the European Union's H2020 Research and Innovation Programme under Grant Agreement No. 820954.

5 cities > EU challenges

#Copenhagen

Flooding and environmental impacts

#Paris

2024 Olympic games

#Berlin

Protection of river quality and drinking water sources

#Milan

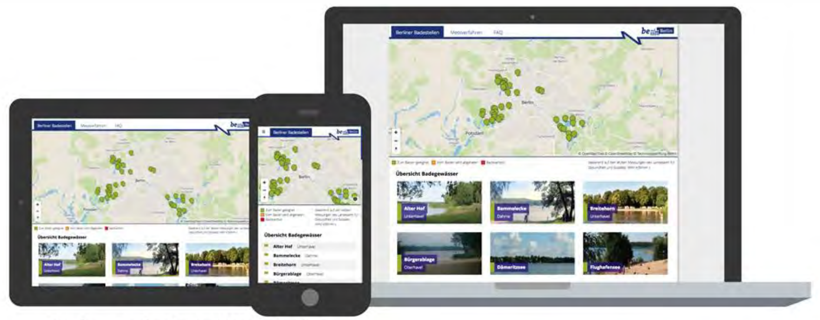
Safe water-reuse

#Sofia

ROI and operational costs

Bathing water

Early warning system to forecast bathing water quality and communicate with the public

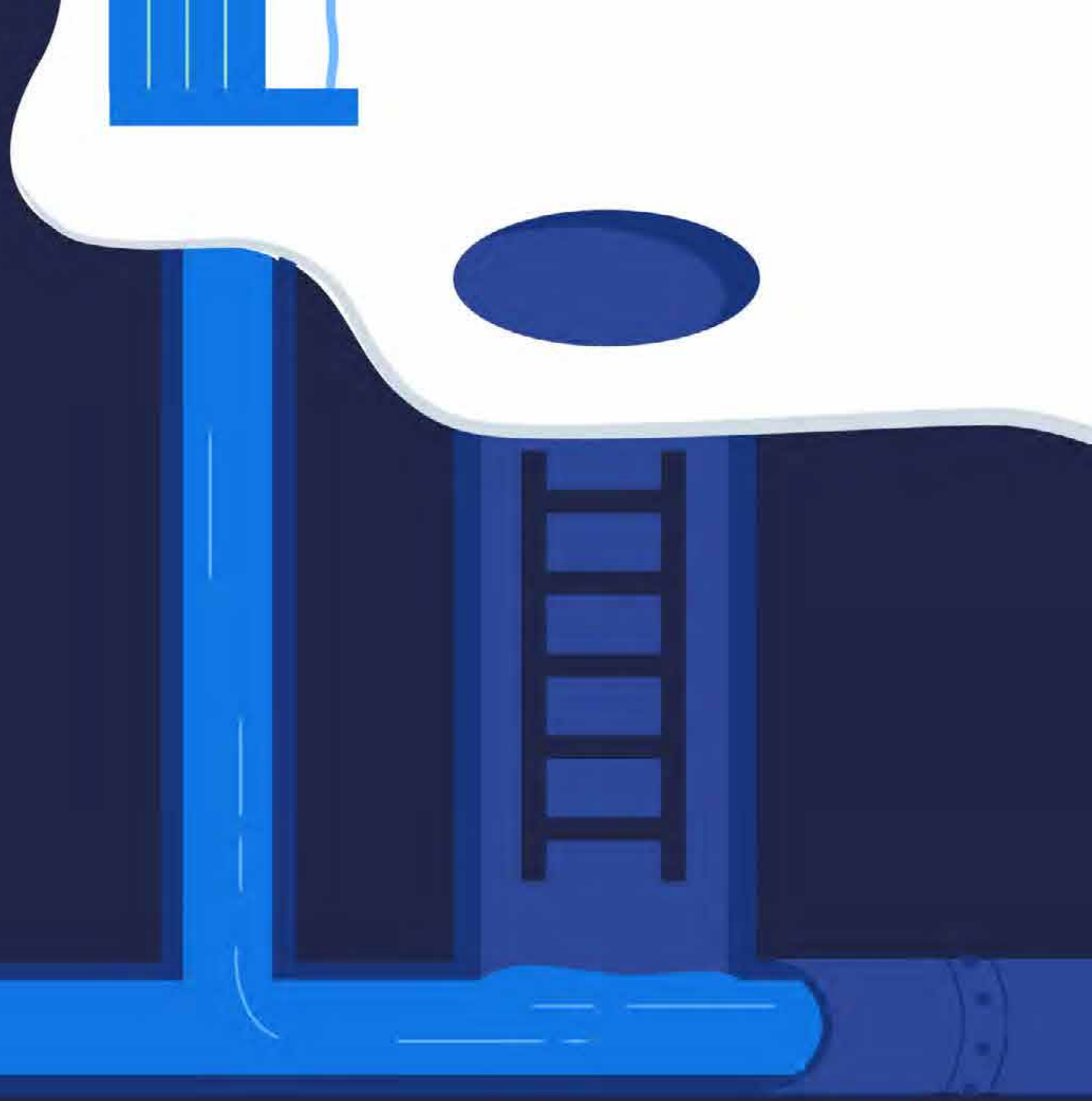


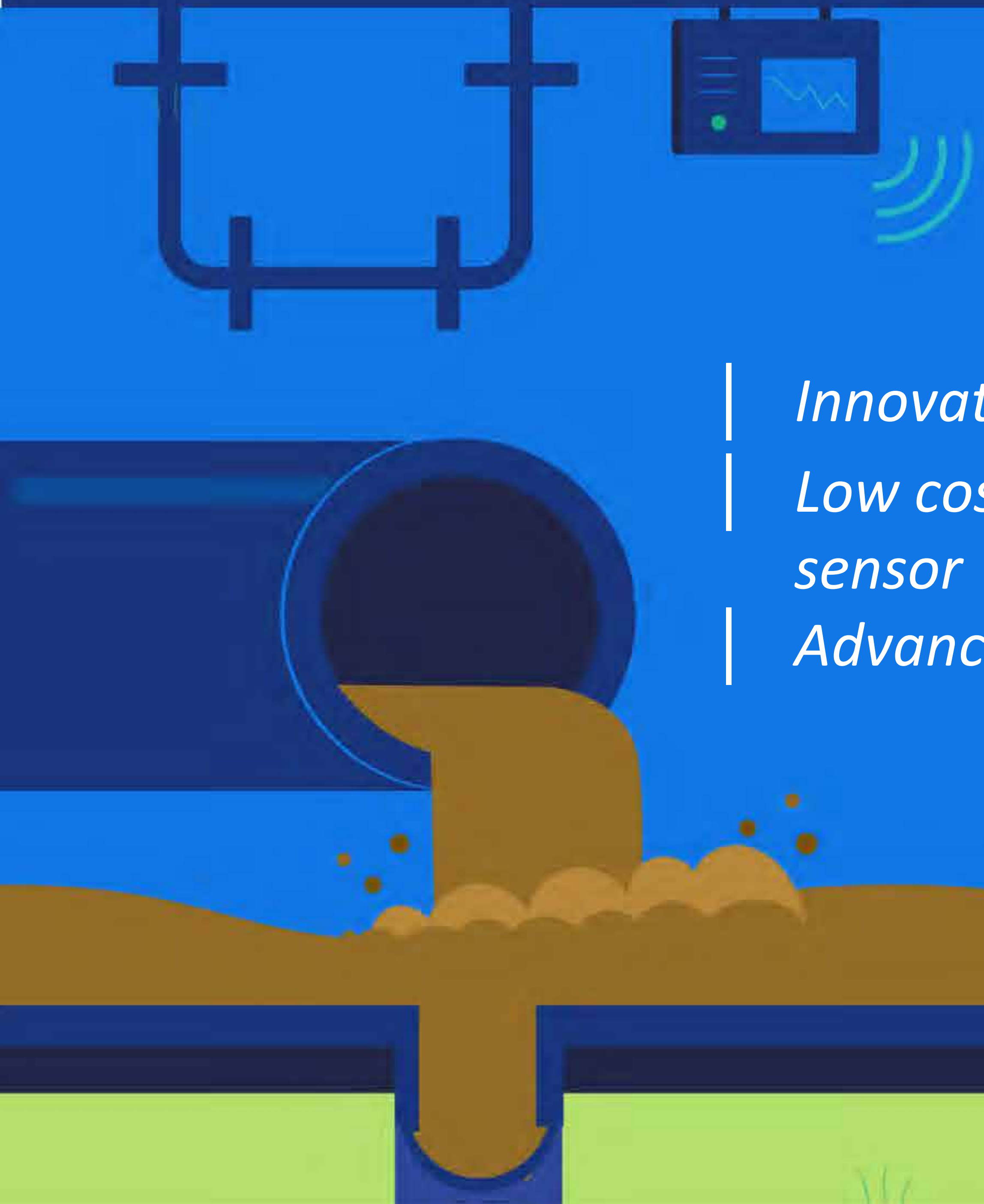
Mockup: Technologiestiftung Berlin

Real-time measurement of bacterial contamination

Drinking water

Predictive asset management of drinking water wells



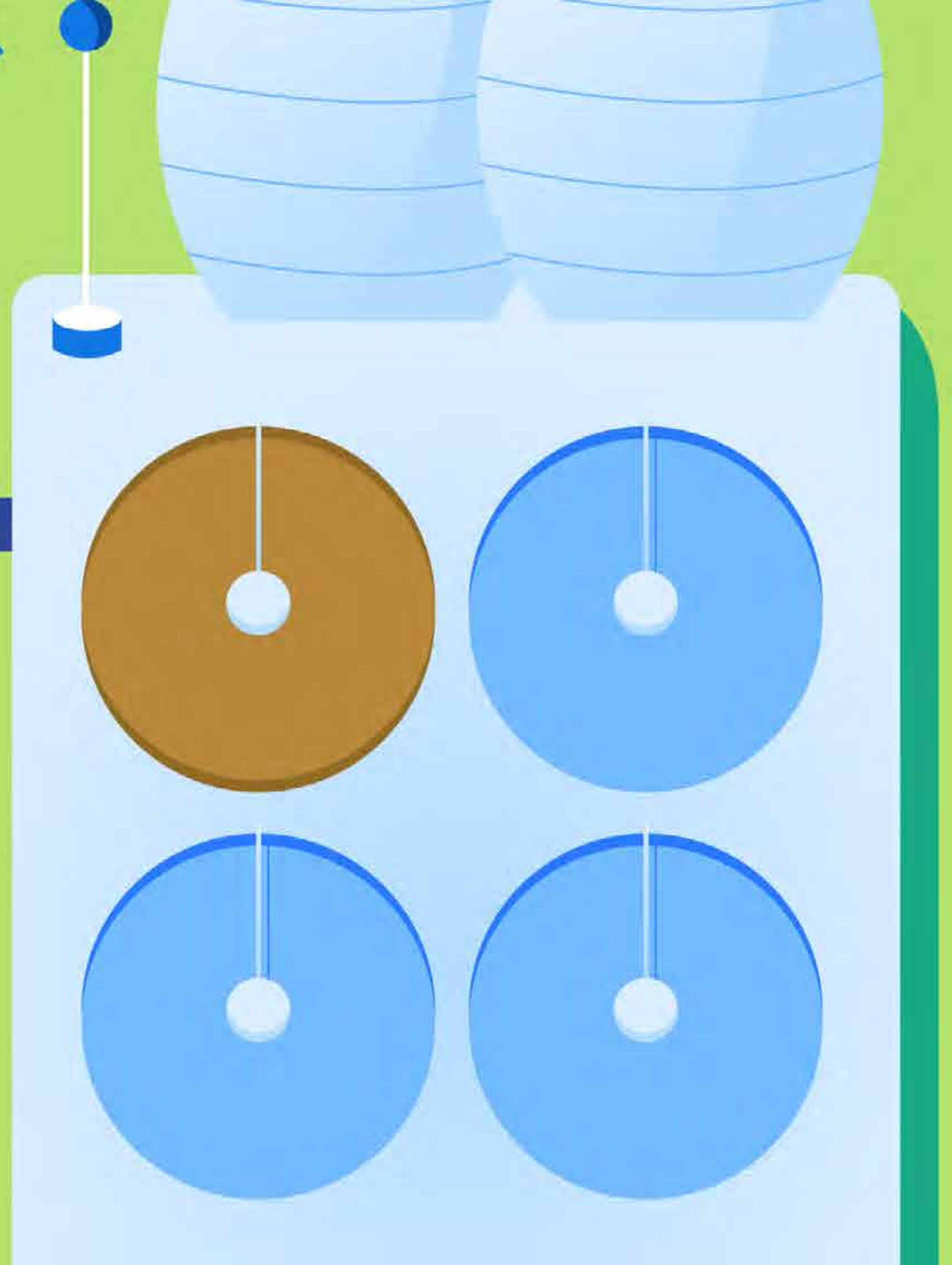


Sewer

- *Innovative monitoring of sewer illicit connections*
- *Low costs CSO monitoring technology with T sensor*
- *Advanced 48h sewer flow forecast*

Treatment plant

- *Real-time control of WWTP and sewer retention capacities*
- *Early Warning System for water reuse*



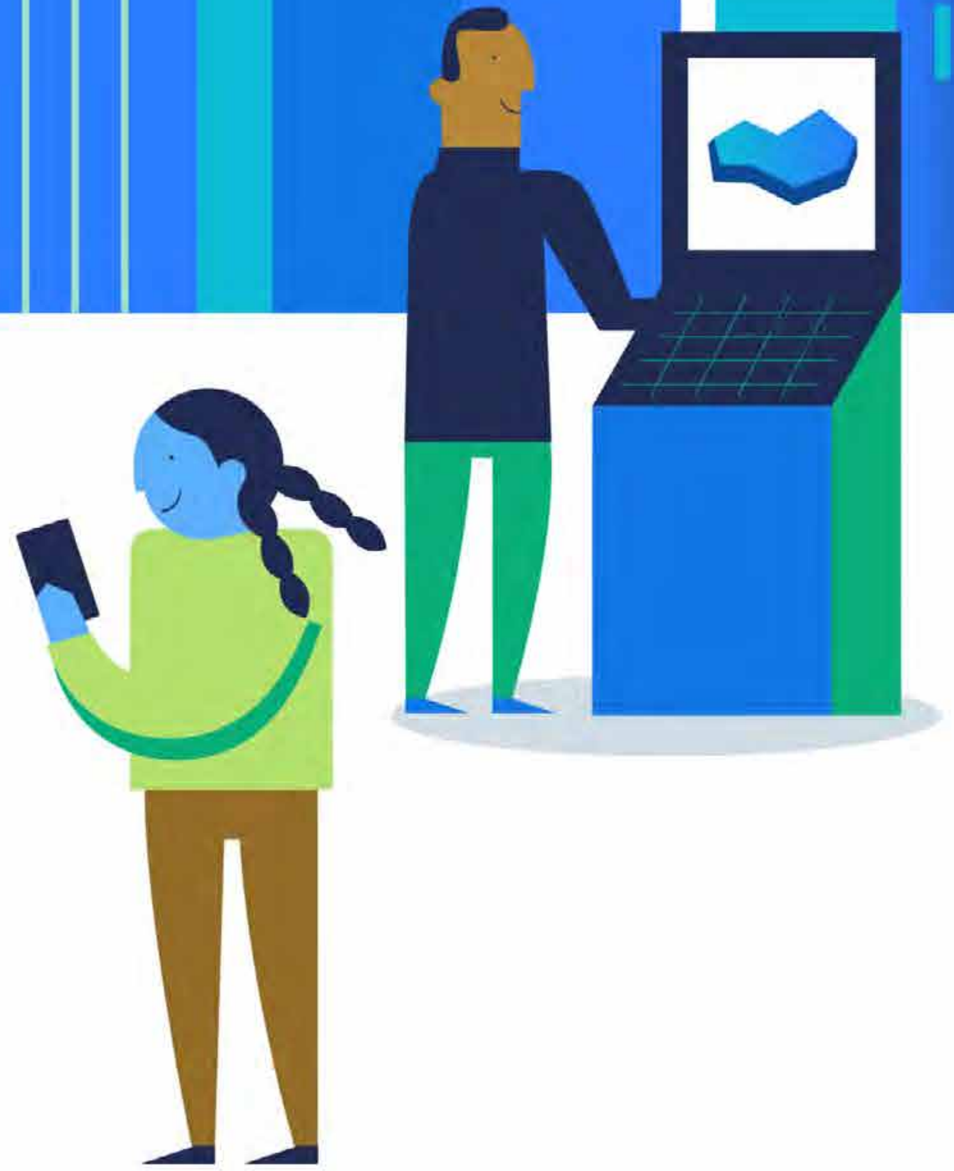
Water reuse

- *Remote monitoring of water stress*
- *Match making platform to support water allocation*

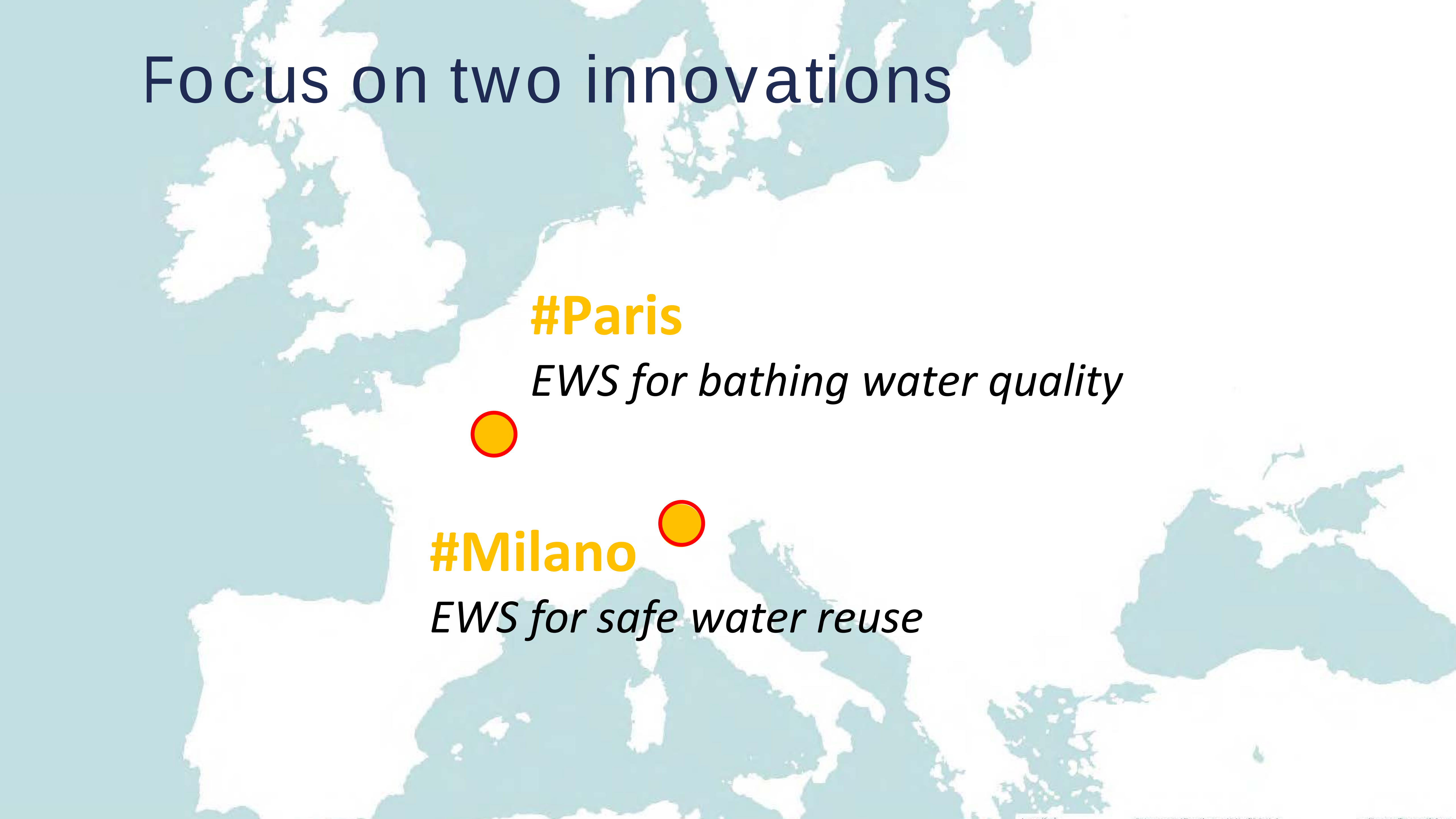
Public involvement

Augmented Reality (AR) app to communicate groundwater issue with the public

Serious game to communicate the benefits of reuse in term of nexus



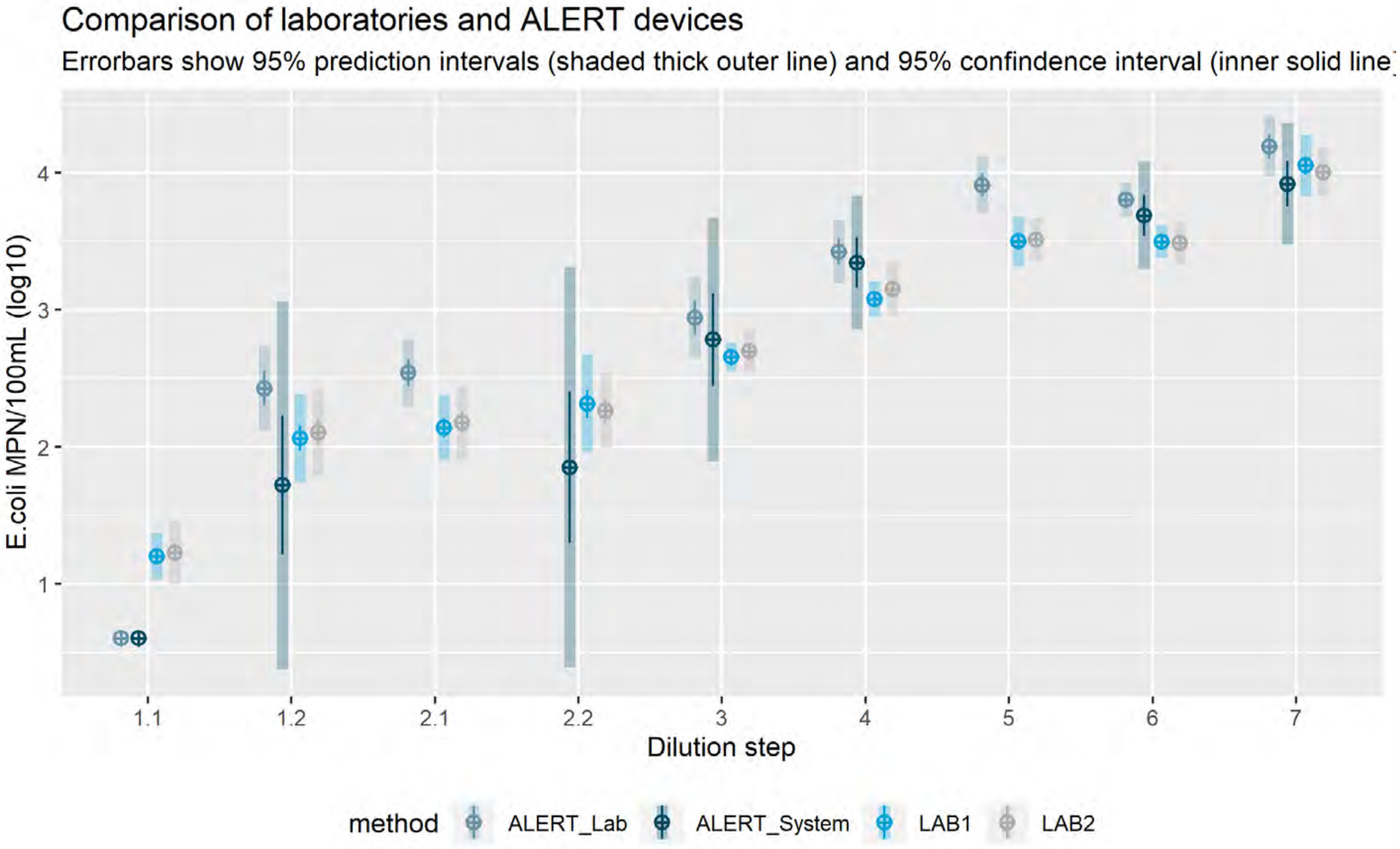
Focus on two innovations



#Paris

Improve bathing water management in the river Seine for the Olympic games of 2024

© Pixabay

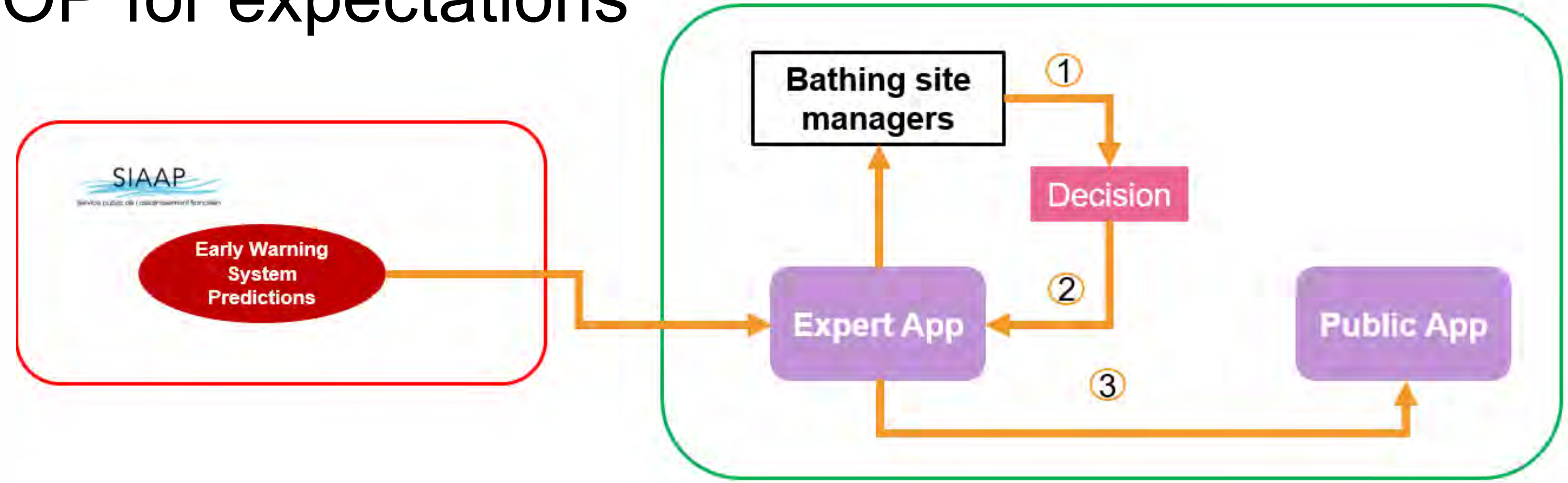


SENSORS FOR REAL-TIME IN SITU E.COLI AND ENTEROCOCCI MEASUREMENTS

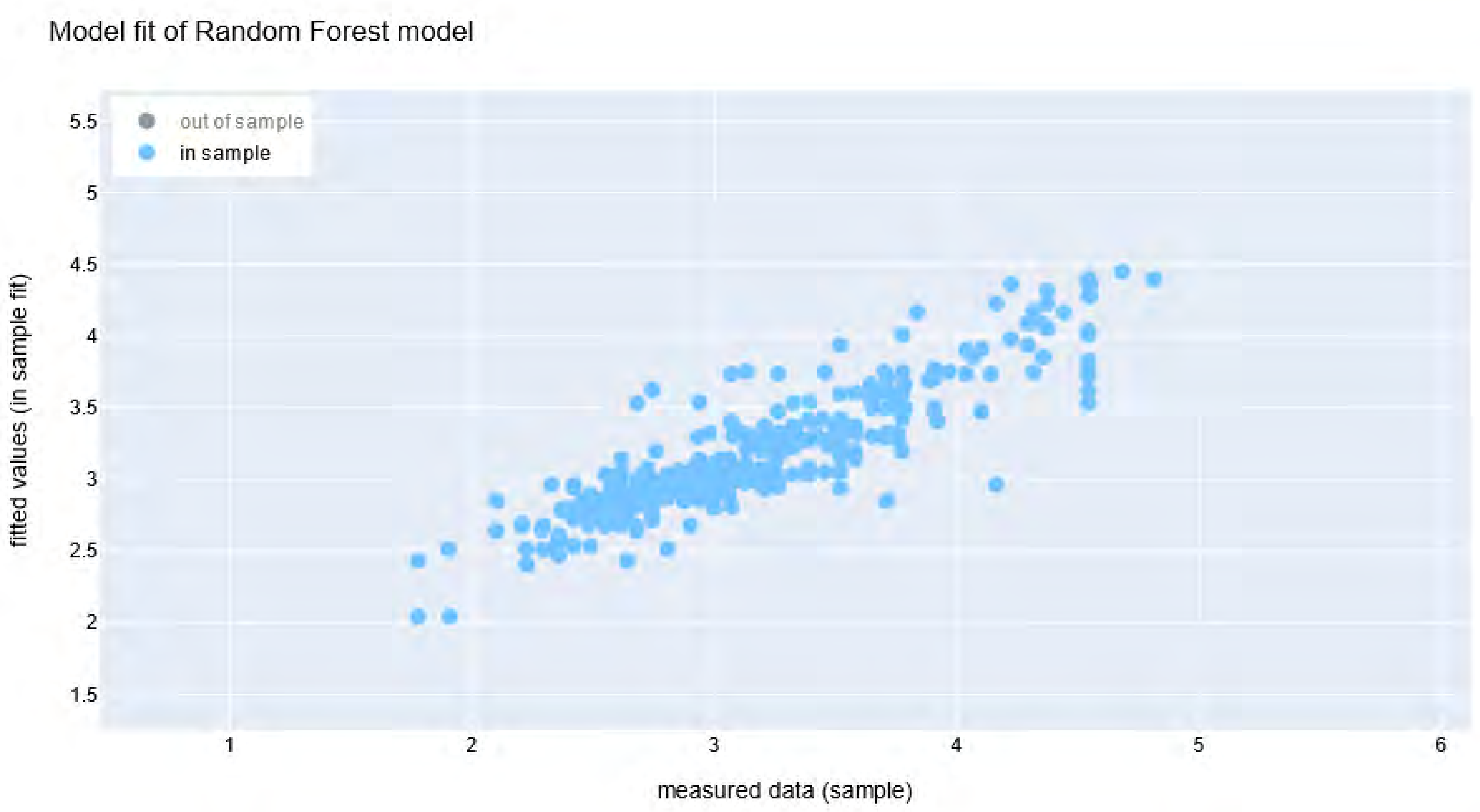
digital-water.city has received funding from the European Union's H2020 Research and Innovation Programme under Grant Agreement No. 820954.

Early warning system for bathing water quality

- The EWS is composed of a statistical and deterministic model of the rivers in Paris
- Developments are based on the FIWARE architecture
- Current activity: validation of the models performance + COP for expectations

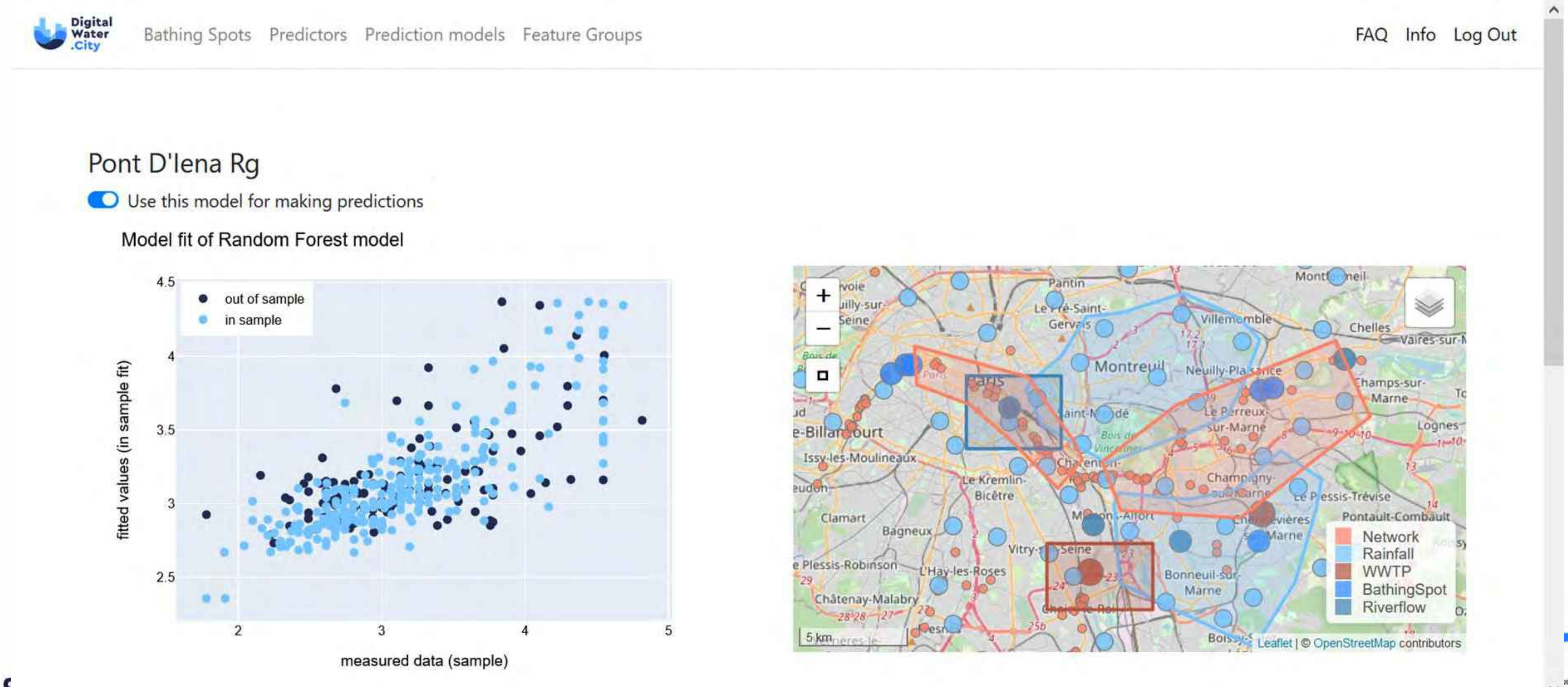


First model runs (24h-Random Forest)

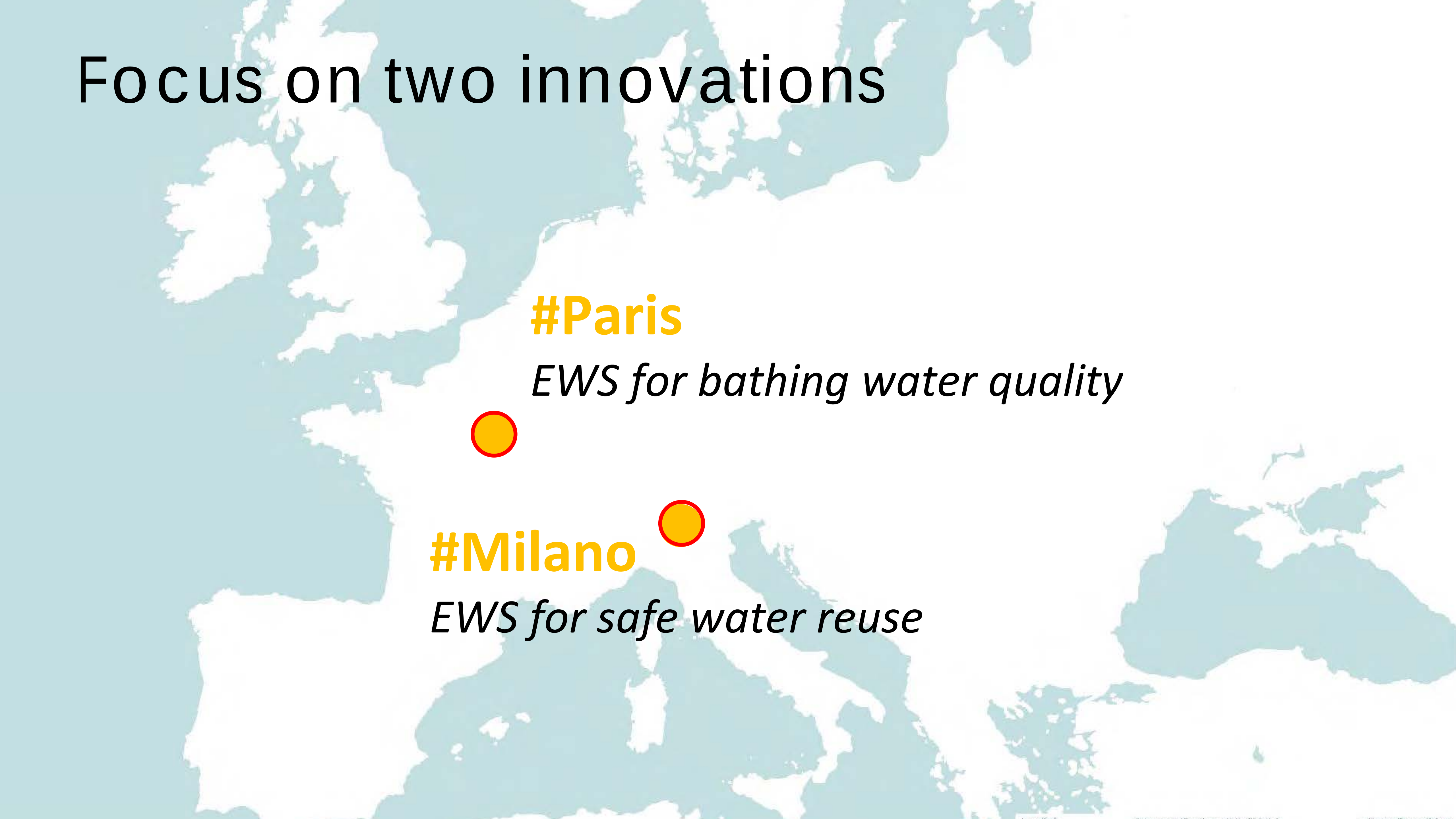


digital-water.city has received funding from the European Union's H2020 Research and Innovation Programme under Grant Agreement No. 820954.

First software architecture



Focus on two innovations



#Paris

EWS for bathing water quality

#Milano

EWS for safe water reuse

DWC in few words

→Leverage the **potential of data and digital** technologies

→**Boost the water management** in 5 EU cities

→**Promote the value** of the digital solutions for the tech providers

→Achieve a **new step in the integration** of digital solutions in EU, in particular regarding cybersecurity, interoperability and governance

digital-water.city has received funding from the European Union's H2020 Research and Innovation Programme under Grant Agreement No. 820954.

nicolas.caradot@kompetenz-wasser.de

digital-water.city is a research project supported by the European Commission under the Horizon 2020 Framework Programme

Grant Agreement No 820954

Duration: 01/06/19 - 30/11/22

FIWARE 4 WATER

FIWARE for the Next generation Internet Services for the WATER sector

Intelligent Control for Wastewater Treatment Plant

Dr Alex van der Helm, Waternet
Siddharth Seshan, KWR Water Research Institute and PhD TU Delft

waternet
regional public water authority
amstel gooi en vecht
city of amsterdam

KWR

Fiware for Water

FIWARE 4 WATER

- 14 partners: water utilities, universities, research institutes, companies, NGO
- Period: 01/06/2019 - 31/05/2022
- Member of:
  - EU ICT4Water cluster
  - EU Synergy Group DigitalWater2020

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 821036.

FIWARE 4 WATER

Demo Case #1 • Greece

Athens • Water Supply System real time operational managment

Demo Case #2 • France

Cannes • Improving the Water Supply System

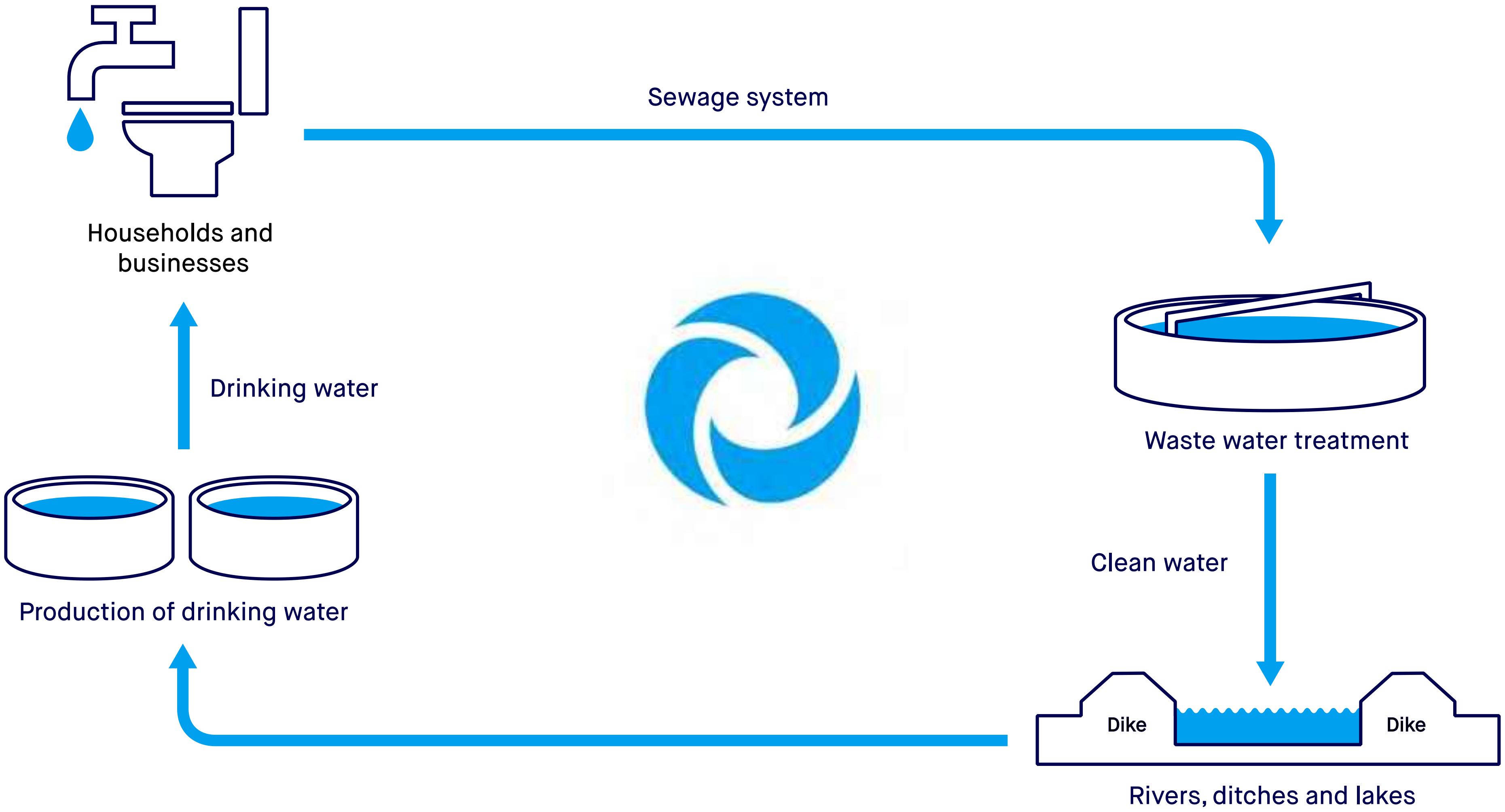
Demo Case #3 • Netherlands

Amsterdam • Intelligent control for wastewater treatment

Demo Case #4 • United Kingdom

Great Torrington • Smart Meters and Customers

Waternet water cycle utility of Amsterdam

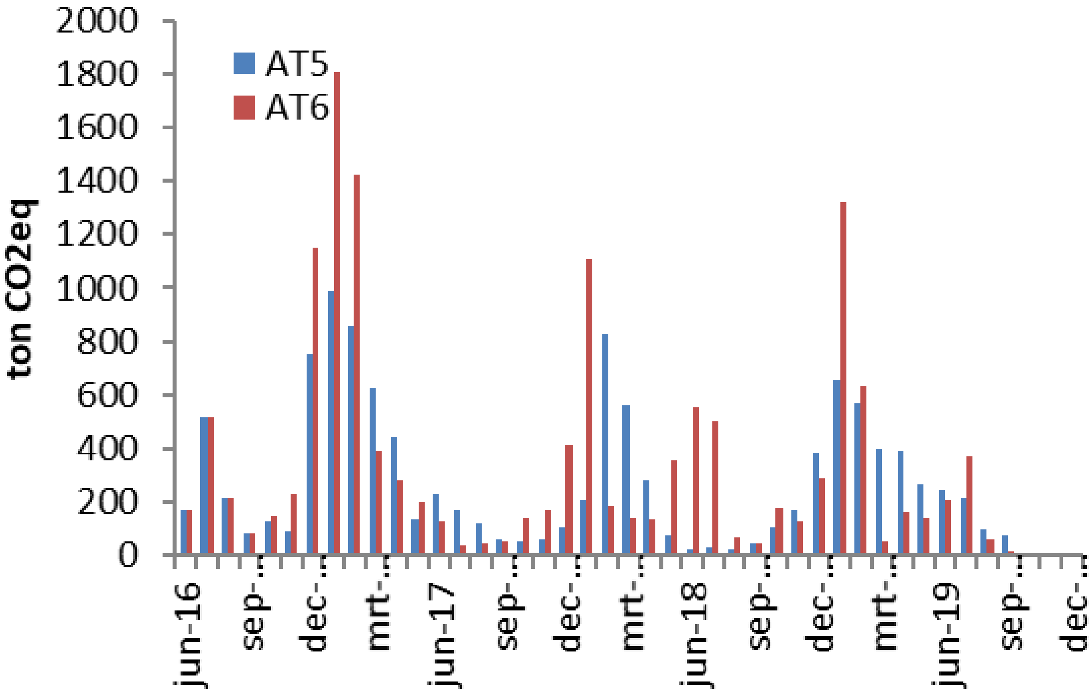


Wastewater treatment plant Amsterdam West

Nitrous oxide (N2O) gas emissions

Real-time measurement in off-gas aeration tanks (ATs) of WWTP Amsterdam West starting 2016:

15 – 28 kton/year CO_2-eq



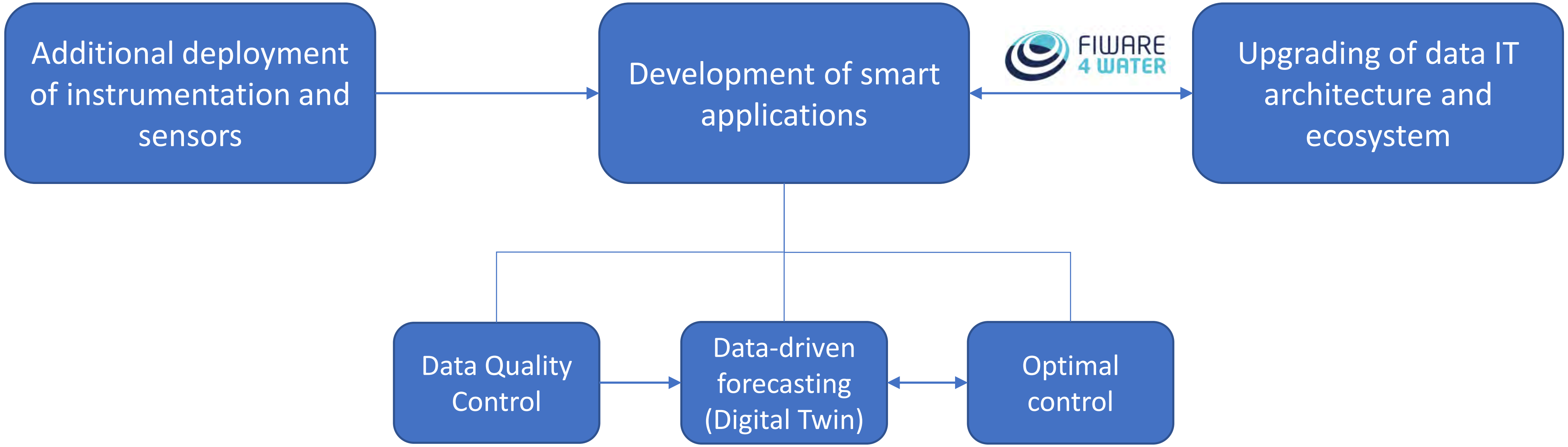
Full-scale research lane

Objective: Reduction of nitrous oxide emission and electricity use aeration

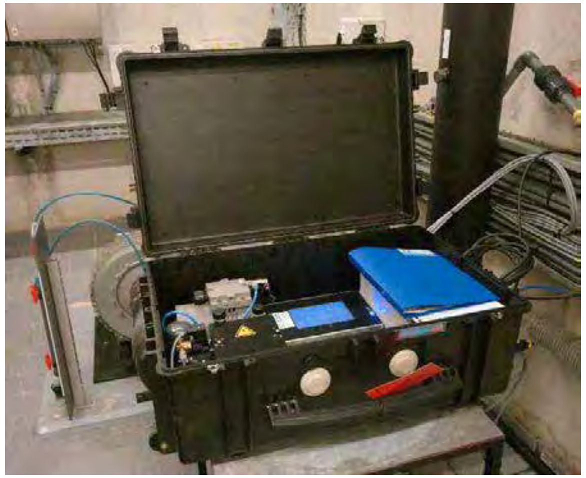
Installing additional sensors

Treatment optimisation with Artificial Intelligence

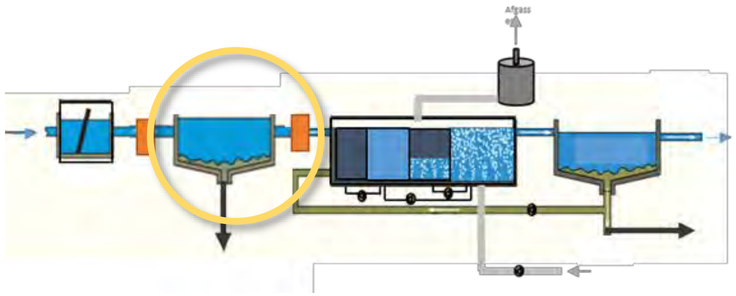
Building Blocks for Digitalization of WWTP

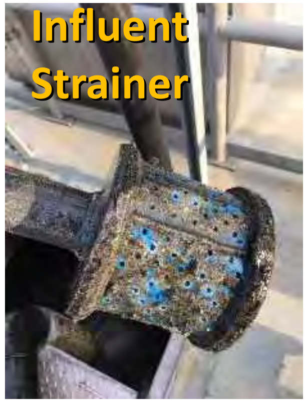


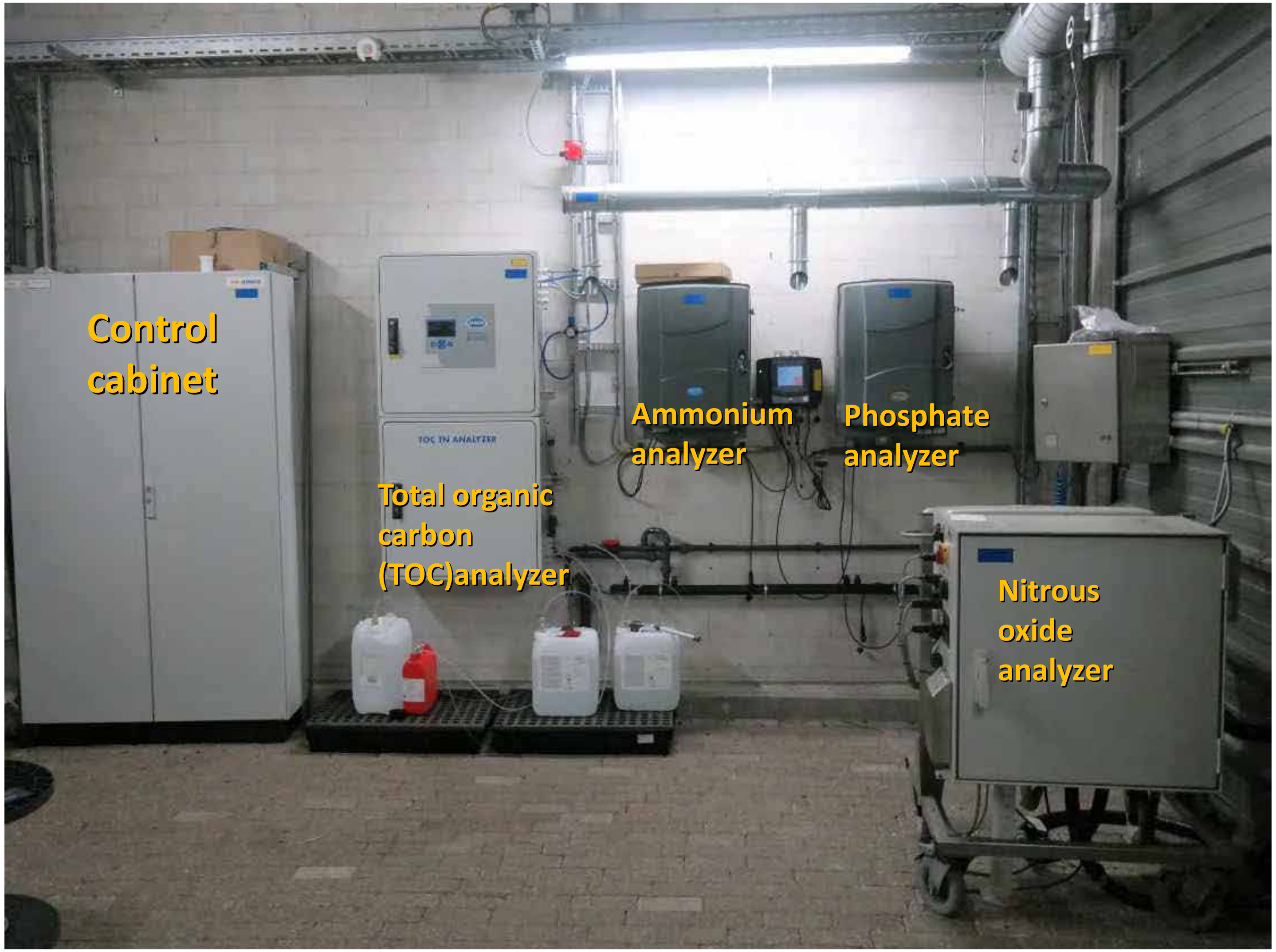
Sensor deployment and research facility



Primary settler

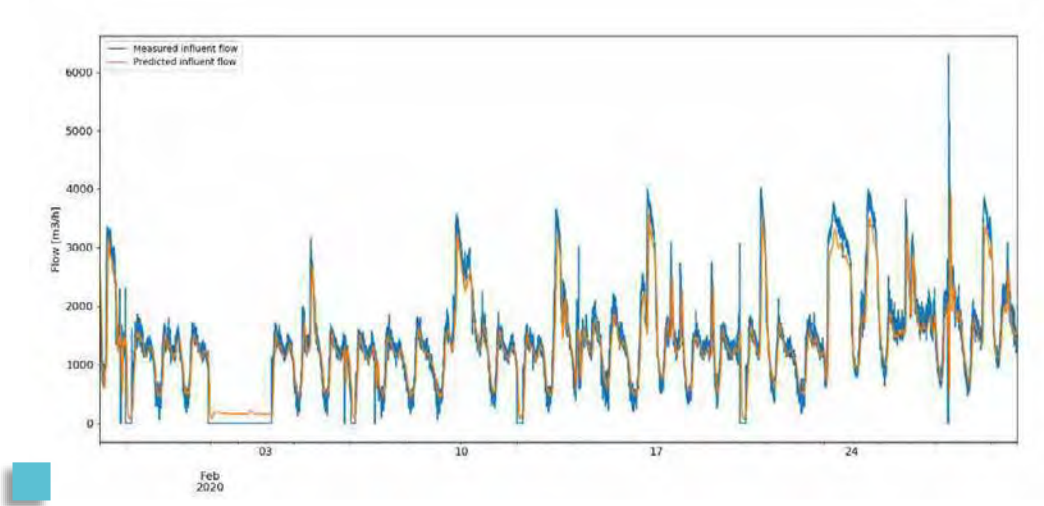




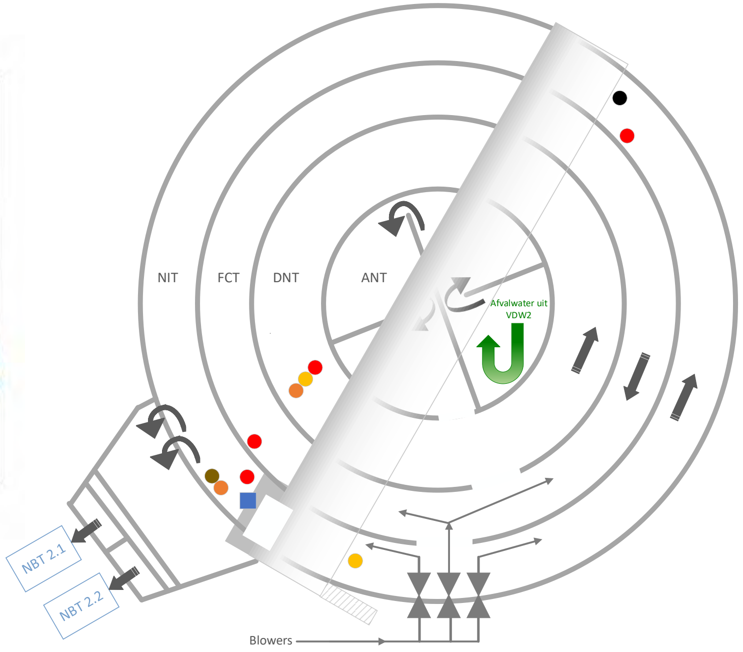


AI models for aeration optimisation

Influent model
"How much wastewater is coming?"



Digital twin model
"What happens if …?"



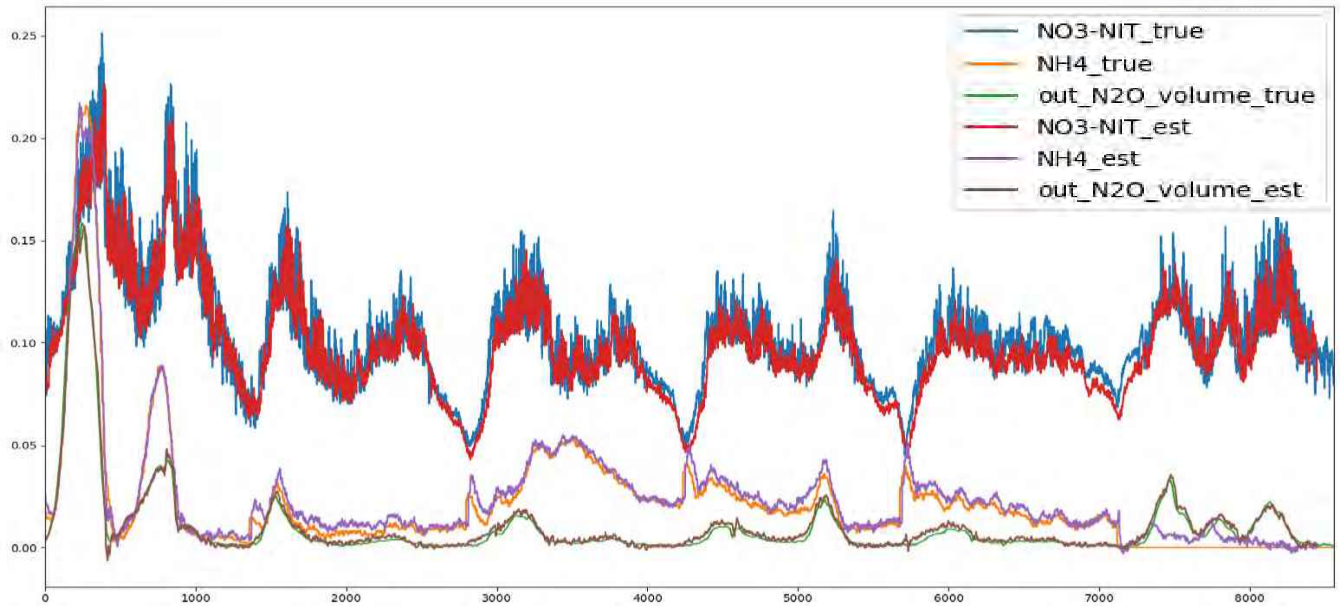
Control model
"What is the best action?"

Objective:
- Low N_2O
- Low kWh

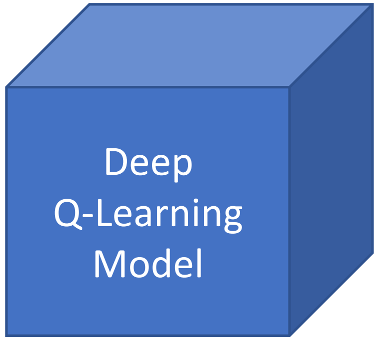
20+ Soft-sensors
"What is the value of this quantity we don't or can't measure?"

Data driven AI digital twin model

Inputs				
Influent	Energy	O_2	Recirc-C	Ctrl-recirc-C
Influent-terrain	Valves-NIT	NH_4	DS-surplus-drain	out-N_2O-volume
Effluent	Valves-FCT	DS	Setpoint-O_2	
Blowers	NO_3-NIT	Recirc-A	Ctrl-recirc-A	
Pressure	NO_3-DNT	Recirc-B	Ctrl-recirc-B	

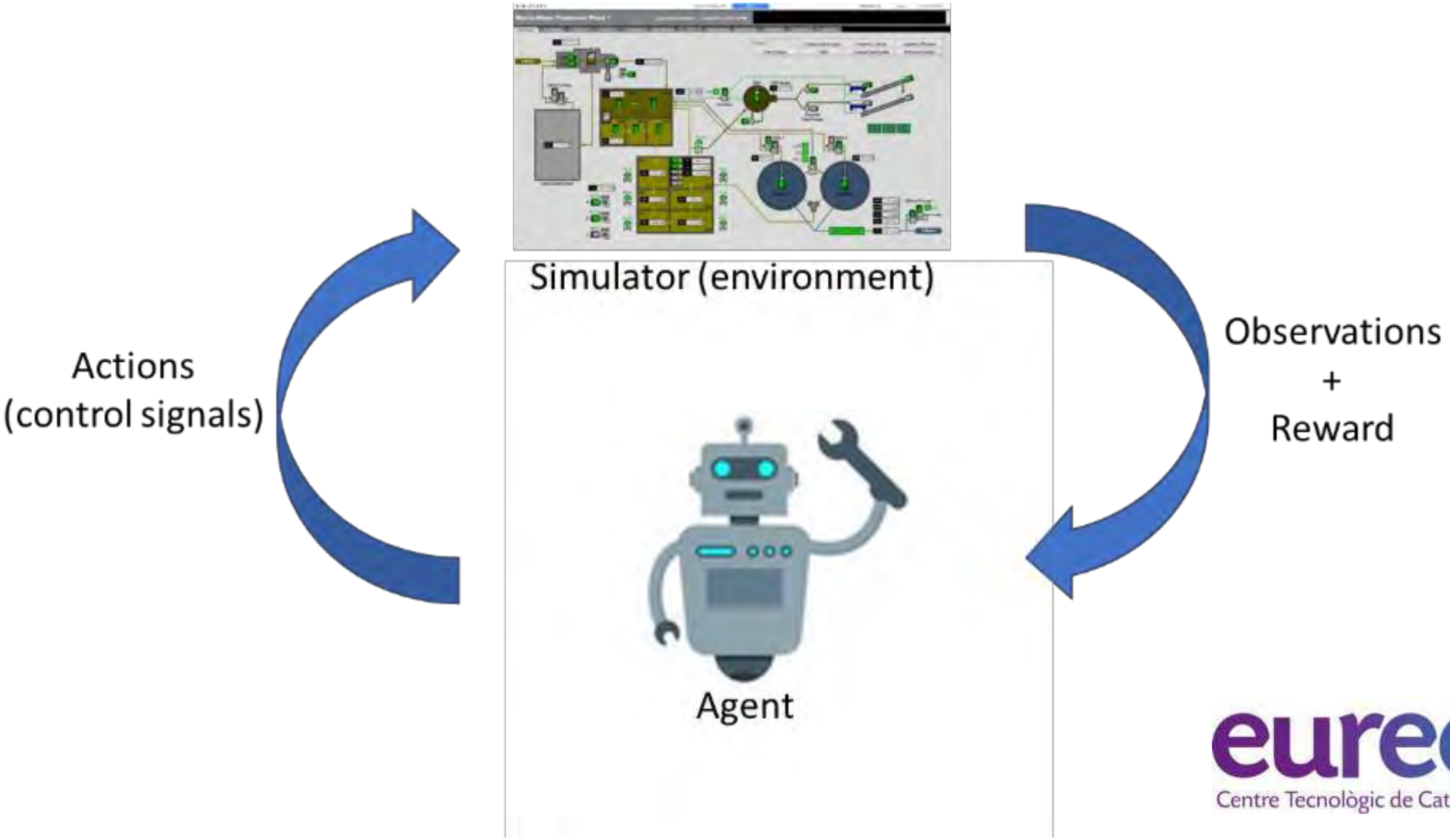


$$[x_1^{t0}, \quad x_2^{t0}, \quad \ldots, \quad x_n^{t0} \ ]$$
$$[x_1^{t-1}, \quad x_2^{t-1}, \ldots, \quad x_n^{t-1} \ ]$$
$$\ldots$$
$$[x_1^{t-95}, x_2^{t-95}, \ldots, x_n^{t-95}]$$



$$[y_1^{t+1}, \quad y_2^{t+1}, \quad \ldots, \quad y_n^{t+1} \ ]$$

A reinforcement learning agent



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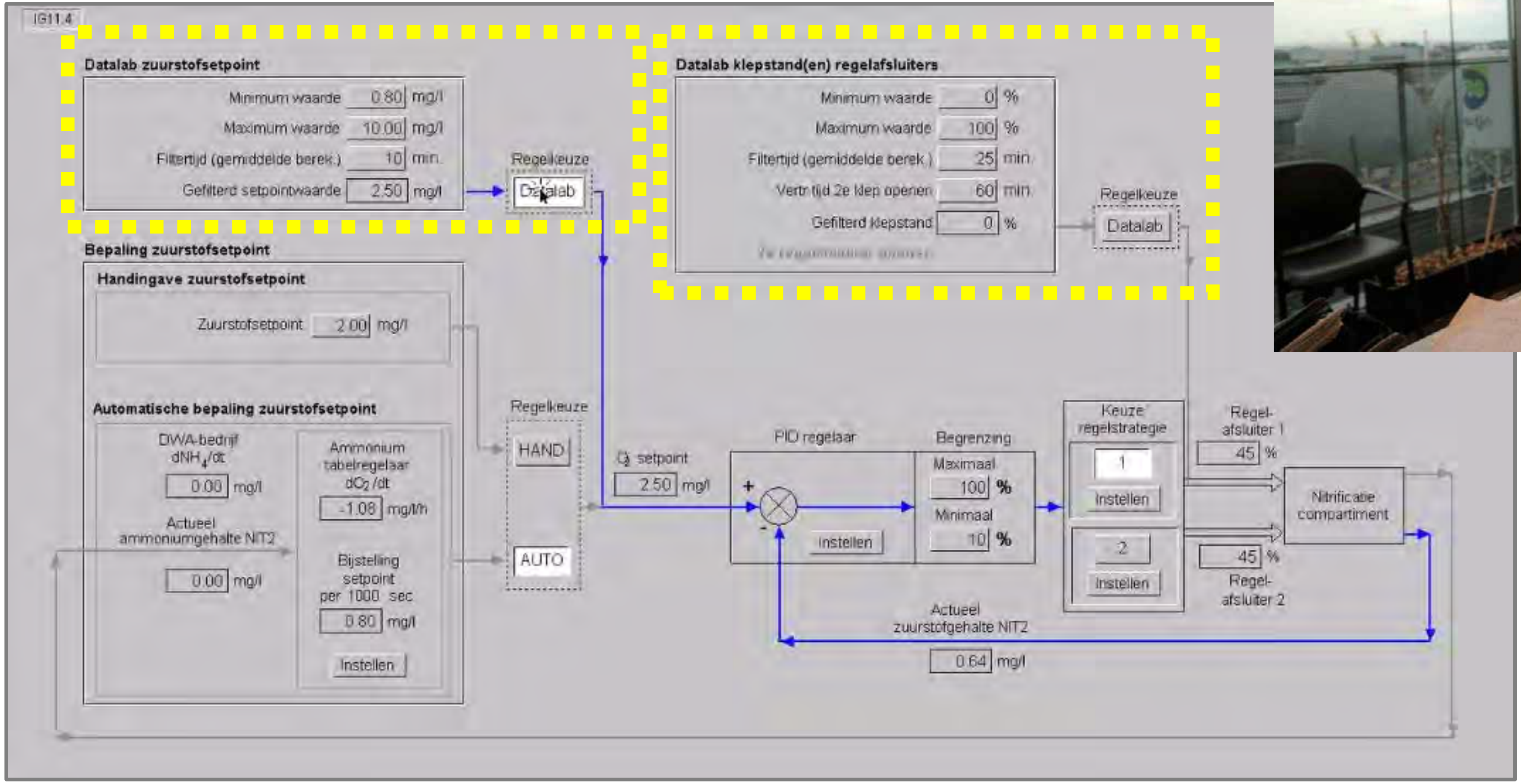
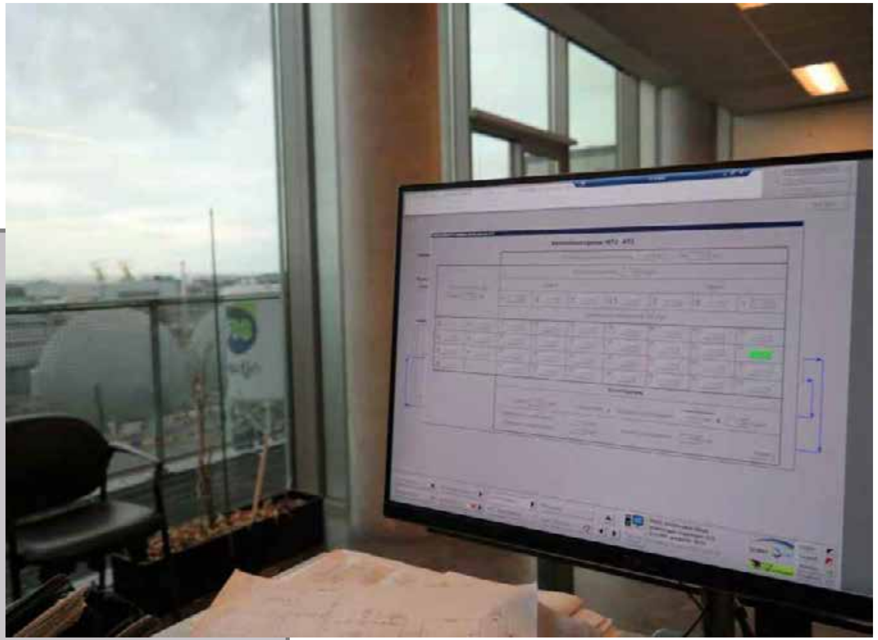
AI control implementation





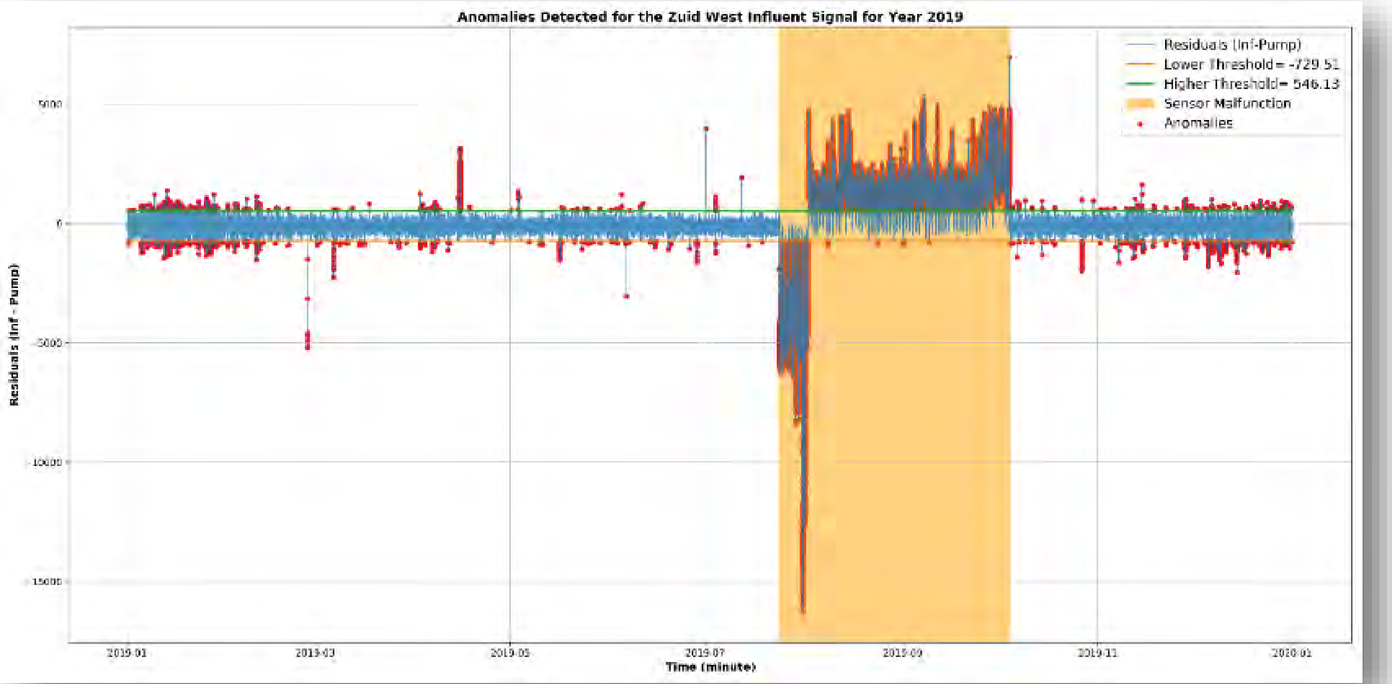
Automatic Data Validation and Data Quality Control

FIWARE 4 WATER

- Data quality can be impacted by sensor faults, (sensor) calibration issues, fouling, connectivity problems during transfer of data between the sensors/actuators and PIMS.

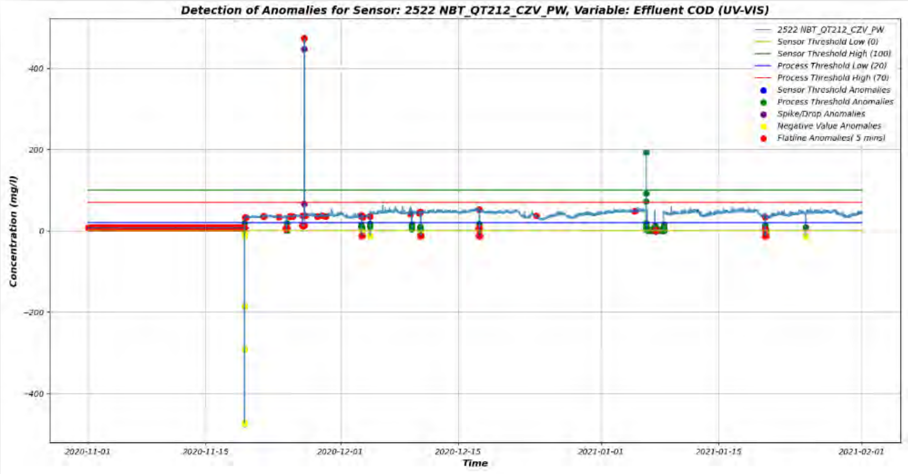
- Manual detection and correction can be labour intensive, particularly for signals used for simulation by AI models.

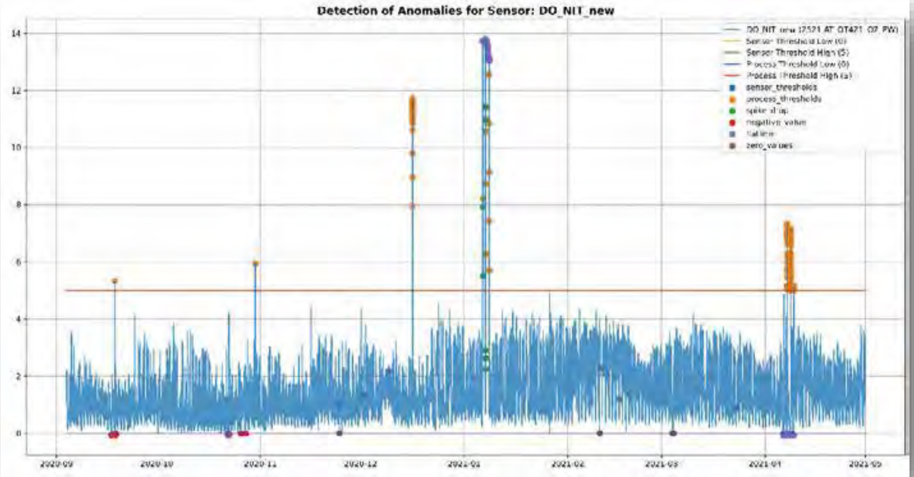
- Development of an automated data validation framework to screen raw data signals prior to model simulations and visualization.



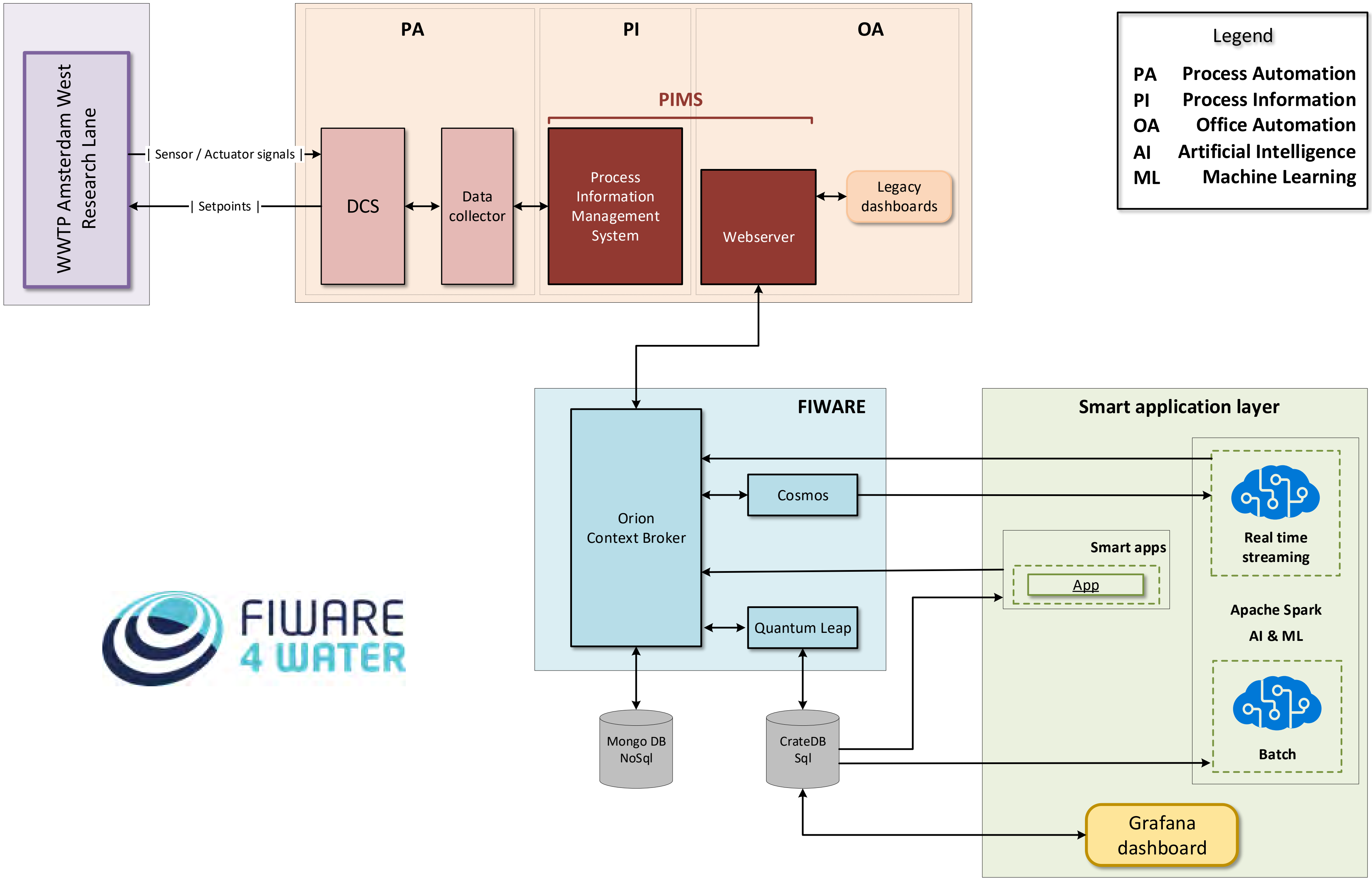
Automatic Data Validation and Data Quality Control

- Simple statistical methods to detect gross sensor anomalies due to sensor failures.
- Involves the collection of crucial metadata on sensors and guidance from process technologists.
- Detection of contextual anomalies using model-based detection.
- Development of soft sensors for crucial parameters (such as NH4 in aerobic tank) for data reconciliation.
- Conduct a (near) real-time data validation process using Fiware.





Integration of FIWARE To Legacy System



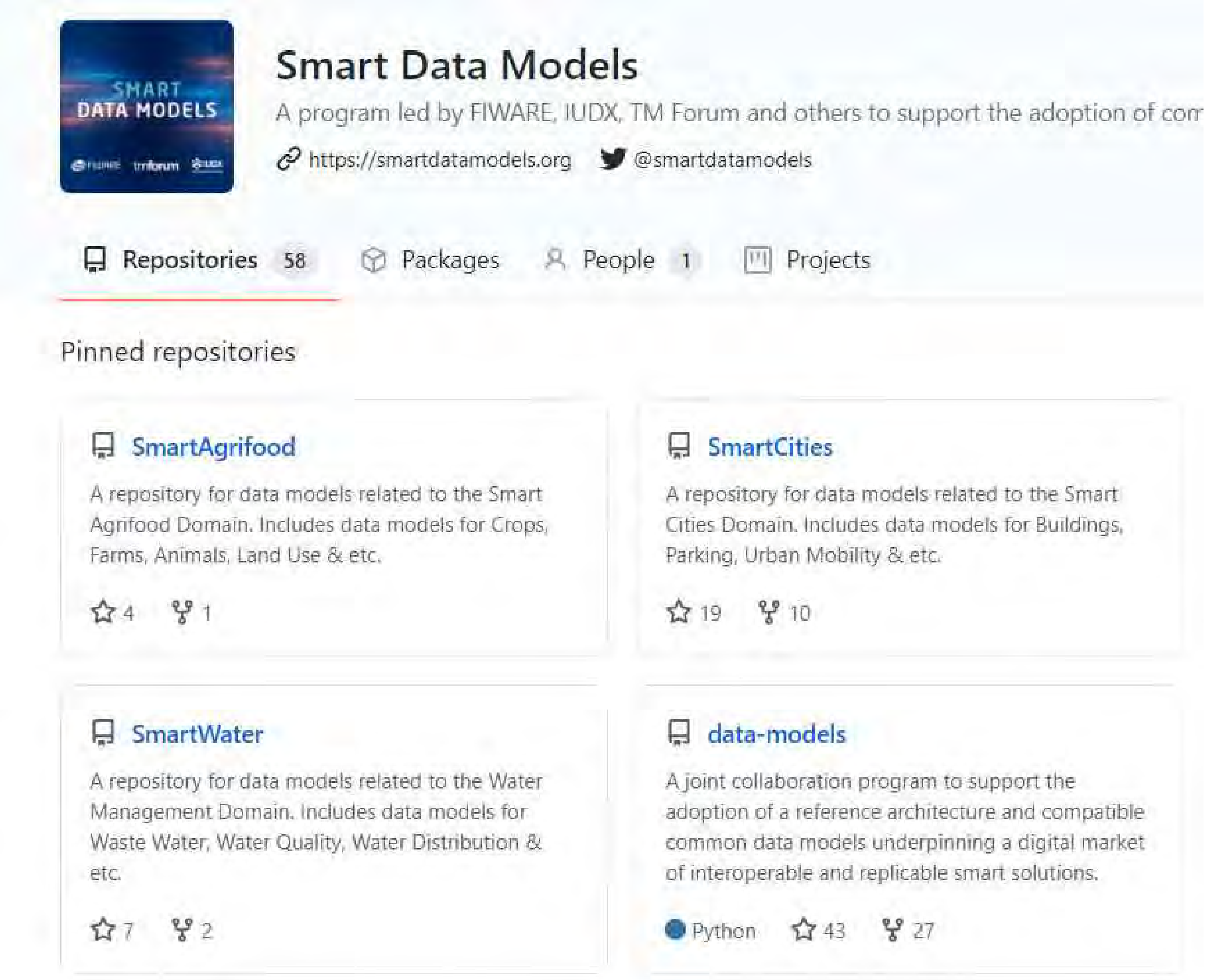
Legend

PA	**Process Automation**
PI	**Process Information**
OA	**Office Automation**
AI	**Artificial Intelligence**
ML	**Machine Learning**

Data Integration Layer

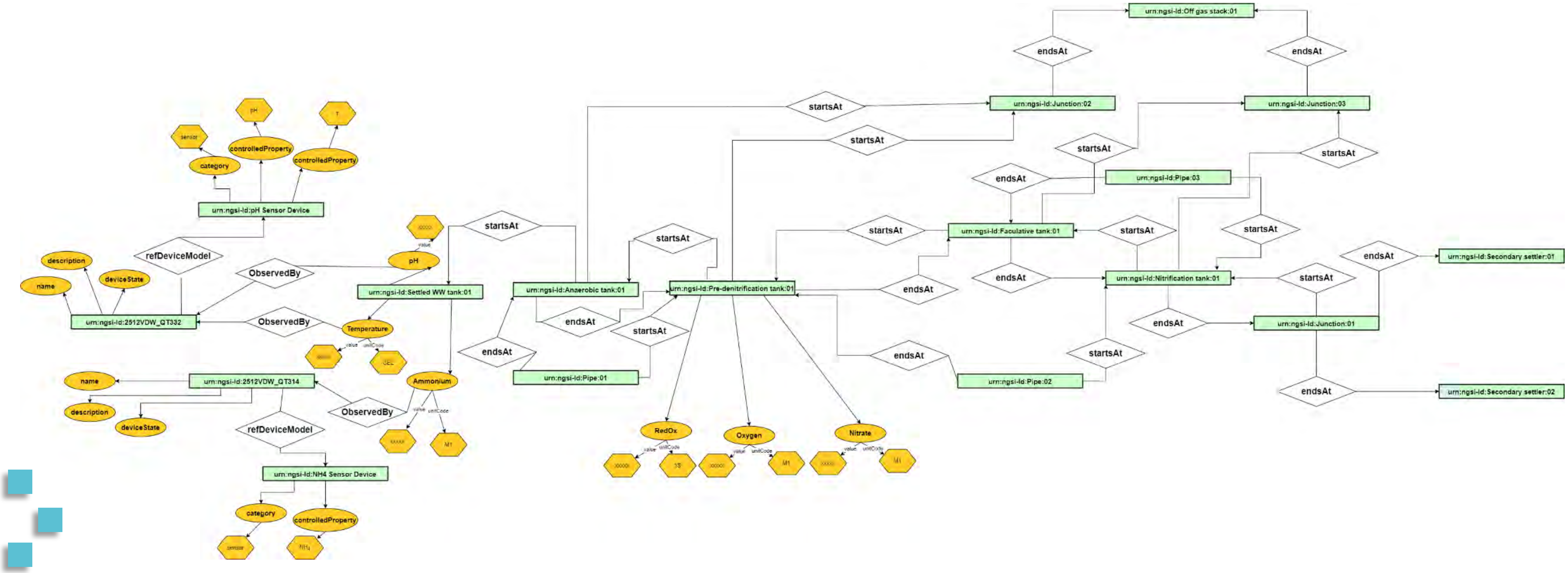
NGSI-LD Data Models Describing the 'As-built' Digital Twin

- Development of common information data models in NGSI-LD for the wastewater domain.
- Ensure interoperability for wastewater treatment systems.
- Using existing definitions by the Fiware/TM Forum/IUDX to promote a standardised approach and ensure interoperability across domains.



Data Integration Layer

NGSI-LD Data Models Describing the 'As-built' Digital Twin



Data Integration Layer

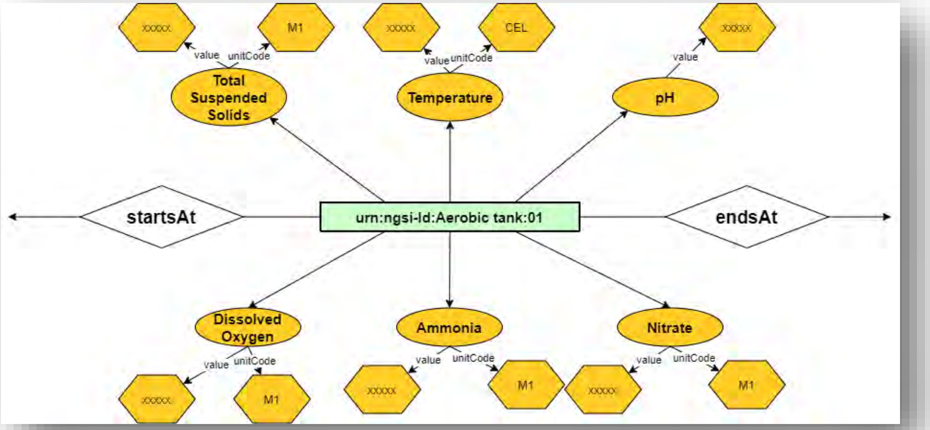
WasteWaterTreatment Data Models

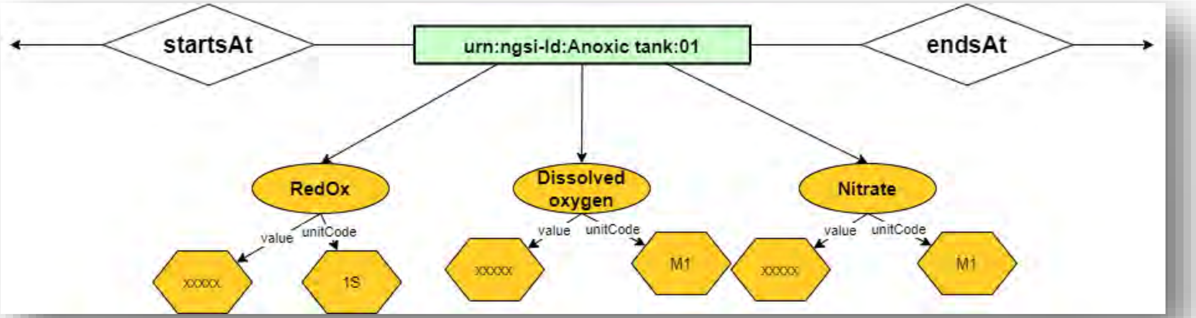
- Following entity types have been developed:
  - WasteWaterTank
  - WasteWaterJunction
  - Blower
  - OffGasStack

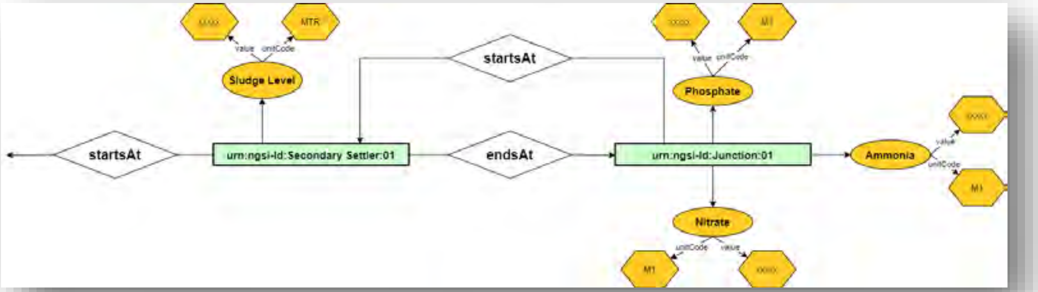
- Models can be found here - https://github.com/smart-data-models/dataModel.WasteWater

- Extension of these models based on the use case requirements.

- Further models applicable to WWTPs in development.







Thank you

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Siddharth Seshan, KWR Water Research Institute and PhD TU Delft
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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 821036.

Annex 8: Presentations – Success secret of WSIS

The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

What is the secret of successful water smart industrial symbioses?

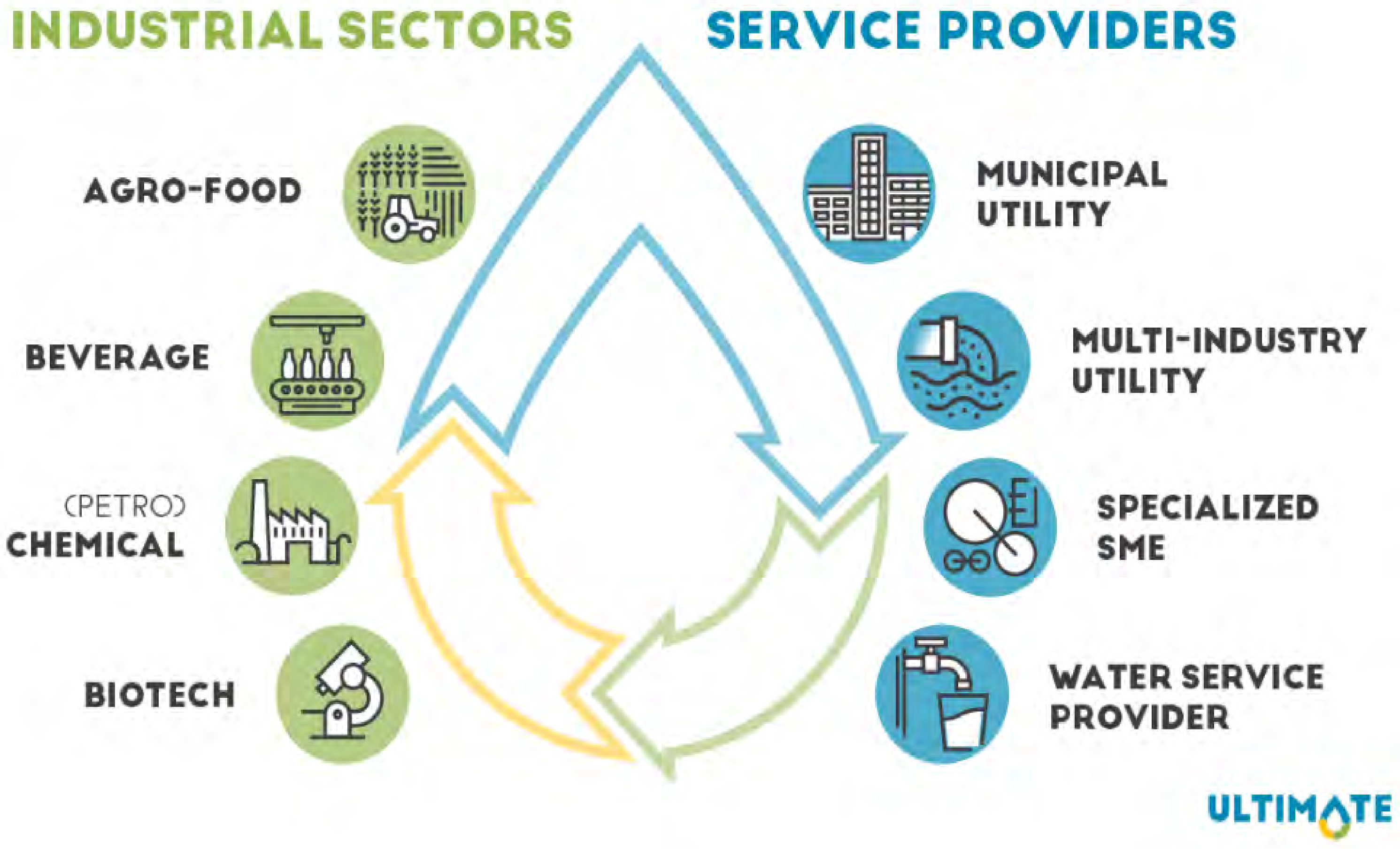
A. Kleyböcker and A. Perkis

March 23rd 2022

Ultimate (June 2020 – May 2024):

- Promotion, establishment and extension of **Water Smart Industrial Symbioses**
- Development and demonstration of **innovative technologies** for symbioses
- **Assessment** of the technologies and development of **digital „support tools“**
- **Engagement of stakeholders** to discuss and enhance our Ultimate solutions
- Development of **new business models** towards marketability

SYMBIOSES BETWEEN:

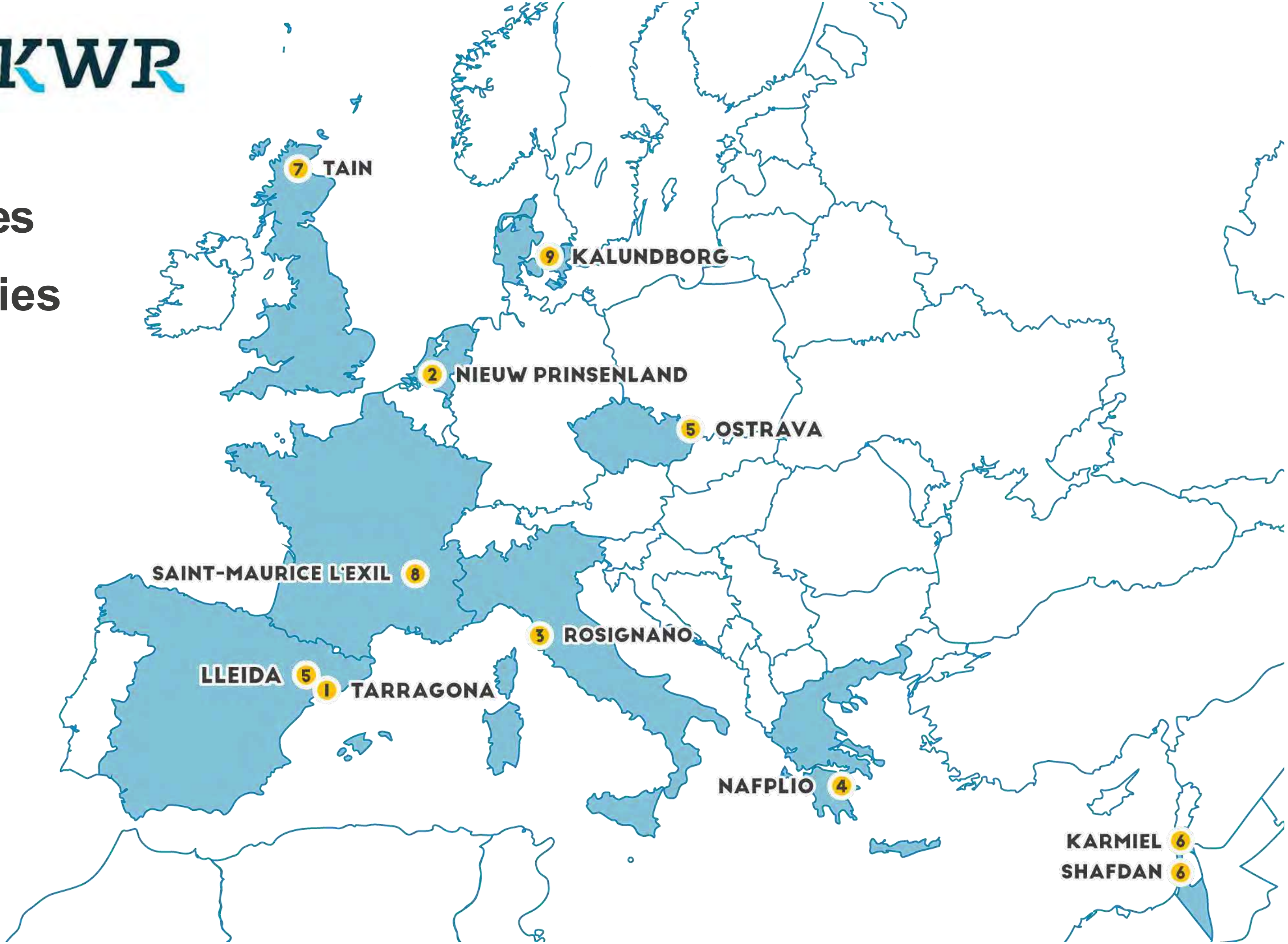


The project leading to this application has received funding from the European Union's
Horizon 2020 research and innovation programme under grant agreement No 869318

Coordinator: KWR

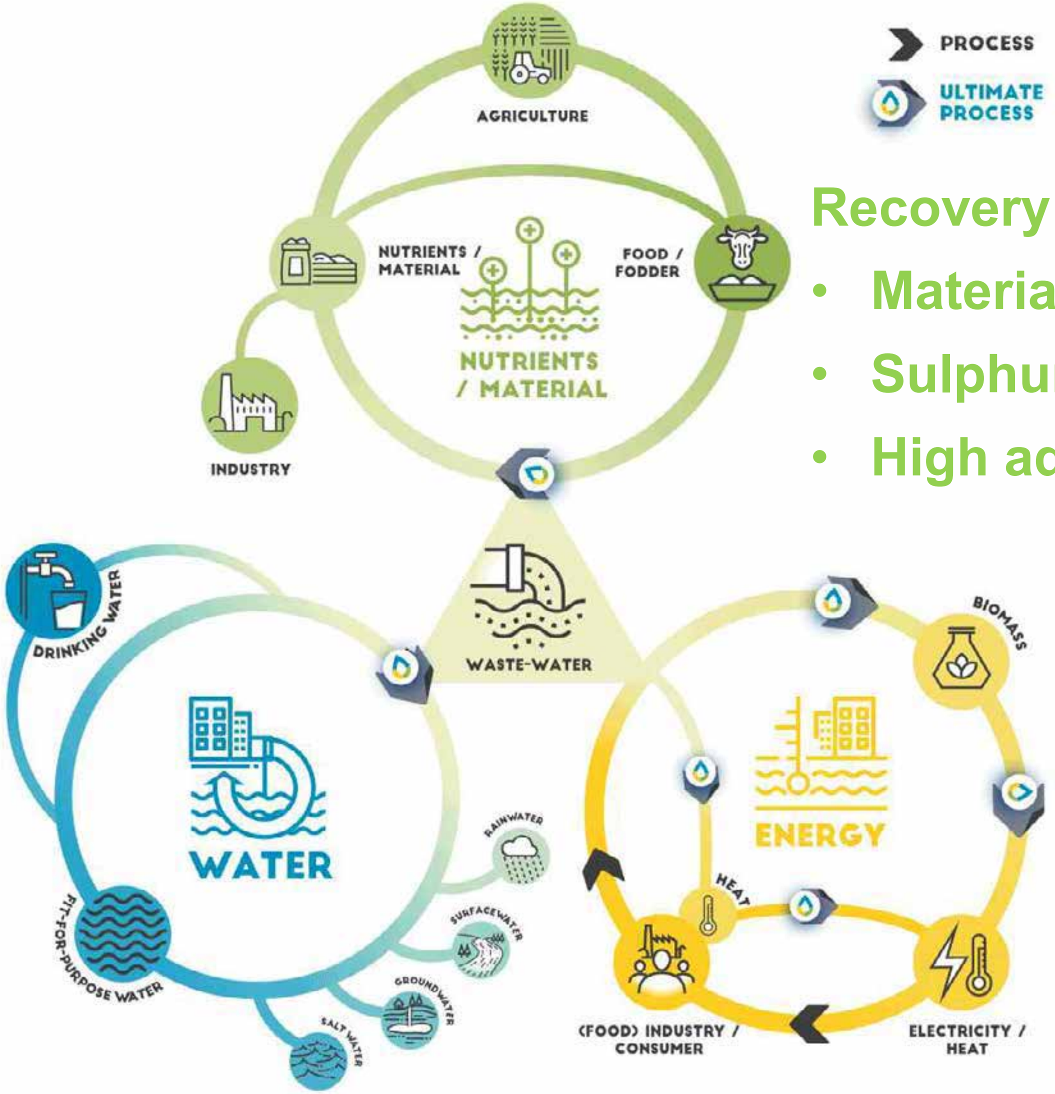
9 Case Studies

37 Technologies



The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

Ultimate solutions involve circular economy technologies



Recovery and reuse of:

- Materials
- Nutrients
- Sulphur
- Metals
- High added value products

- Membrane technologies
- Adsorption technologies
- Electrostimulated systems

- Biogas technologies
- Heat recovery
- Digitalization

The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

Tools to engage stakeholders

The main vision is to design and promote active stakeholder engagement and innovation co-creation by transdisciplinary knowledge and capacities from Art, Technology and Digital Humanities.
In this way, we will produce knowledge capable of addressing the complexities inherent in symbiotic arrangements engaging industry, water utilities and the general public

The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

Coordinator: KWR

9 Case Studies

37 Technologies

The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

What is the secret of successful WSIS?

10:05	**CS9: Kalundborg Symbiosis and the secret behind a resilient partnership** *Lisbeth Randers (Kalundborg Symbiosis)*
10:20	**Strategy and role of multi-utilities to deliver territorial symbioses and circular economy** *Enrico Pochettino (IREN)*
10:35	**CS3: The ARETUSA symbiosis for local and regional water-smart sustainability** *Gianluca Pettinello (Solvay) & Lorenzo Bagnoni (ARETUSA)*
10:50	**Break**
11:00	**CS1: Success of the Tarragona Symbiosis and strategy of the Water-Smart Industry Vision Leadership** *Miquel Rovira Boixaderas (Eurecat)*
11:15	**AquaSPICE: Capitalising the experience of others to achieve a successful symbiosis** *Athanasios Angelis-Dimakis (Huddersfield University)*
11:30	**Discussion** *(Moderation: Stefania Munaretto)*
12:15	**End**

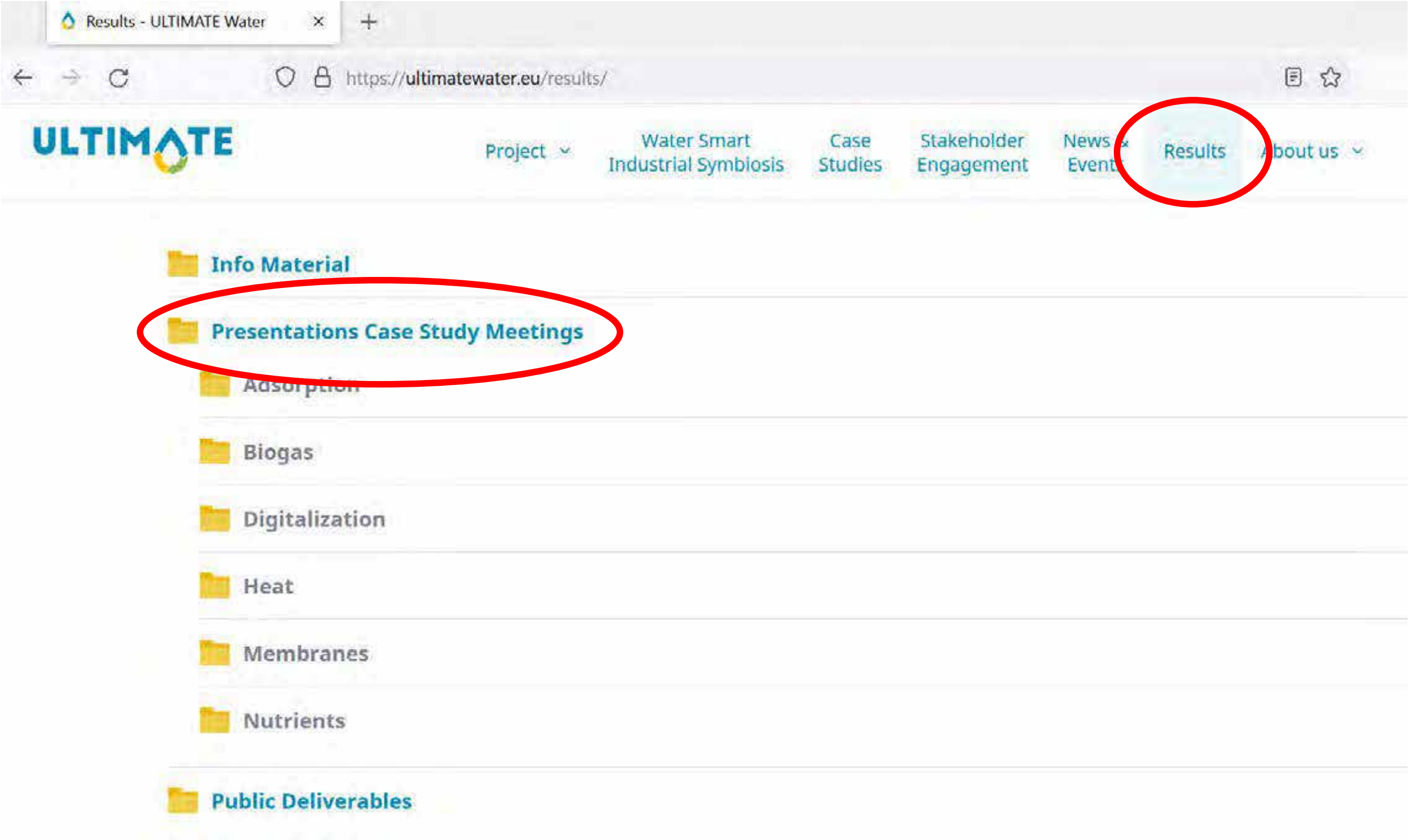
Please mute your microphone and use the chat to ask questions!

Please note: we will record the workshop

The recording starts at the beginning of the meeting.

The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

Presentations will be available on our webpage: **ultimatewater.eu**



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Success of the Tarragona Symbiosis and Strategy of the Water-Smart Industry Vision Leadership

Miquel Rovira Boixaderas and col.

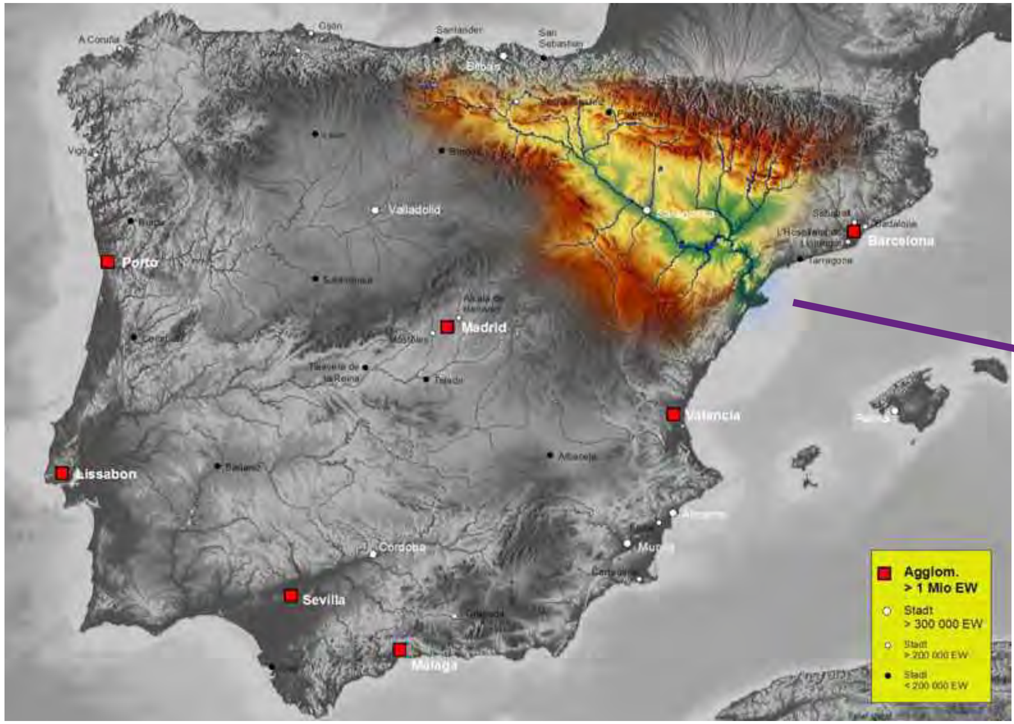
Eurecat – Centre Tecnològic de Catalunya
Water-Smart Industry VLT, Water Europe

23 III 2022

Ebre (Ebro) River

Centre Tecnològic de Catalunya

Ebre River: Largest River (volume) of Spain
Ebre River Delta:
- 1983 categorized as Natural Park
- 2013 UNESCO Biosphere Reserve Network



Contrasting Territories

The main economic activities in Terres de l'Ebre and the Metropolitan area of Tarragona depend on Ebre's water resources.

Camp de Tarragona

Metropolitan area of Tarragona-Reus with an economy based on industry, tourism and agriculture.

Terres de l'Ebre

Sub-region with an economy based on the primary sector

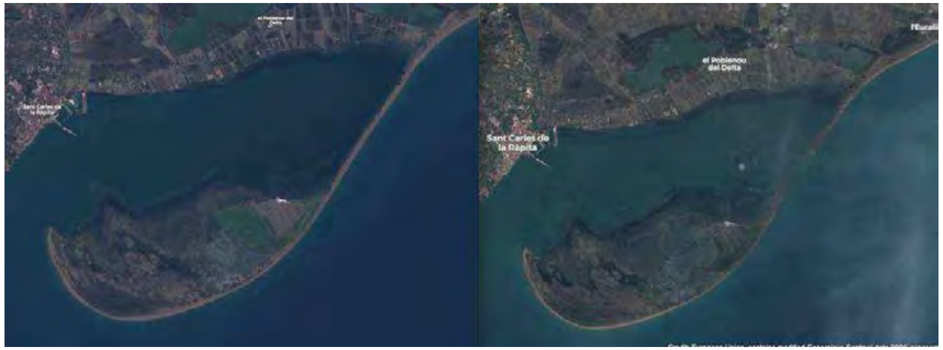
Contrasting Territories

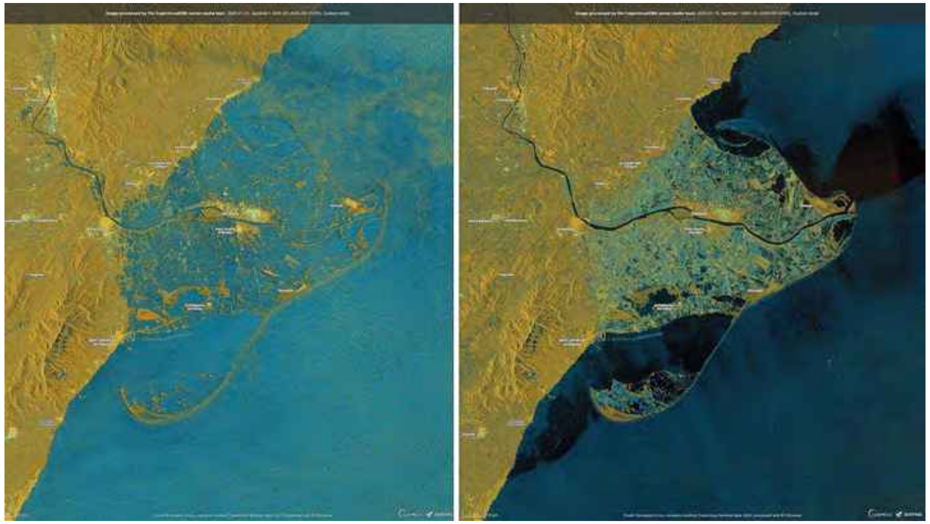
Historical water shortages affecting the Tarragona province were significantly overcome in 1989 by the formation of the Tarragona Water Consortium (CAT), a public water agency integrated by municipalities and industries, and charged with the construction and operation of a surface water transfer system from Ebro River.

Consorci d'Aigües de Tarragona

Both sub-regions are linked through water, since the Metropolitan area receives water from the Ebre River before entering the Ebre Delta trough a water transfer.

Ebre Delta





The lower Ebre River and its delta are a crucial ecosystem for the future of the whole region. Physical maintenance of the Ebro Delta depends on the inputs of water and sediments coming from the river.

Climate change adaptation is a deal in the area.

Camp de Tarragona

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Camp de Tarragona is a seasonal water stressed region, with historical water shortages.

This area takes Ebre River water for: municipal drinking water, tourism, industrial petrochemical complex and agriculture.

Camp de Tarragona: Petrochemical Industry

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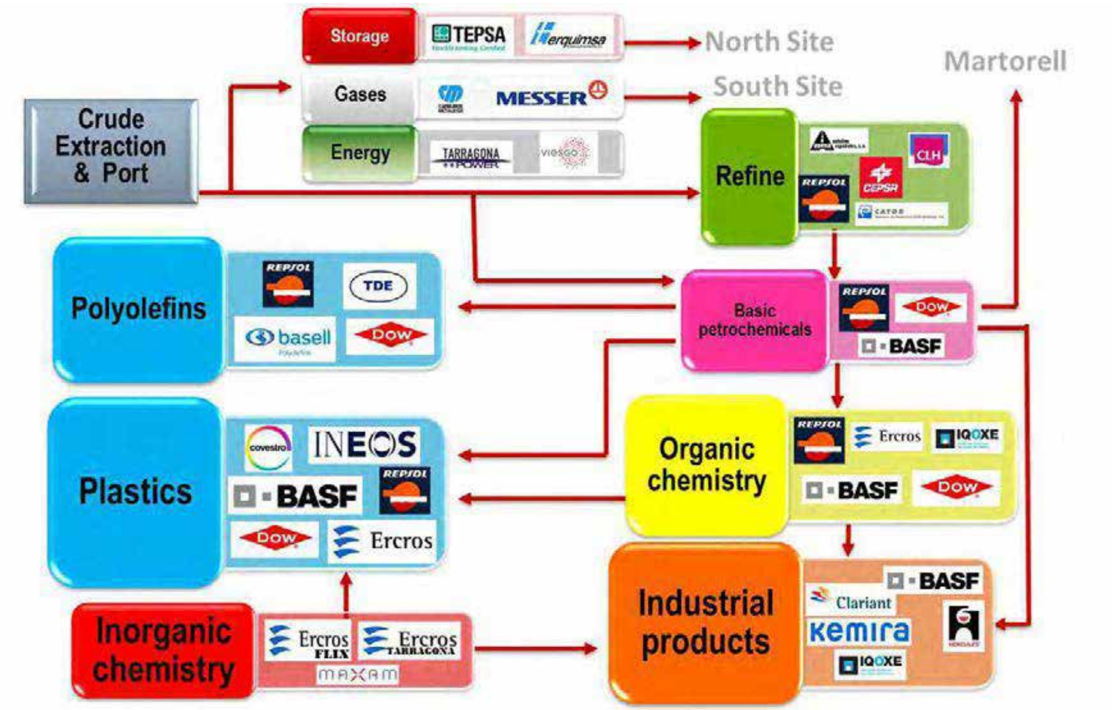
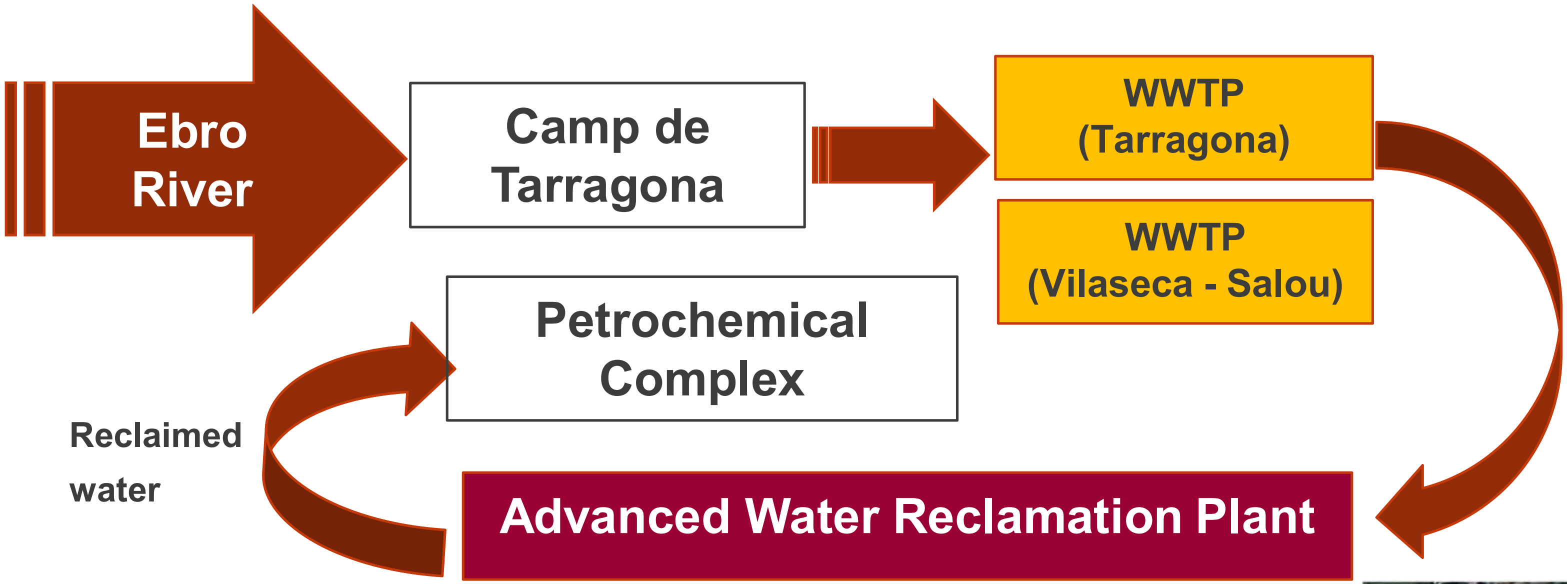
More than 100 chemical companies of all sizes, with 25% of chemical production in Spain and > 40,000 direct and indirect workplaces

Logistics Operators: SM Resinas, CHEMIPRATS S.L., Vopak Terquimsa, TEPSA, DP WORLD, BERTSCHI



The Symbiotic Solution



The Camp de Tarragona Advanced Water Reclamation Plant (CTAWRP) is fed with the secondary effluent water coming from Wastewater Treatment Plants (WWTP) of the nearby municipalities of Vilaseca, Salou and Tarragona.

The Symbiotic Solution

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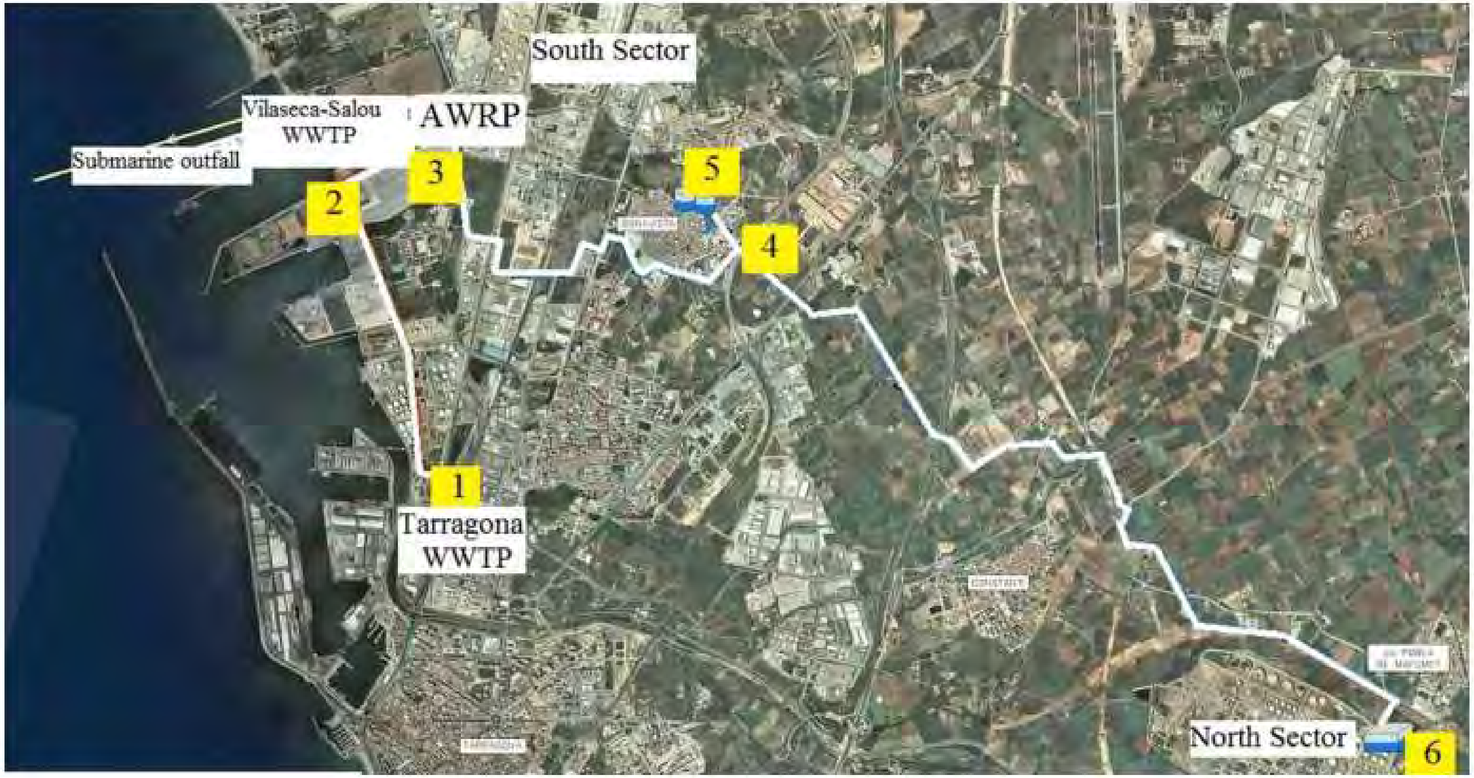

Figure 1 | Camp de Tarragona AWRP and reclaimed water supply network for industrial facilities at the Tarragona petrochemical park. (1) Tarragona wastewater treatment plant (WWTP); (2) diversion for submarine outfall; (3) Vilaseca-Salou WWTP and Camp de Tarragona AWRP; (4) diversion to north and south sectors of the petrochemical park; (5) reclaimed water storage tank for south sector; and (6) reclaimed water storage tank for north sector.

Reclaimed Water for the Tarragona petrochemical park. Sanz et al. (2015). Water Science & Technology Water Supply 15(2):308

Other uses in less extent:

urban Parks

golf courses

aquatic parks

Main Actors and Facts

Tarragona Water Consortium (CAT), a public water agency integrated by municipalities and industries.

AEQT is community-based association that includes chemical corporations operating in the area. There is a Public Advisory Panel.

AITASA is formed by the chemical companies of the Tarragona industrial area. Its objective is to supply industrial water to companies (more than 10 MHm3/y with a 43.5 km distribution network).

ACA is the public company of the Catalan Government Catalunya that is in charge of planning and water management in Catalonia.

Citizen involvement

Main Actors and Facts

In 2004 AEQT submitted a proposal to ACA for a project that would eliminate the need to take water from the Ebro transfer and instead supply the industry with water from treatment plants.

Since 2012, AITASA operates the The Camp de Tarragona Advanced Water Reclamation Plant producing water for boilers and cooling towers.

This locally available additional water supply replaces surface water, that before was transferred from the Ebro River. An equivalent volume of water is now available for other uses. With this new water source, industrial growth has been supported.

Main Actors and Facts

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Regulation
Spanish RD 1620/2007

Funding
With the contribution at 3 levels: europan, spanish and catalan governements

R&D&i
DEMOWARE (FP7), ULTIMATE (H2020), REWATCH (Life)…

Technology
Filtration, membranes, desinfection, monitoring…

Conclusions

Reclaimed water can be used in the industry instead of pre-treated river water with a positive impact in the environment.

Symbiosis between an industrially owned water utility and industry is successful.

PPP initiative.

Industrial climate change adaptation is in progress and with an increasing relevance.

Social awareness increasing regarding water, climate change and Ebro Delta.

Demonstration of the technology is important.

Citizenship involvement is crucial.

A living project,… enlargement of the plant under study.

VLT-Water Europe alignement

The Water-Smart Industry VLT pursue a future Water-Smart Society aligned to Water Europe's Vision with a focus on Industrial end-user needs, circular economy and climate change resilience.

The VLT will support the implementation of this Vision and look for opportunities to update it over time. In particular, the VLT will be mindful of the need to support the transition to climate neutrality and circularity as per the EU Green Deal goals as well as the Horizon Europe partnerships supported by WE (Water4All and Process4Planet).

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Thank you !

miquel.rovira@eurecat.org

ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

CS3: The Aretusa Symbiosis

G. Pettinello – L. Bagnoni

What is the secret of a successful symbiosis?

A **common target** between Industry, Public Authorities, Universities, Local Stakeholders

Often the target comes from a **common need**:

Water scarcity

↓

Need to recycle and reuse water for the industry

The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

Solvay ONE Planet

Reduce the environmental impact of our operations at planetary scale: tackle climate & biodiversity

CLIMATE

	Baseline 2018
Greenhouse gas emissions: Align its trajectory with "well below 2°C temperature increase" (2015 Paris Agreement)	-26% (-2%/y)
No more coal plant and phase out coal usage in energy production: wherever renewable alternatives exist	Achieve 100%
Biodiversity: reduce negative pressure on biodiversity beyond climate change: terrestrial acidification, water eutrophication, marine ecotoxicity	30% reduction

Accelerate the transition toward circular business and operations models

RESOURCES

Sustainable Solutions: increase the share of revenue in Sustainable Solutions	Achieve 65% vs 50%
Circular economy: increase the percentage of sales of products based on renewable or recycled resources	Achieve 15% vs 7%
Industrial waste: reduce non-recoverable industrial waste (landfill or incinerated without energy recovery)	30% reduction
Water use efficiency: decrease the impact on freshwater withdrawal by reducing intake of freshwater	25% reduction

Improve the quality of life of our employees and the society at large

BETTER LIFE

Safety: a zero accident policy aiming to protect the safety and security of employees	Aim for zero accident
Inclusion and Diversity: Gender parity for mid-and senior-level management by 2035	Parity vs 24%
Extending maternity and paternity leave: Solvay is adapting its global policy of 14 weeks maternity leave to 16 weeks, extending it to co-parents inside the company regardless of their gender, by 2021.	Extension to 16 weeks (by 2021)

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ASA – Aretusa Commitment

<u>Objectives in terms of Water-Footprint reduction</u>:

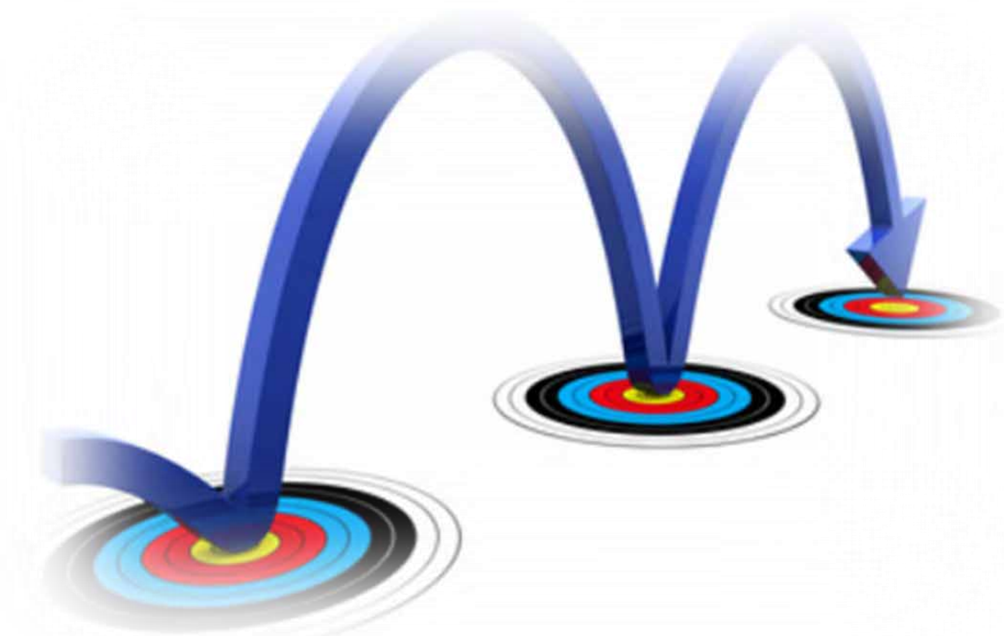
→ Collaboration in the growth of water re-use by Solvay;

→ Processes optimization in Aretusa WRP;

→ Enhancement of digital solutions: smart monitoring and control, Early Warning System model-based;

→ Collaboration in the analysis of potential replication of this system;

→ Enhancement of ASA's institutional tasks as head of a more circular Integrated Water Management in the area;



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What is the secret of a successful symbiosis?

Open communication between the parties:

Local community, Public Authorities, stakeholders have to drive the industry towards a more sustainable footprint

A **scientific approach:**

Science and Technology are the only sensible tool to solve the environmental challenge

Willingness to “**make it happen**”:

Aretusa Consortium has been successful because of the “make it happen” approach. Ultimate is showing the willingness to go one step beyond

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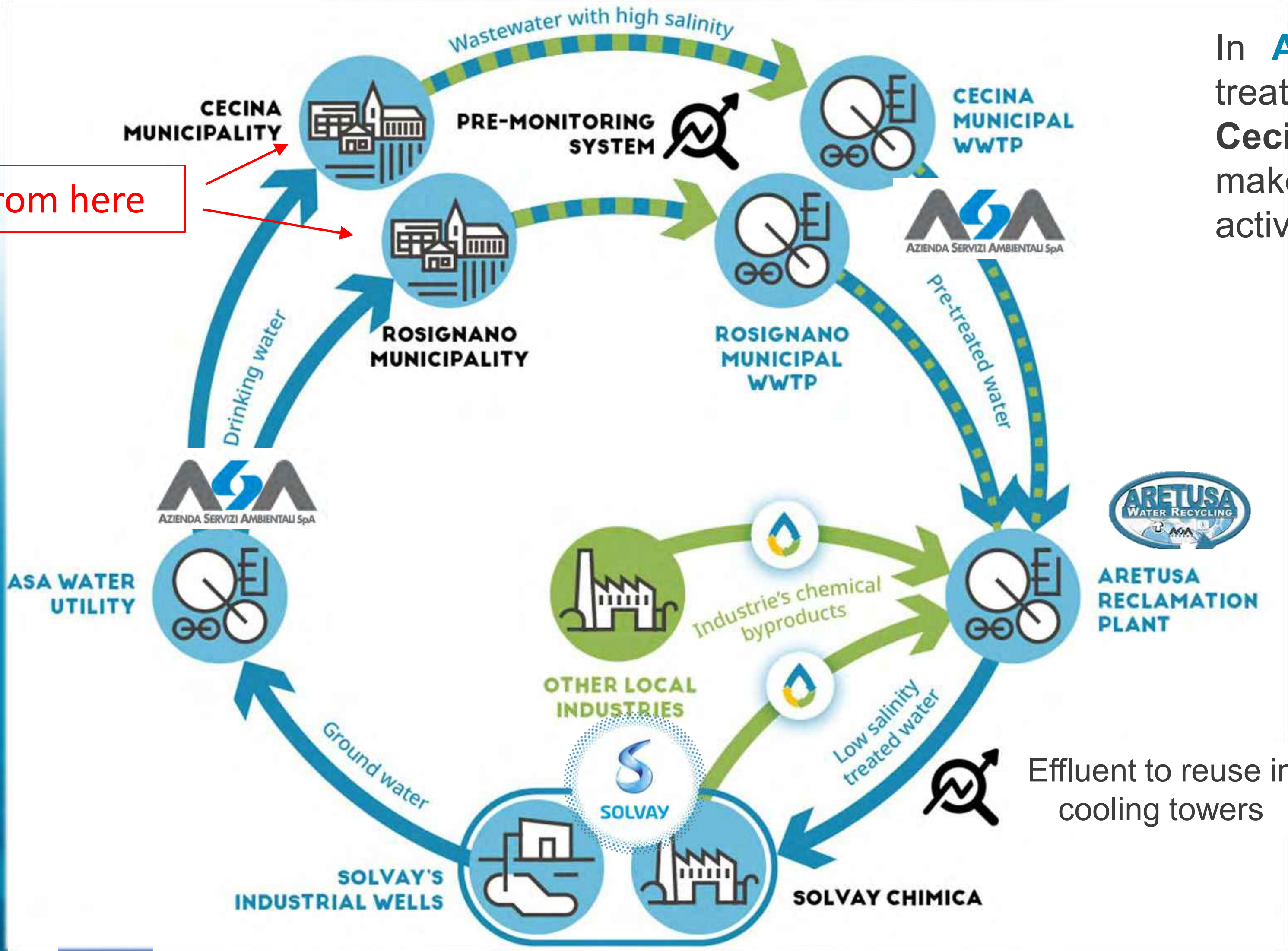
Aretusa concept – The technical idea



In **ARETUSA** Water Reclamation Plant we treat the secondary effluent coming from **Cecina** and **Rosignano WWTP** plants to make it **suitable for being reused** in industrial activities.

From ARETUSA WRP to Solvay Industry

3.5 M m3/y

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Ultimate – Going beyond

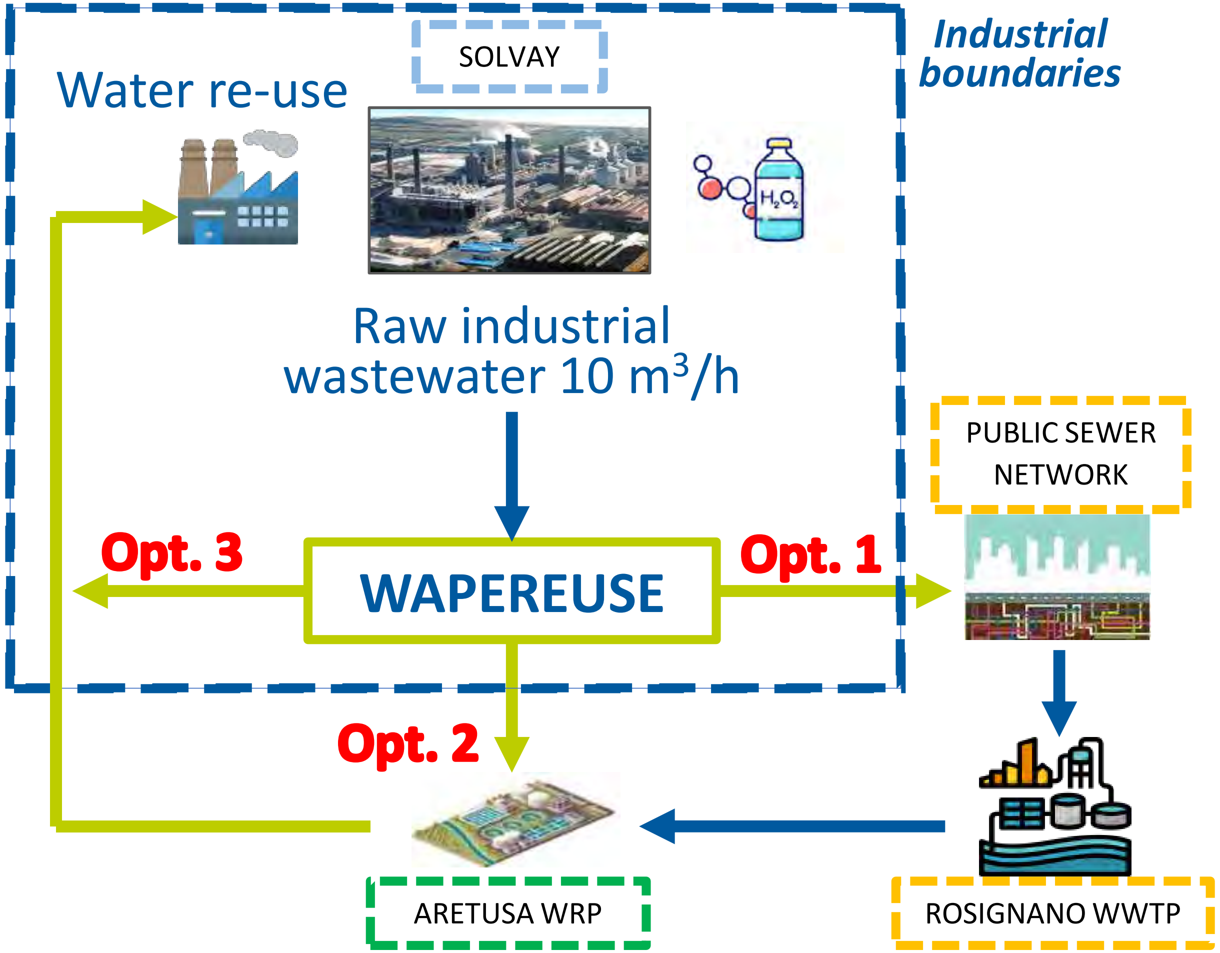
- Because the need to **reduce the environmental footprint** of industry has **grown** over the years
  - More social awareness of the climate change
  - Stakeholders expect the governments and the industries to act and act quickly
- Because the system can be **further optimized**
  - Improved water quality
  - Other more demanding uses within the Industry

The Aretusa Water Symbiosis attracts new actors, new activities

The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

Aquaspice – Co Creation

- Example of building on top of Aretusa concept
- Ambitious project to build a H_2O_2 zero effluent plant



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The lessons of Aretusa Symbiosis

Aretusa shows that the key factors for a successful symbiosis are:

- Keep **continuous dialogue** between the parties so that the needs/expectations are shared.
- Remove **prejudices**
- Listen and "**talk the same language**", not necessarily technical.
- Dedicate **adequate resources and competencies** to reach the common target

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Social learning systems

“A tree falling makes more noise than one million trees growing”

Solvay, ASA and UNIVPM are working to make local communities aware of water reuse concept and to look for opportunities:

- Projects of water reuse for **agricultural** use in the local district of Val di Cecina
- Meeting with local schools (ISIS Mattei 21-22 March 2022) to **stimulate young generations** to look at the territory with its critical issues as **opportunity** for the development of new ideas and businesses

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ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

Contact

lorenzo.bagnoni@solvay.com

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Kalundborg Symbiosis
Surplus from circular production
Kalundborg
SYMBIOSIS

The secret behind a resilient partnership

Lisbeth Randers, head of secretariat Kalundborg Symbiosis

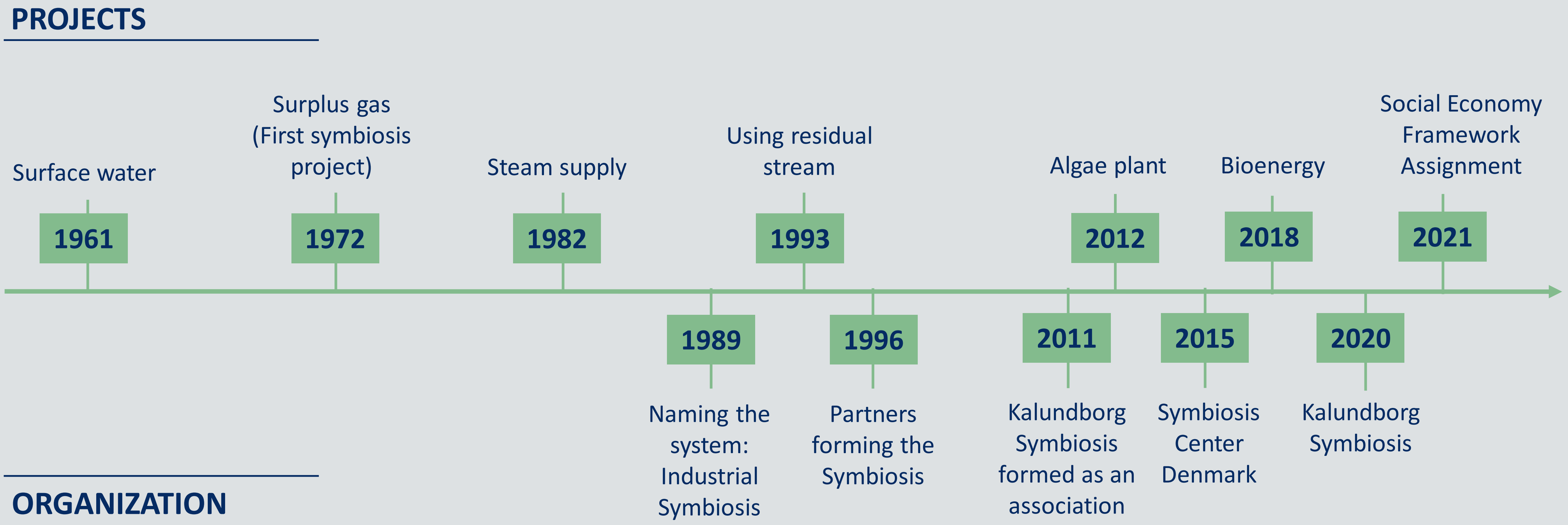
Ultimate conference, March 23rd 2022

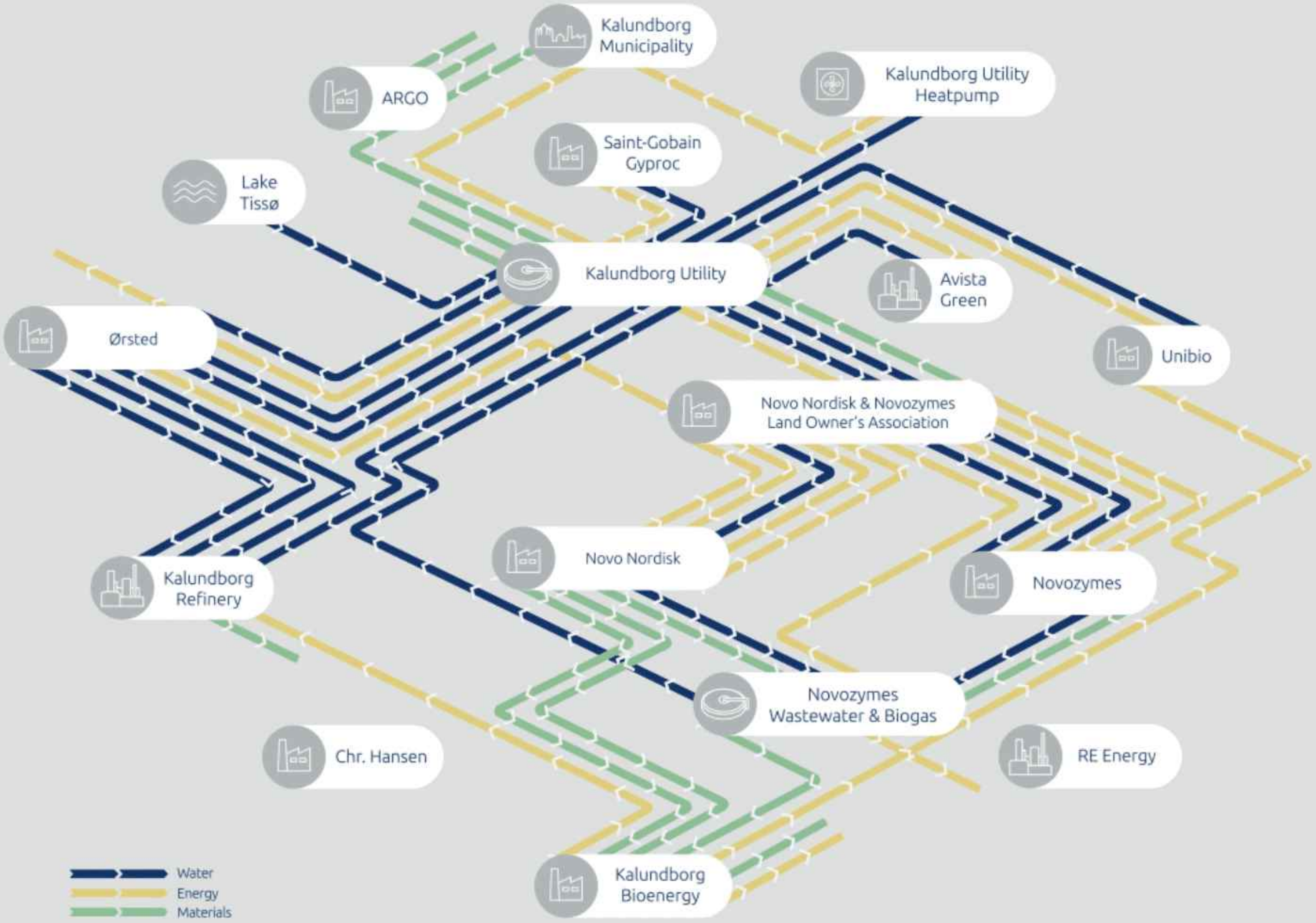
Kalundborg
SYMBIOSIS

Agenda

- The history
- The ecosystem
- Four drivers for the resilient partnership

More than 50 years of cooperation





Kalundborg Municipality
ARGO
Kalundborg Utility Heatpump
Saint-Gobain Gyproc
Lake Tissø
Kalundborg Utility
Avista Green
Ørsted
Unibio
Novo Nordisk & Novozymes Land Owner's Association
Novo Nordisk
Kalundborg Refinery
Novozymes
Novozymes Wastewater & Biogas
Chr. Hansen
RE Energy
Kalundborg Bioenergy
Water
Energy
Materials

Annual savings (by LCA)

586t. tons CO_2
The local energy production has reached NET-ZERO

4 million m3
of groundwater

62,000 tons
of residual materials recycled

Case 1: water as a mutual challenge

Surface water

Case 2: changing times – changing business models

Energy

Case 3: Innovation

Production in full scale

Case 4: Social Economy

The triple bottom-line


Kalundborg Symbiosis
Surplus from circular production
For more information please contact:
symbiosecenter@kalundborg.dk

Strategy and role of multi-utilities to deliver territorial symbioses and circular economy

Enrico Pochettino, Head of Innovation

Iren Group

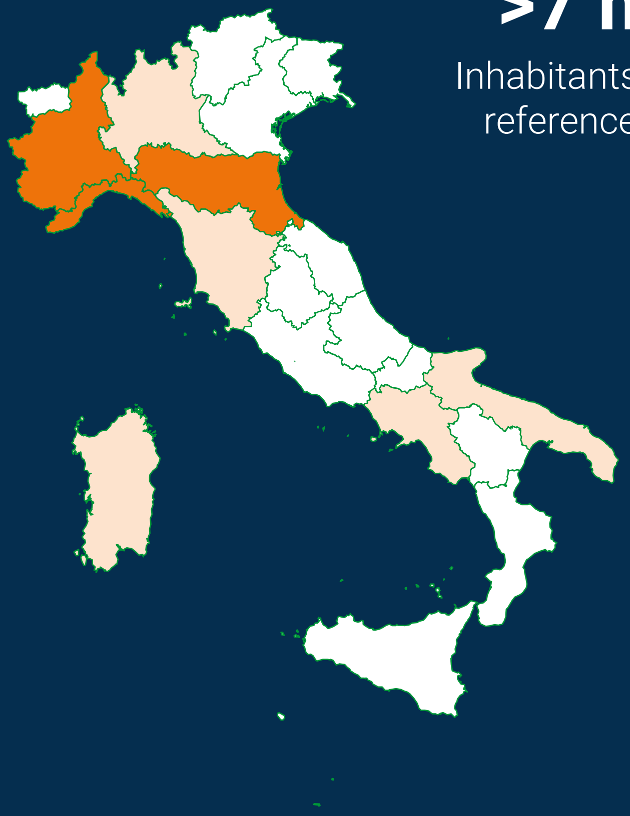
Networks
- Power
- Gas
- Water
- District Heating

Environment
- Collection
- Management

Energy
- Renewables and Storage
- Thermoelectric and CHP

Market
- Commodity (Gas)
- Commodity (power)
- Iren Plus

Smart solutions
- Energy Efficiency
- **E-mobility**
- **Infrastructural services for local communities**



>7 mln

Inhabitants in the 3 reference areas

1st national player in **district heating sector**

3rd national player in **water sector** (water sold)

3rd national player in **waste management sector** (tons treated)

25th among Italian industrial companies for revenues

Some figures about IREN

1st national player in district heating sector

3rd national player in water sector (water sold)

3rd national player in waste management sector (tons treated)

25th among Italian industrial companies for revenues

1,9
million customers
ENERGY SECTOR

> 3
million inhabitants
WASTE MANAGEMENT

2,8
million inhabitants
INTEGRATED WATER CYCLE

3,7
Billion €
FY 2020 REVENUES

9.000 employees

IREN's strategic plan in number

12,7 Bln €
in new investments
2021-30

Ecological Transition

- Progressive **decarbonisation** of businesses
- Strengthening leadership in the **circular economy**

Sustainable

80%

Territoriality

- Entry into **new territories**, also through acquisitions
- Becoming a **reference partner** for local stakeholders

Local

85%

Service Quality

- Excel in **network performance** and resilience
- Strengthen **customer satisfaction** in all business sectors

For improving service quality

50%

The ESG targets drive all business initiatives

34% Resilient cities
30% Decarbonization
19% Water Resources
17% Circular Economy

Environment

- **Decarbonisation** across activities
- Leadership in the **circular economy**
- **Sustainable** use of natural resources

- Carbon intensity halving
- 5x waste recovery
- Significant reduction of water losses

Social

- **Diversity** and inclusion
- Dissemination of **ESG best practices** and support for local communities

- More than 30% women in top corporate positions
- Supply chain involvement in ESG best practices

Governance

- ESG responsibility of senior management
- Maximum transparency and communication on ESG issues'

- Strengthening variable remuneration components linked to ESG issues
- Strengthening ESG-based policies

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Symbiosis with citizens and local communities

Iren Local Committees

Iren Local Committees are bodies, set up in 2014, to strengthen and make the dialogue with stakeholders systematic, thanks to participatory planning actions and moments of consultation, with the aim of:

gathering project proposal from local communities

citizens, associations, municipalities put forward ideas and proposals on sustainability issues. The Committees evaluate them, study their feasibility and implement them.

promoting

solutions to improve the environmental and social impact for the territory

improving

quality of the services provided by the Group

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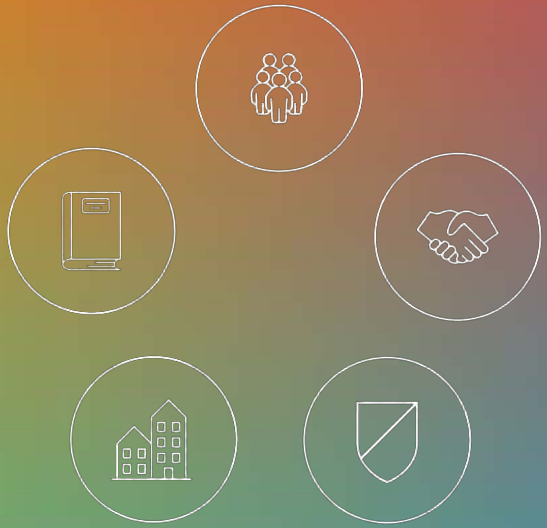
Local Committees structure

5 Local Committees: Genova, Parma, Piacenza, Reggio Emilia and Torino

15/18 REPRESENTATIVES OF CIVIL SOCIETY

- *Consumer, environmental, cultural, voluntary and third sector associations*
- *Employees and suppliers*
- *Trade associations*
- *Shareholders/Institutions*
- *Schools and Universities*
- *Social Cooperation*



5 MEMBERS

- *Iren Chairman*
- *Iren Vice-Chairman*
- *Province capital*
- *Province municipalities*
- *Universities*

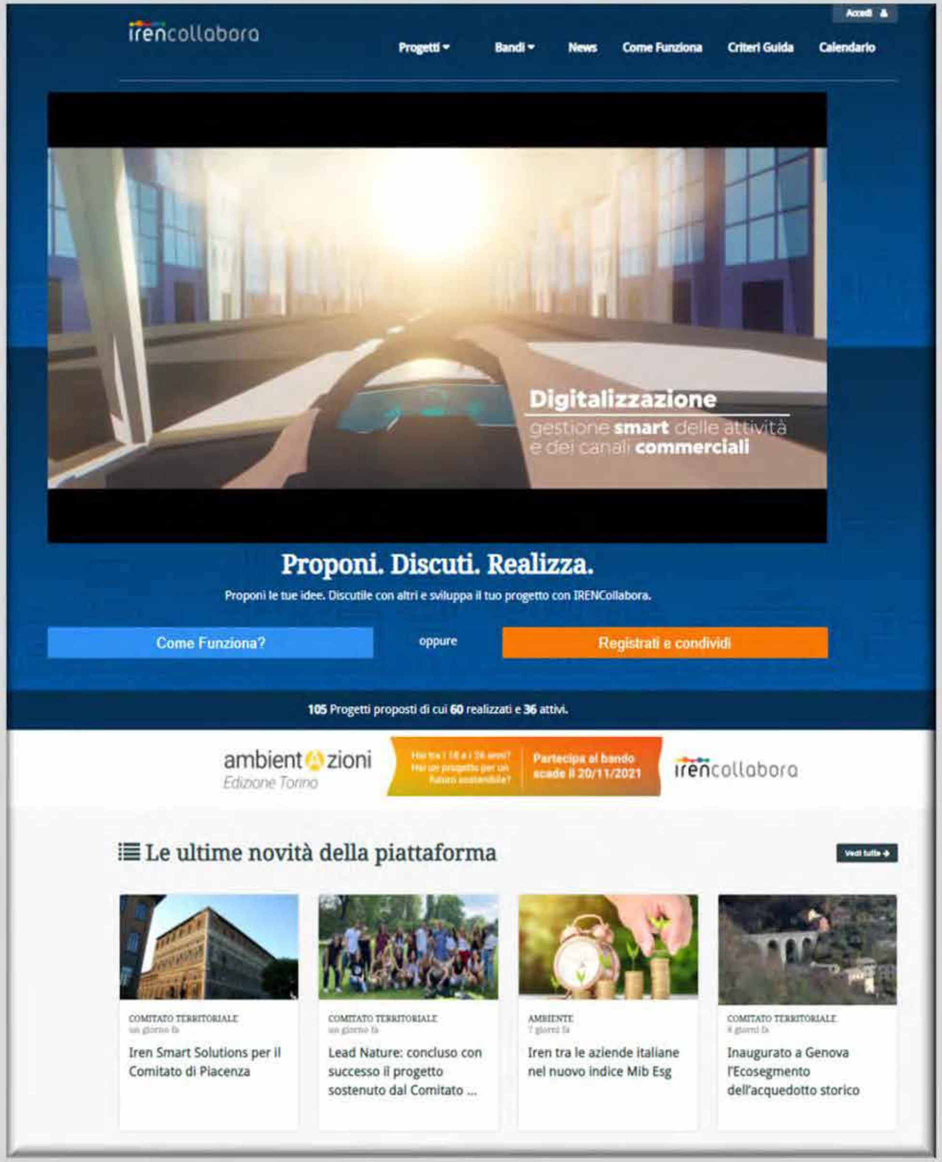
Participation is voluntary and free of charge.

Each committee has an annual budget to implement projects

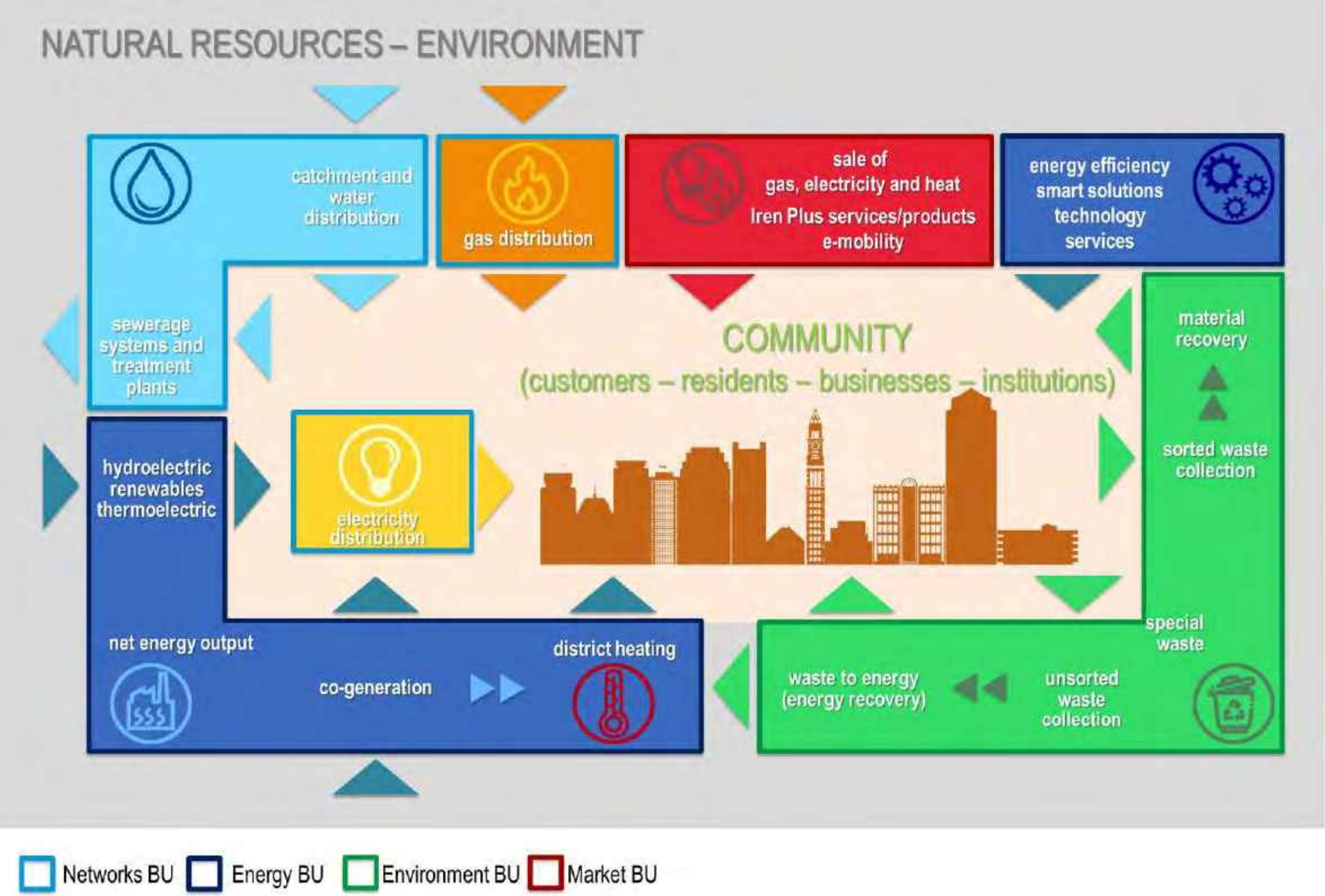
Citizens engagement

Irencollabora.it is the web platform in which citizens can publish project proposals addressed to the Local Committees

- encourages an **active involvement of stakeholders,** promoting problem analysis and projects deployment
- creates **new opportunities of collaboration** with citizens and civil society
- allows to adopt **innovative service strategies** and anticipate the needs of the territories



IREN «Multicircle Economy» concept



I.BLU: an example of Industrial Symbiosis in waste management

Using proprietary/patented processes and technologies **I.BLU** (IREN Group Company) develops new circular raw materials: **BLU-POLYMER** for industrial processes and **BLUAIR,** a revolutionary techno-polymer used in **metallurgical and steel processes**. I.BLU R&D department also has experimental projects in progress concerning the chemical recycling of mixed plastics.

I.BLU
Gruppo Iren

300K /TON YEAR
CURRENT PRODUCTION CAPACITY (plastic sorting + recycling)

500K /TON YEAR
TARGET FUTURE PRODUCTION CAPACITY (plastic sorting + recycling)

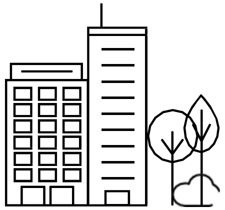
4
PRODUCTION PLANTS**

300
QUALIFIED TECHNICIANS

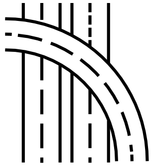
**San Giorgio di Nogaro (Udine), Reggio Emilia and Costa di Rovigo (Rovigo)

Blupolymer

BLUPOLYMER is a polyolefin granule mainly used to make:



- CONSTRUCTION AND INFRASTRUCTURE PRODUCTS, INSULATION SYSTEMS.



- AS A POLYMERIC ADDITIVE FOR HIGH PERFORMANCE ASPHALTS

BLUPOLYMER can be used to make materials and articles for industrial, logistics, and automotive purposes as well as outdoor urban furniture.

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Blupolymer

CIRCULAR PAVING

BLUPOLYMER increases the strength and durability of asphalt, ensuring greater safety and, at the same time, lower maintenance costs and waste of resources. It can be used for motorways, urban and suburban roads, industrial areas, logistics centers and airports.

URBAN FURNITURES

BLUPOLYMER can be used in several urban applications:

- Waterproofing and insulation systems
- Grass car parks, truck stops
- Furniture for public and private outdoor spaces (flooring and building accessories, green and service areas)

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BLUAIR

BLUAIR is a process optimizer engineered for **iron and steel production**. It can used in blast furnaces (BF) and electric arc furnaces (EAF) as **Secondary Reducing Agent** (SRA) in place of fossil carbon sources.
BLUAIR production and industrial applications are patented.

The use of **BLUAIR** represents an established and readily available opportunity to **decarbonise the steel industry**, while contributing to the Circular Economy.

In addition to **significantly reducing CO_2 emissions** and coal consumption, **BLUAIR** leads to increased industrial productivity and energy efficiency.
Many steelworks in Italy and Europe are currently replacing unsustainable fossil raw materials with **BLUAIR** in BF and EAF processes.

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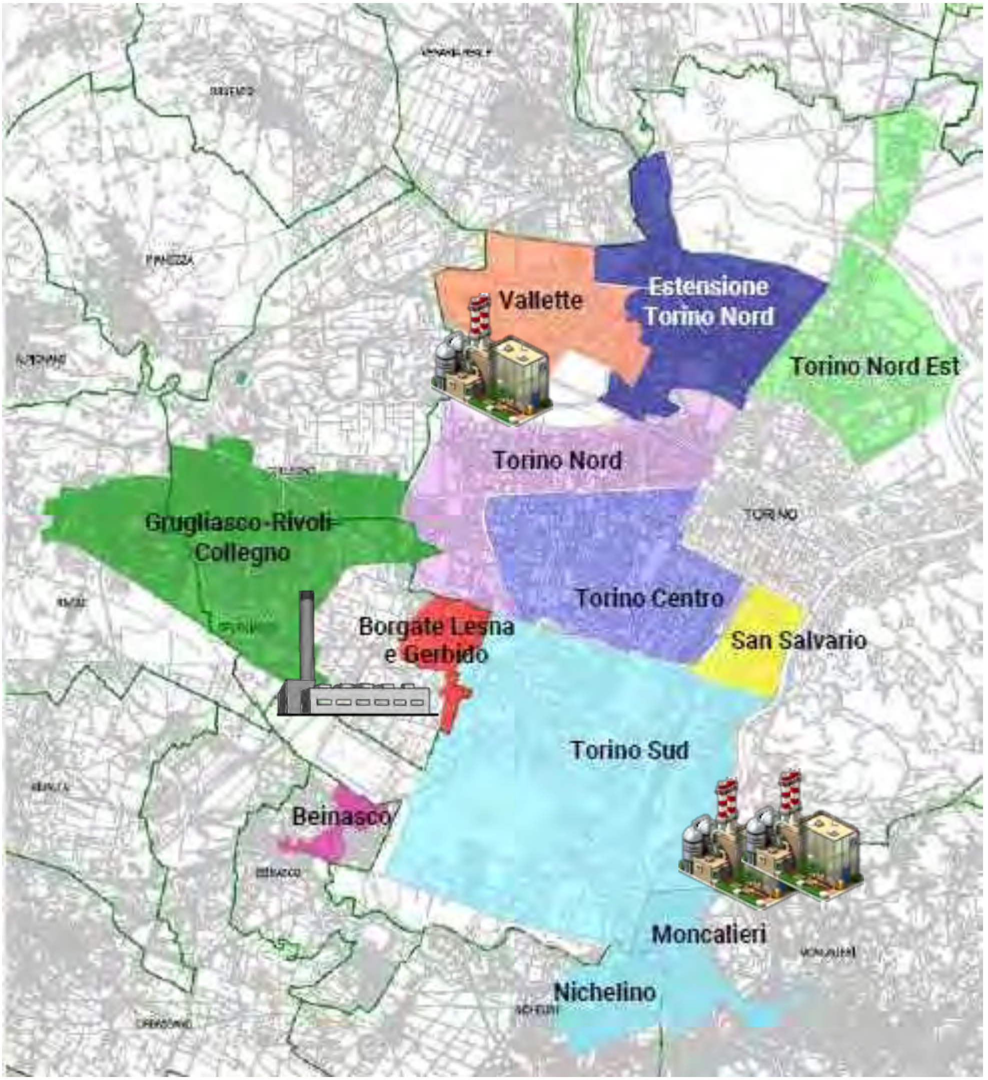
Mancasale WWTP: waste water reuse for agriculture

Mancasale (RE) WWTP represents the first plant in Emilia Romagna region equipped with an **advanced tertiary** treatment of waste water for **agriculture reuse.**

The project has been realized also thanks to the contributions of the European Union, through the Life project ReQpro.

The advanced tertiary treatment on the Mancasale WWTP includes a rapid filtration on sand (16 units) coupled with a **disinfection process** that combines the dosage of hydrogen peroxide (H_2O_2) with UV radiation and is able to remove the most persistent pollutants (mineral oils and surfactants) and significantly reduce the bacterial load (Salmonella and E. Coli).

Heat recovery: Turin district heating network



Some figures about the Turin district heating network:

- 71,35 million m^3 heated volumes
- 700 km of double pipelines
- 7.584 substations connected to the network
- 1.860 MWth e 1.160 MWe installed power

Heat recovery from CHP power plants + Waste-to-Energy plant (thermal generation 2020: 2.278 GWh)

Largest district heating network in Italy

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Thanks for your attention

Iren S.p.A.
Reggio Emilia | Via Nubi di Magellano, 30 - 42123
Torino | Corso Svizzera, 95 - 10143
Genova | Via SS. Giacomo e Filippo, 7 - 16122
Parma | Strada S. Margherita, 6/A - 43123
Piacenza | Strada Borgoforte, 22 – 29122

www.gruppoiren.it

Advancing Sustainability of Process Industries through Digital and Circular Water Use Innovations

AquaSPICE: Capitalising the experience of other projects to achieve a successful (water) symbiosis

Dr Athanasios Angelis-Dimakis - *University of Huddersfield*

Prof George Arampatzis – *Technical University of Crete*

Dr Johann Poinapen – *KWR Water Research Institute*

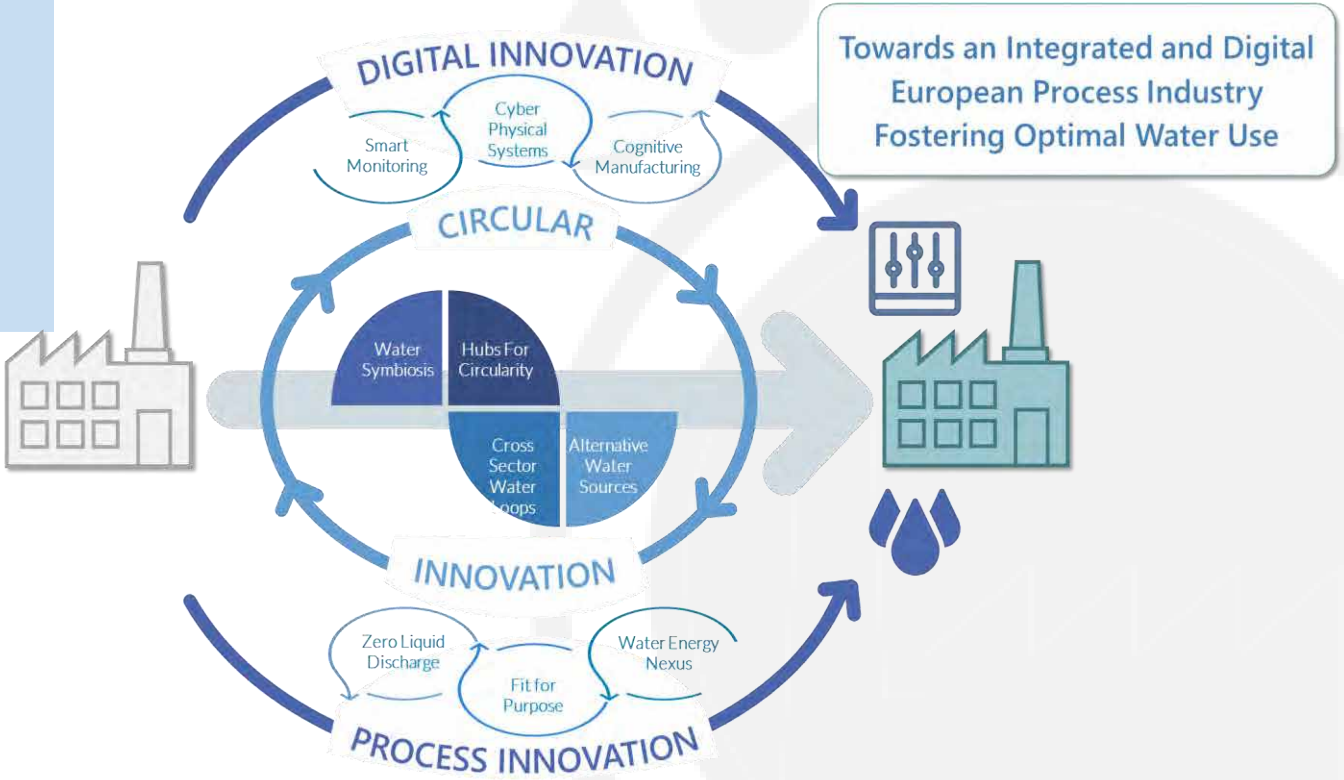
23 March 2022

The AquaSPICE project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 958396.

AquaSPICE Innovation Pillars

CIRCULAR INNOVATION

- Water re-use options at different levels
- Design, monitoring and evaluation of demonstration schemes using systemic methodologies and tools, based on holistic modelling concepts



PROCESS INNOVATION

- Installation,
- Operation, and
- Assessment of advanced technologies and practices with energy and substances recovery

DIGITAL INNOVATION

- Water-specific Cyber-Physical-System (WaterCPS) synthesises digital twins of industrial and value chain entities to provide advanced water-saving awareness and optimised water efficiency at different industrial levels
- Real-time monitoring and distributed data management system connects the physical and digital worlds through smart sensor networks, IIoT and cloud/edge technologies

Capitalising the experience of relevant EU funded projects

Name	Year	Waste	Type	Region	Led by
enCO_2re	2015-2016	Carbon Dioxide	Gas	Northern Europe	Industry
Bri4Food	2016	Brines	Liquid	Mediterranean	Industry
SWAN	2019-2020	Solid Waste	Solid	Balkan Region	Public Authority
AquaSPICE	2020-2024	Industrial Water	Liquid	EU	RO

- Different Characteristics, Different Barriers and Different Problems
- Main factors examined
  - Technical Considerations
  - Industrial and Public Awareness
  - Common Sense

AquaSPICE

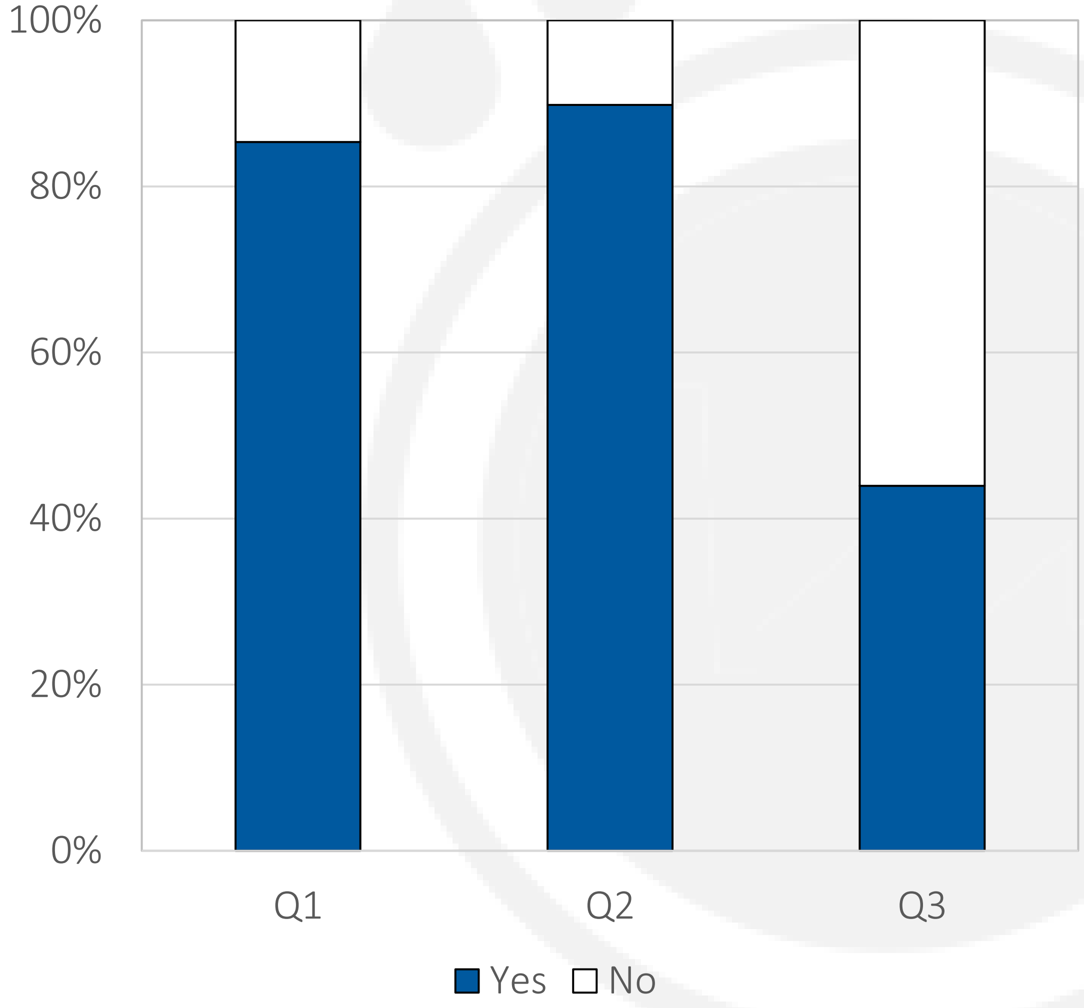
Technical Considerations

	Solid Waste	Gas Waste	Liquid Waste
Waste Source	Manual or mechanical sorting and separation	Capture and Purification	Purification/Treatment
Storage	Most probably required	Only if liquified (as intermediate step)	Rarely Considered
Matching Sources with Receivers	Challenging since the streams are not uniform/homogenous	Based on purity of main component / presence of hazardous compounds	Based on stream composition / presence of hazardous compounds
Transportation	Trucks only	Trucks, pipes, ships	Mostly using pipes
Environmental Impact	Carbon Footprint	Carbon Footprint	Carbon & Water Footprint
Safe Reuse	Hazardous waste excluded from the matching process	Need for end-of-waste criteria	EU/National Directives for reuse based on sector
Aspects for IS success	Industrial Awareness	Distance, Product Acceptability	??

Industrial Awareness and Support

- 315 industrial plants in the Balkan Region
  - Q1 Are you familiar with the concept of industrial symbiosis?
  - Q2 Would the plant be interested in participating in symbiotic value chains?
  - Q3 Are there any existing symbiotic links in the company?

Industrial awareness exists but the **instruments** are missing. **AquaSPICE** will (hopefully) contribute closing the gap by facilitating stakeholder engagement at Case Study level



Public Awareness

- In order of the new business models to be economic viable, there needs to be a market for the new products.
- Would you buy a fizzy drink with captured CO_2 from a nearby chimney?
- Would you buy an exfoliant from used coffee grains?

Would you buy:	1: Strongly Disagree 5: Strongly Agree
Petrol for your car	4.31 (SD 0.91)
Mattress for your bed	4.06 (SD 0.96)
Concrete for your house	4.20 (SD 0.91)
1 kg tomatoes	3.79 (SD 1.11)
1 bottle of fizzy drink	3.88 (SD 1.06)
Dietary supplements	3.75 (SD 1.07)

Public knowledge affects acceptability and thus success of symbiotic schemes. Public showed willingness to support such schemes. **AquaSPICE** will (hopefully) contribute to increase awareness via its Communication, Dissemination, Training and Social Awareness strategy.

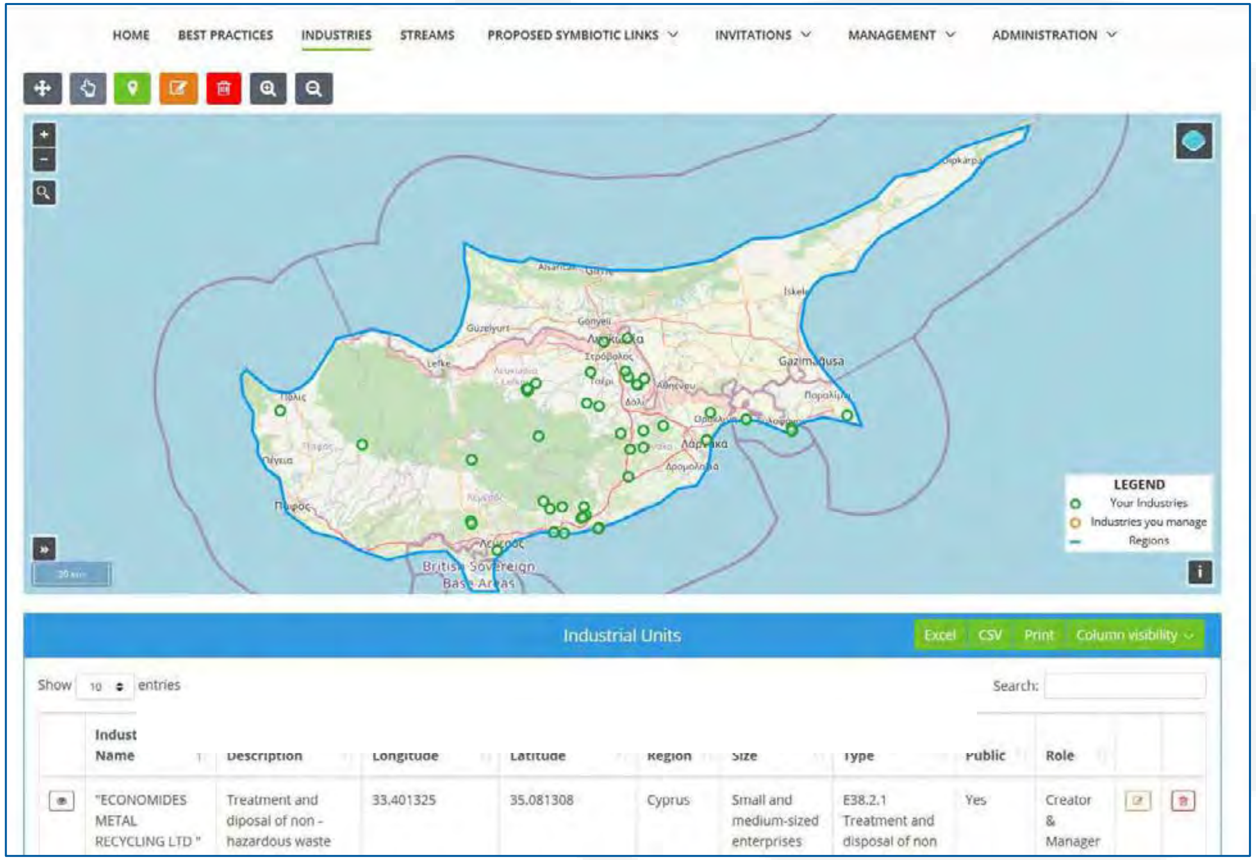
Common Sense

- Usually, the waste stream in a symbiotic scheme is incorporated in the final product.
- What might go wrong if the waste stream is not incorporated but used as a supplementary resource in a different production line?
- A desalination unit provides drinking water to the local community, and has the right to discharge water to the water body quid pro quo…
- What if they want to redirect the wastewater stream to another local industry?

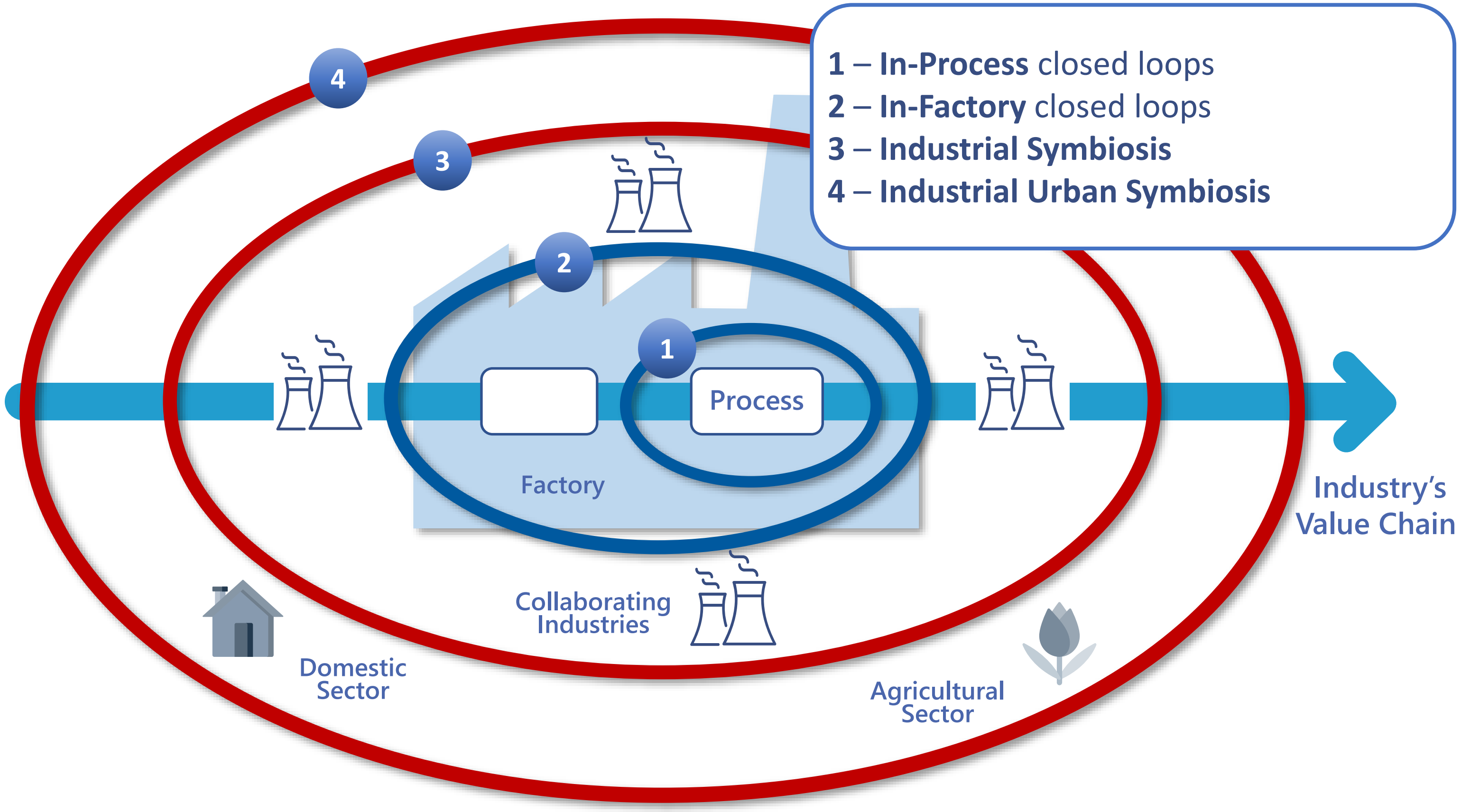
Should we / can we address everything?

Promoting Industrial Symbiosis in AquaSPICE

- Design and develop an online platform that will facilitate the formulation of novel symbiotic business models focusing on water/wastewater reuse.
- Propose alternative solutions and assess their technical feasibility using a semantic approach based on the qualitative and quantitative characteristics of the water/wastewater streams
- Assess the economic viability of all the technically feasible symbiotic schemes.



Applying Industrial Symbiosis in AquaSPICE



Waste to fuel transformation in a Biorefinery at JEMS
Location: Ljubljana (SL)
Symbiotic potential between biorefinery, agricultural stakeholders, local municipality and industrial plants

Water treatment and re-use with peroxide production units at SOLVAY
Location: Tuscany and Marche (IT)
Symbiotic potential between Solvay, ARETUSA and local municipality

Advancing Sustainability of Process Industries through Digital and Circular Water Use Innovations

Thank You!

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