ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

Deliverable 1.10

Lessons learned from synergy workshops



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[1] PU = Public
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Executive Summary

Background and objective of the synergy workshops

ULTIMATE promoted, established and extended water smart industrial symbioses (WSIS) between the industrial sector and service providers of the water sector. WSIS are the foundation for a successful implementation of circular economy technologies, because one partner produces a resource or product, and the other partner has the demand for it. Therefore, the partners cooperate for their mutual advantages. In ULTIMATE, circular economy technologies were developed and demonstrated via a symbiotic management through the WSIS at nine case studies.
In this frame, eighteen workshops have been conducted for the case studies to identify synergies among the ULTIMATE partners and with other Horizon 2020 projects.
This deliverable provides an overview about the main contents of the presentations, the lessons learned from the discussions and take home-messages from the workshops. D1.10 is an update of D1.8 with results from the case studies dealing with water, energy and material recovery related technologies and provides recommendations for European policy, what should be considered to boost the market uptake of the ULTIMATE technologies to replicate them.

To establish and make a WSIS successful, we identified the attitude of the symbiosis partner, having commitment and willingness to act together to “make it happen”, being extremely important. 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. In addition, lighthouse cases such as the WSIS in Kalundborg, Tarragona and Rosignano are extremely helpful for WSIS newcomers to learn from them for their own WSIS establishment. All potential stakeholders, including administrative actors, should be part of the establishment already from the very first idea onwards.

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, Fiware4water, Routes, Res-urbis, Water2-Return, Sludge4.0, Circular Biocarbon and BioKS. The case study leaders profited from the lessons learned and discussions about their concepts to set up their demo cases properly. This contributed to the successful implementation of thoughtful ULTIMATE solutions and provided 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

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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.

However, still European policy can highly support the market up-take of the ULTIMATE solutions and their replication. Therefore, the following policy recommendations were identified in the workshops:

- **Water recovery**

Policy recommendations are crucial for fostering water reuse and promote a water circular economy model. Increasing treated wastewater quality requirements under the revised Urban Wastewater Treatment Directive (UWWTD) can simplify water reclamation processes, potentially eliminating the need for additional advanced treatments. Monitoring remains crucial but can be costly, impacting the economic feasibility of water reuse. Public engagement and awareness are essential to overcoming negative perceptions and increasing acceptance of reused water. Business models, funding, and pricing are critical for successful implementation, with multi-user systems enhancing technical and economic viability. Clarifying responsibilities and developing consistent guidelines for water reuse licensing and service provision across the EU are essential to ensure effective practices. The strategic agenda proposes comprehensive coverage of all water reuse types, emphasizing safety, environmental impact assessment, and the integration of reclaimed water into local water balances based on regional circumstances. Future regulations should establish minimum standards for non-agricultural uses, enhance risk assessment, and promote research on innovative water reuse technologies and practices.

- **Digital technologies such as early warning and control systems**

Providing access to publicly available data (historical and real-time) being digital and of a uniform data type, e.g. same time periods for different regions and countries, can highly boost the replication of such systems such as the water demand forecasting tool. The requirement to develop digital solutions based on FIWARE architecture and

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publishing them open access can contribute to a better compatibility of different solutions and strongly helps to replicate such solutions.

- **Biogas related technologies**:

To replicate biogas production and valorisation technologies in Europe, stable prices for upgraded biogas and electricity are needed at least for a period of five years to amortise the plant. Another five years would be beneficial, after an adaption on the energy market, to provide incentives to the investors. To bridge a potential gap between the guaranteed price and the actual market price, subsidies might be needed. A minimum quota for upgraded bio-methane in the gas grid can further support the willingness of investors to implement biogas production technologies and upgrading units. A simplification of administrative formalities and financial support related to the gas grid connection can highly accelerate the implementation of biomethane producing technologies.

- **Heat recovery and reuse**

To investigate the potential of the implementation of an HT-ATES, test drillings to characterise the subsurface are expensive and time consuming. They are considered as a barrier for an easy market uptake of this technology. Hence, more research and demonstration projects are recommended to establish inexpensive, reliable and innovative technologies and their combinations in order to avoid uncertainties during planning of an HT-ATES and to accelerate the planning process. The highest risks are considered to be uncertain permit procedures and public perception. Furthermore, the permit procedure for a HT-ATES requires usually several years. We strongly suggest accelerating this procedure and to promote the demonstration of full-scale pilot systems in order to develop suitable policies and to show in practice that HT-ATES is a renewable, clean and safe technique.

- **Material recovery and end of waste status**

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, and synergies for increasing water and/or energy recovery.
Material recovery from industries has enormous potential, but the number of by-products that are currently obtained are far below their maximum due to significant challenges that have to be overcome. The recovery of value-added compounds usually requires the implementation of different treatment steps to be implemented in existing plants to reach an adequate quality of the necessary quality of the circular products (products recovered from wastes). The quality of the final product is fundamental for the market accessibility, but in the current market it is often complicated to introduce circular products due to the competition with conventional products, low production of

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circular products that avoids having significant impact in the market, scarce social acceptance and sometimes a lack of regulation.

Legislation is also fundamental for the recognition of a recovered material as product if it is generated by a waste (end-of-waste criteria). However, some regulatory barriers and gaps have been also detected. The end-of-waste criteria as defined nowadays is often unclear, especially for certain by-products obtained from emerging technologies. In this respect, it is often hard to demonstrate all the conditions that need to be accomplished, especially with certain products such as alternative building blocks.

Lack of successful large-scale case studies, scarce interest in waste producers to adopt circular processes, and variability of byproducts' characteristics were also some detected barriers for the recovery of materials. Material recovery is even more challenging from urban wastewater. In fact, it is barely mentioned in the new wastewater treatment directive. Industries can be more relevant actors to exploit the high potentiality of material recovery from industrial wastewaters as they can be associated more efficiently (industrial symbiosis).

The implementation of successful industrial symbiosis cases (at demonstrative scale), together with improved public-private collaboration are expected to improve the current situation on material recovery. It is also essential to obtain subsidies in terms of grants, loans or other to assume the high investment in circular technologies.The main barriers for the implementation of such concepts were related to regulatory barriers and gaps, the need of increasing social acceptance, market competition, low production to significantly enter in the market, lack of successful large-scale case studies, scarce interest on waste producers to adopt circular processes, and variability of byproducts' characteristics.

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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
MLSS	Mixed liquor suspended solids
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 promoted, established and extended 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 a product, and the other partner has the demand for it. Thus, they cooperate for their mutual advantage. In ULTIMATE, circular economy technologies were 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
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, 2024a). Depending on the type of wastewater and resource, different treatment trains were applied. In total, 24 innovative technologies were investigated in ULTIMATE (Naves Arnaldos et al. 2024, Kleyböcker et al. 2024b and Gonzalez Camejo et al. 2024). In order to exploit synergies between the different cross-cutting technology groups (CTG) for water, material and energy, similar concepts and the development as well as the performance of those technologies were discussed. For each CTG, different topics were defined as shown in Figure 1.

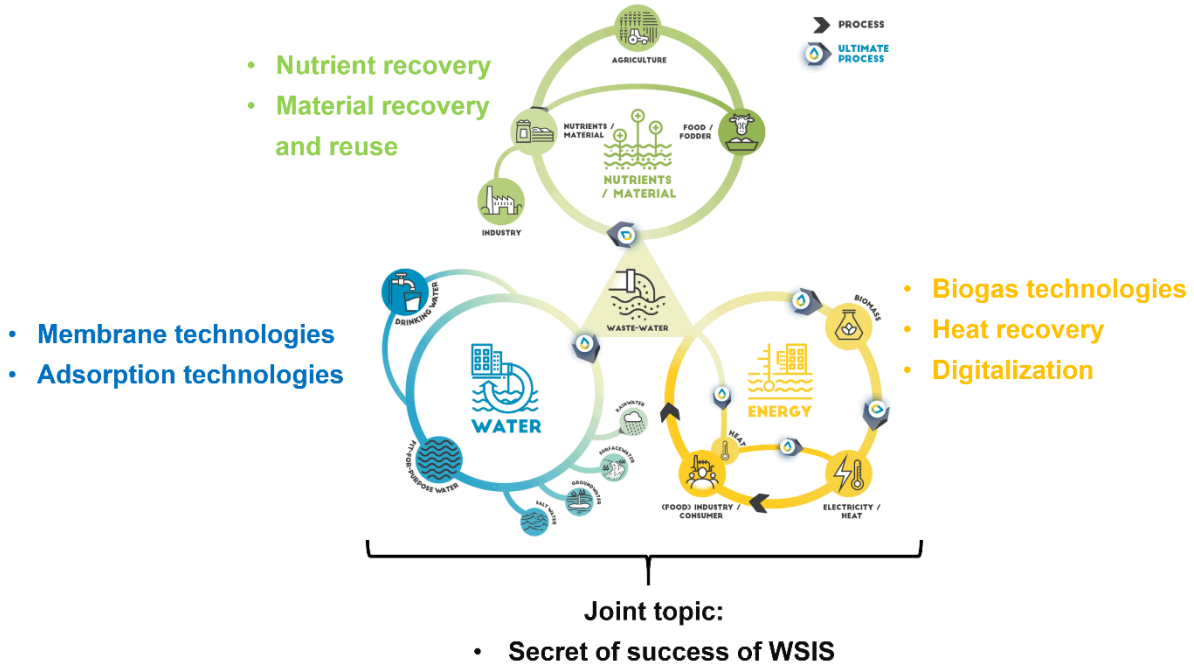

Figure 1 *Cross-cutting technology groups and their sub-categories related to the types of technologies applied in ULTIMATE*

In this frame, eighteen workshops were conducted, each dedicated to one of the topics in Figure 1. In the workshops, the ULTIMATE concepts were discussed and external experts from sixteen research 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 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), BioKS (0324029A), and Circular Biocarbon (GA 101023280) 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, B-WaterSmart, wider uptake
	CS4	Filtration and small bioreactor platform for wastewater reuse in the food industry	
	CS5	Experiences in Aqualia with Anaerobic Membrane Bioreactors, core for future water resource recovery facilities	
	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, SEA4VALUE, water mining
	CS3	Innovative sensors and alternative materials for the removal of organic matter and micropollutants by adsorption and AOP technologies in ARETUSA	
	CS4, CS6	Hybrid adsorption and subcritical water extraction	
Water recovery	CS1	Increasing reclaimed water availability of the petrochemical complex of Tarragona	B-WaterSmart
	CS2	Optimizing water reclamation for agro-food industries in N. Prinsenland	
	CS3	20 years of municipal water reuse in chemical industries: governance, technologies and future perspectives	
	CS9	Novel membrane treatment for biotech or biotech+municipal WWTP effluent for water reuse in Kalundborg	

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Workshop	CS	Topics of ULTIMATE presentations	Presentations from other projects or organisations
Biogas technologies	CS5	AnMBR and ELSAR for biogas production from brewery wastewater	nextGen Circular Water Solutions; wider uptake; SMART-Plant
	CS6	Immobilised high-rate anaerobic system & biogas process stabilizing measures	
	CS7	Biogas production in an anaerobic membrane reactor from distillery wastewater	
	CS5	Early warning system for membrane fouling	
	CS9	Joint control system for two WWTPs	
Heat recovery	CS2	High temperature aquifer thermal energy solution in greenhouses	nextGen Circular Water Solutions; BioKS; water mining
	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; B-WaterSmart
	CS5	Early warning system for membrane fouling	
	CS9	Joint control system for two WWTPs	
Nutrient recovery	CS2	Recovery of nutrients from greenhouse wastewater via electrodialysis	nextGen Circular Water Solutions; B-WaterSmart; water mining; RUN4LIFE; REwaise; SMART-Plant
	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	SMART-Plant; CIRCULAR BIOCARBON; Water2Return; wider uptake; water mining; Routes; ARETUSA; sludge 4.0
	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	iren; AquaSPICE
	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. A second membrane technologies workshop was conducted on March 6th, with 24 participants. This time, Tarragona (CS1), Lleida (CS5) and Kalundborg (CS9) were presented. Furthermore, B-watersmart and Wideruptake sister projects participated as well, presenting two case study. 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 and 9.

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 high conductivity stream or 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) Testing a technology at the laboratory scale provides an initial proof of concept to assess the technology’s feasibility for treating specific water quality. It also helps to identify or estimate the optimal operating conditions. The data collected during this phase is essential for scaling up the technology and designing a suitable pilot plant that can generate robust, extrapolatable results.

5) Membrane technologies have been identified to not only facilitate water treatment for potential water reuse but also enable the recovery of nutrients or other value-added materials through its concentration for further recovery processes.

6) In some cases, and depending on the quality of the incoming water, membrane technologies require pre-treatment technologies to protect downstream processes.

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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.

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.

In the follow-up meeting on March, 6th 2023, Andrea Naves, from Eurecat, gave an update on the case study progress. One objective of the CS1 is to increase reclaimed water availability for the complex by 20%, treating industrial WWTP effluent through a near Zero Liquid Discharge system, based on membrane technologies: reverse osmosis and membrane distillation.

At the beginning of the project, bench scale tests were performed to determine optimal operation conditions for these both technologies. These tests were conducted with real wastewater from petrochemical complex discharge network because iWWTP effluent was not available (industrial WWTP was commissioned in April 2022). AITASA sent different water batches during the experimental phase and a great variability in analytical water characterisation was detected. Furthermore, a high suspended solids concentration was found in the wastewater, and for this reason, a previous ultrafiltration step as pre-treatment was studied.

Ultrafiltration tests were conducted at 25ºC and 1 bar, comparing the flux and permeabilitiy of different membrane materials and cut-off sizes: Likuid tubular ceramic membranes (1000 kDa and 100 kDa) and tubular PES membrane, CUT (150 kDa).

Reverse osmosis tests were carried out with permeate from previous UF tests (better permeate quality with ceramic Likuid membrane 100 kDa, conductivity=19.1 mS/cm). During the tests, it was assessed membrane selection, brackish (Suez flat sheet) *vs* seawater (Toray flat sheet) and the optimization of operating conditions (TMP) to obtain the highest water recovery.

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Membrane distillation tests were carried out with the concentrate of the RO previous tests to study the effect of T=70, 60 and 50 °C on distillate flux, to evaluate the maximum water recovery and the quality of distillated water.
Main results from bench scale tests showed that the optimal operation conditions are: 100 kDa UF ceramic membrane, 1 bar operation pressure; seawater RO membrane at 40 bar and Air Gap membrane distillation configuration, operating at T=70 ºC. Under these conditions, a global recovery of 56% can be obtained.
Optimal operation conditions obtained experimentally were considered in the subsequent pilot plant design.

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. Experiences in Aqualia with Anaerobic Membrane Bioreactors, core for future water resource recovery facilities (CS5)

Antonio Giménez-Lorang, from Aqualia, explained their experience with an Anaerobic membrane bioreactor for water recovery in a brewery, in Lleida (Spain).
Aqualia has previous experience operating this technology at room temperature in several WWTPs in Spain, in the framework of other R&D projects where they treated municipal wastewater.
Anaerobic Membrane Bioreactor have several advantages, in comparison with other aerobic treatments, such as lower energy demand (70% less), net energy production

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(>0.1 kWh/m^3), lower sludge production (50%), lower CO_2 emissions (80% less), opportunity for nutrient recovery, high-quality permeate, low footprint (25% less) and complete biomass retention (biosolids).
Very promising results were obtained in previous projects, where Aqualia was involved, testing this technology at pilot plant scale: Life Memory, Run4Life, BioWaMet and Life Metamorphosis.
With this previous expertise, Aqualia is going to treat 50 m^3/day of wastewater from San Miguel brewery WWTP to obtain biogas, water to be reused for irrigation and study potential nutrient recovery from sludge.

2.1.4. 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. 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.

2.1.5. 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

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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.

On the second workshop hold on March 6th, 2023, Jeanette Jährig, from KWB gave an update of CS9 in Kalundborg. Kalundborg municipal wastewater treatment plant (mWWTP) receives wastewater from various sources: 40% from Kalundborg municipality, 55% from an industrial WWTP, and 5% from other industries. The goal is to reclaim water from the mWWTP effluent for cooling purposes in the industrial facilities. Due to its composition, the effluent from the municipal WWTP has a high potential for scaling and organic fouling, which can very likely increase the operational pressure of a reverse osmosis (RO) system for water reclamation. These factors lead to higher operational costs and increase maintenance effort.

To mitigate this, the mWWTP effluent was pre-treated using a novel ultra-tight (4 kDa) UF membrane, an open NF membrane (1 kDa), and a commercial UF membrane (150 kDa) to prevent fouling of the subsequent RO process. The comparison of the pre-treatment membranes demonstrated that all membranes effectively protected the RO from fouling, provided that a biocide was dosed simultaneously. In terms of energy consumption and water recovery, the UF membrane was the most suitable.

The study concluded that chemical parameters for cooling water can be easily met with the UF-RO treatment. Consequently, the currently used lake water/Tisso II water can be replaced with RO permeate, although chemical stabilization is required, a mature process that is easy to implement.

As next steps, a dual media filter before the membrane units will be installed. Furthermore, more measurements on microbial parameter will be needed for validation of cooling water quality through a microbial risk assessment concept.

2.1.6. 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.

2.1.7. B-WATERSMART: Brine valorisation for disinfectants production through selective electrodialysis

Eric Santos, from (Cetaqua), explained their participation in B-Watersmart CS1, assessing the RO brines of Rincón de León WWTP in Alicante (Spain). They propose a selective electrodialysis technology (SED) to treat RO brines, allowing to separate monovalent and divalent ions, selectively.
SED permeate, with divalent ions, can be reused, mainly, for irrigation purposes. ED concentrate, with monovalent ions, mixed with sodium chloride, will be softened and, through an electrochlorination, sodium hypochlorite will be produced.
The main expected benefits for this technological solutions are to increase overall reclaimed water production, to reduce costs in brines disposal and in chemical consumption (NaClO), to own NaClO production (protection against shortages or market changes), to boost of biofactory and circular economy concept, to improve the environmental footprint of WRP plants: lower waste disposal and consumption of chemicals and, finally, the recovery of divalent ions useful for agricultural fertilization: lower chemical fertilisers consumption.
Cetaqua conducted laboratory scale tests, with different ionic compositions, to evaluate the effect of brine composition variability in the valorization process. Lab tests demonstrated that SED was able to concentrate NaCl 5 to 10 times. On the other hand, average energy consumption of the overall process, including SED and electrochlorination was 10.3 kWh/kg of active chlorine produced. The produced dilute had a low conductivity below 3 mS/cm, enabling its use for reclaimed water applications. The proposed process appears to be a cost-effective alternative to conventional brine management, reducing the environmental impact of nitrate-rich brines while producing sodium hypochlorite that can be used on-site.
The results obtained in the laboratory tests will be validated in a semi-industrial prototype that is being installed in the water reclamation plant of Alicante and will be operated until December 2023. Selective electrodialysis pilot plant, installed in the

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WWTP facilities, has 80 cell pairs, total membrane area 8 m2 and 3 tanks for concentrate, dilute, electrode rinse solution.

2.1.8. WIDERUPTAKE: Water reuse in Sicily within WiderUptake Project

Giorgio Mannina, from Università de Palermo, explained Sicily water reuse in the framework of WiderUptake project.

WiderUptake project aims to facilitate industrial symbiosis by co-development of a roadmap towards wider uptake of water-smart solutions for wastewater reuse and resource recovery, enhancing a transition to a circular economy in the water sector.

Sicily case study is focused on the Water Resource Recovery Facility at UNIPA, involving wastewater treatment pilot plant, polyhydroxyalkanoates (PHA) production pilot plant and nutrient recovery system by biochar and zeolite.

During the execution of the project, three different investigation lines will be assessed: sewage sludge and water reuse, PHA production plant and nutrient recovery by adsorption-desorption columns.

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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" their concepts 45 persons. In addition, the projects Smart-Plant, Sea4Value and Water Mining presented their outcomes. A second follow-up workshop was celebrated on July 10th, 2023, where CS1, CS3, CS4 and CS5 gave their updates. After the key lessons from the discussion, the main take-home-messages of the presenters are summarised. The full presentations are shown in Annex 2 and 10.

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 highly versatile for removing both inorganic and organic pollutants from water, including ammonium, polyphenols, and organic matter. However, the characteristics and properties of the adsorbent significantly impact the selectivity and efficiency of pollutant removal, as well as operational conditions such as linear velocity and contact time.

3) Adsorption technology is proposed not only for removing pollutants from wastewater but also for selectively recovering value-added materials from the adsorbent or 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 (hydrochar from municipal sewage sludge).

5) Testing adsorbents at the laboratory scale provides an initial proof of concept to evaluate the technology's and adsorbent feasibility for adsorbing specific compounds or pollutants from water. It also helps to identify and estimate the optimal operating conditions, which significantly impact adsorption capacity. The data collected during this phase is crucial for scaling up the technology and designing a suitable pilot plant capable of generating robust, extrapolatable results.

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

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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.

On July, 10th, Andrea Naves, gave an update of the status of CS1. Adsorption experiments were conducted at laboratory scale using reverse osmosis permeate, which was previously obtained at lab scale by treating real wastewater from the petrochemical complex discharge network and doped with an ammonium salt to reach 35 mg ammonium/L (the inlet concentration for the water reclamation plant).

Initially, batch tests were performed with commercial zeolites to select the one with the highest ammonium adsorption capacity. Each test lasted 3 hours, using 50 mL of water and 2.5 g of zeolite. The commercial zeolites tested (both synthetic and natural) included Zeolite 4A (by IQE), Zeolite 13X (by IQE), and Zeolita ZN Aqua (by Zeocat). The natural zeolite, Zeolita ZN Aqua (Clinoptilolite, 82-86%), with a granulometry of 0.5-1 mm, showed the highest ammonium adsorption capacity.

Once the best zeolite was selected, tests at laboratory scale were carried out in a laboratory column (1 cm diameter and 10 cm height) with downflow operation using RO permeate doped with ammonium. Breakthrough time was determined when NH_4 at the outlet reached 0.8 mg NH_4/L (reclaimed water quality limit). Three different bed contact times were tested (1, 10, and 15 minutes), using new zeolite for each experiment. The adsorption capacity was 14.8 mg NH_4/g zeolite after zeolite regeneration, with a linear velocity of 0.4 m/h and a hydraulic retention time of 15 minutes. These experimental results were considered in the design of the pilot plant.

2.2.2. Innovative sensors and alternative materials for the removal of organic matter and micropollutants by adsorption and AOP technologies in ARETUSA (CS3)

Cecilia Bruni, from Università Politecnica delle Marche, explained CS3 involving the Aretusa Consortium (Italy). Currently, there is a partnership between the chemical industry Solvay Chimica Italia S.p.A. and the public water utility A.S.A. Azienda Servizi Ambientali S.p.A. Along with technology provider Termomeccanica Ecologia, these entities form Consorzio Aretusa, which supplies reclaimed water to Solvay facilities. The Aretusa Water Reclamation Plant processes effluents from the Cecina and

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Rosignano Municipal Wastewater Treatment plants, producing reclaimed water that is then pumped to the Solvay plant.
In CS3, the production of hydrochar from sewage sludge is being evaluated. Hydrochar can be produced through two different processes: chemical activation or slow pyrolysis. Laboratory-scale tests indicated that chemical activation of hydrochar at pilot/demo scale is challenging, therefore, pyrolysis was tested as a more feasible alternative.
The pyrolysis pilot plant operates continuously, treating 100 kg/h of biomass and producing 40 kg/h of hydrochar. The process runs at a temperature of around 450°C, maintained inside a rotating drum, with a residence time for the material not exceeding 2 hours. Various parameters are monitored, including pH and conductivity. Additionally, the organic content is monitored using a UV absorbance sensor reading at 254 nm and a fluorescence sensor reading at the excitation/emission couple of 325/445 nm, which is more sensitive and reliable.

2.2.3. 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.
On July 10th, Dimitri Iossifidis, from Greener than Green, gave an update of the CS4. Regarding the initial adsorption process, batch experiments were conducted at laboratory scale to determine the maximum adsorption capacity of several adsorption materials, as well as to establish adsorption kinetics and model the kinetics. The maximum adsorption capacity was found to be 22.8 g polyphenol/kg resin, with 60% adsorption achieved in 30 minutes and 95% adsorption in 60 minutes. These adsorption efficiencies indicate that 130 mg of polyphenol per liter of wastewater could be recovered.

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During dynamic tests at laboratory scale, it was demonstrated that the adsorbent could be used for at least 10 regeneration cycles, allowing for the treatment of 1.7 m^3 of wastewater per kilogram of resin per cycle.
In the pilot plant results, it was shown that over 80% of polyphenols in orange juice could be adsorbed, corresponding to a 20% reduction in TOC of the orange juice by-product. Better extraction results were achieved using a methanol-water solution. For advanced oxidation processes (AOP), pilot plant scale tests were conducted using 2,4-dichlorophenol and sunset yellow as model compounds. The photocatalytic reactor demonstrated the ability to remove 90% of these compounds.
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.

2.2.4. MET 3D printing of catalytic membranes and supports for cleaning AOPs in water (CS5)

Pablo Ortega, from Colfeed4Print, explained MET 3D printing of catalytic membranes and supports for cleaning AOPs in water. Colfeed4Print is a company, founded in 2020, that manufactures filaments/granules of functional materials for 3D printing by material thermal extrusion (MTE).
MTE technology, based on additive manufacturing, have several advantages in comparison with other 3D printing technologies: economical and accessible, less materials restrictions, easy to change material, room conditions printing, multiprinting and printing of different final 3D parts, low know-how requirements for digital designs and it is being expanded in the medical sector (hospital and clinical).
Colfeed4Print explained twp products from their catalogue: Philament-Eco (photo- and electroactive materials for catalytic and energy applications) and Philament-Cer (ceramics for high temperature and abrasive conditions).

2.2.5. 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.

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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 (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.

2.2.6. 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.

2.2.7. 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.

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

2.2.8. 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. Water recovery and reuse

On June 11th 2024, the ULTIMATE case studies Tarragona (CS1), New Prinsenland (CS2), Rosignano (CS3) and Kalundborg (CS9) discussed in the workshop "Water recovery and reuse workshop" with 10 persons their concepts and results. In addition, the project B-Watersmart presented its 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 16.

Key lessons from the discussion:

1) Various case studies have demonstrated the technical feasibility of different technologies for industrial water treatment, enabling the production of water of sufficient quality for reuse in various applications (industrial, irrigation, etc.). This validates the symbiosis between water treatment plants and different industrial sectors.

2) In CS1, it has been demonstrated that a treatment process combining ultrafiltration and second-pass reverse osmosis can produce reclaimed water from an existing effluent discharge. This reclaimed water is suitable for reuse as cooling water in the Tarragona petrochemical complex, with a recovery rate exceeding 30%.

3) According to experimental results in CS2, capacitive electrodialysis (CED) is a promising solution for reclaiming fit-for-use irrigation water from greenhouse wastewater, achieving high-quality irrigation water (EC<0.2 mS/cm, Na^+<0.1 mmol/L) with optimal operation conditions and specific energy consumption (kWh/m3) a factor 4 lower than reverse osmosis.

4) Currently, there are existing instances of symbiosis between wastewater treatment plants and water treatment facilities, exemplified by the Aretusa consortium. There remains ample opportunity to enhance and optimize these processes further, particularly in promoting the reuse of regenerated water within industry.

5) A novel ultra-tight UF membrane (4kDa) was tested in CS9 to purify effluents for reuse in industrial applications, focusing on cooling water and boilers. A Dynasand filter was installed to reduce suspended solids and membrane blockages. Operational difficulties were noted due to non-standard effluent quality, necessitating enhanced pre-filtration efforts. Despite fouling risks from organic matter and alkalinity, UF-RO treatment effectively met cooling water chemical standards, allowing potential substitution of current water sources with RO permeate, contingent on pH adjustment and stability measures.

6) Various scenarios were analysed in CS9 Life-Cycle Assessment: freshwater from Lake Tisso, seawater desalination, and reclaimed water from wastewater treated with

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different membrane processes. The study found that water reuse increases greenhouse gas emissions compared to lake water but reduces water footprint and nutrient release into the Great Belt. Conversely, water reuse decreases greenhouse gas emissions compared to seawater desalination, though if brine treatment to achieve Zero Liquid Discharge is required, emissions increase significantly. Based on these findings, the preferred treatment option appears to be conventional UF and Reverse Osmosis with UV disinfection of RO feed water instead of biocide dosing due to its lower environmental footprint.

7) Regarding Microbial Risk Assessment, in CS3, the current treatment approach shows promising potential to meet health-based irrigation targets in agriculture, although the lack of local validation data necessitates ongoing monitoring. Introducing additional RO units is expected to further mitigate risks below these targets. In CS9, assessments indicate minimal risk of *Legionella* contamination in cooling waters post UF/RO or NF/RO treatment, meeting standards suitable for car washing and street cleaning purposes. However, employing UF alone as a pre-treatment for car washing requires additional verification monitoring to address lingering uncertainties regarding virus removal efficacy.

8) Regarding policy recommendations, increasing treated wastewater quality requirements under the revised Urban WasteWater Treatment Directive (UWWTD) can simplify water reclamation processes, potentially eliminating the need for additional advanced treatments. Monitoring remains crucial but can be costly, impacting the economic feasibility of water reuse. Public engagement and awareness are crucial to overcoming negative perceptions and increasing acceptance of reused water. Business models, funding, and pricing are critical for successful implementation, with multi-user systems enhancing technical and economic viability. Clarifying responsibilities and developing consistent guidelines for water reuse licensing and service provision across the EU are essential to ensure effective practices. The strategic agenda proposes comprehensive coverage of all water reuse types, emphasizing safety, environmental impact assessment, and the integration of reclaimed water into local water balances based on regional circumstances. Future regulations should establish minimum standards for non-agricultural uses, enhance risk assessment, and promote research on innovative water reuse technologies and practices.

2.3.1. Increasing reclaimed water availability of the petrochemical complex of Tarragona (CS1)

Andrea Naves, from Eurecat, explained CS1 in Camp de Tarragona (Spain), where the private company AITASA (Aguas Industriales de Tarragona) are operating a Water The Camp de Tarragona Reclamation Plant supplies reclaimed water to the Tarragona petrochemical complex, complemented by AITASA's Industrial Wastewater Treatment

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plant (iWWTP), which processes wastewater from multiple petrochemical facilities before discharge into the Mediterranean Sea.
ULTIMATE explores a novel Zero Liquid Discharge (nZLD) system based on ultrafiltration, reverse osmosis, and membrane distillation to treat this effluent. Pilot plant tests showed that ultrafiltration followed by two-pass reverse osmosis achieves permeate quality (conductivity <40 µS/cm and ammonium <0.8 mg/L) suitable for reclaimed water. However, membrane distillation for treating reverse osmosis concentrate did not meet required standards due to conductivity and ammonium concentrations. Additionally, zeolite adsorption was tested for ammonium removal as a low-cost alternative for the Water Reclamation Plant second pass of reverse osmosis, but its capacity proved insufficient.

2.3.2. Optimising water reclamation for agro-food industries in N. Prinsenland (CS2)

Tavishi Guleria, from KWR, explained CS2, related with greenhouse horticulture in Nieuw Prinsenland (The Netherlands). This area has to face up several challenges, such as water scarcity (alternative sources are needed), restrictions in concentrate disposal and strict legislation for effluent quality.
The horticulture industry is advancing towards a zero liquid discharge system, prompting CS2 to evaluate capacitive electrodialysis (CED) technology at pilot scale for producing high-quality irrigation water from greenhouse wastewater. This technology utilizes carbon-based electrodes and operates through ion adsorption/desorption on porous capacitive surfaces, thereby avoiding gas production, eliminating the need for electrode rinsing solutions, and improving energy efficiency.
Experimental findings indicate that capacitive electrodialysis is highly promising for reclaiming irrigation water meeting stringent quality criteria (EC<0.2 mS/cm, Na^+<0.1 mmol/L) under optimal conditions. Its specific energy consumption (kWh/m^3) is four times lower than that of reverse osmosis (RO). However, despite its competitiveness, energy consumption and membrane costs constitute significant expenses in deployment.

2.3.3. 20 years of municipal water reuse in chemical industries: governance, technologies and future perspectives (CS3)

Chiara Giansanti, from Consorzio Aretusa, explained the situation in CS3 in Rosignano (Italy). Currently, there is a partnership between the chemical industry Solvay Chimica Italia S.p.A. and the public water utility A.S.A. Azienda Servizi Ambientali S.p.A., along with technology provider Termomeccanica Ecologia, these entities form Consorzio Aretusa, which supplies reclaimed water to Solvay facilities. The Aretusa Water Reclamation Plant processes effluents from the Cecina and Rosignano Municipal Wastewater Treatment plants, producing reclaimed water that is then pumped to the Solvay plant. CS3 focuses on efficiently preventing chloride peaks and other critical parameters in the Water Reclamation Plant influent from the Cecina and Rosignano

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sewer systems, as well as optimizing wastewater reuse. To achieve this, a real-time data process control system for salinity management, featuring an Early Warning System and a Smart Equalization System, has been developed. Additionally, a matchmaking platform monitors the water quality at the Water Reclamation Plant's outlet. Depending on the quality, the water is designated for industrial reuse rather than irrigation. CS3 serves as a valuable example of industrial water facilities symbiosis, showcasing practices that could be replicated elsewhere.

2.3.4. Novel membrane treatment for biotech or biotech+municipal WWTP effluent for water reuse in Kalundborg (CS9)

Jeannette Jährig from KWB presented CS9 in Kalundborg (Denmark). The municipal wastewater treatment plant (mWWTP) receives wastewater from different sources: 40% from Kalundborg municipality, 55% from an industrial WWTP and 5% from other industries. The aim is to reclaim water from the effluent of the mWWTP for cooling purposes. According to the wastewater composition, the effluent of the municipal WWTP has a high potential for scaling and organic fouling processes, which will increase the operational pressure of a reverse osmosis for water reclamation. All these factors translate into higher operational costs. Therefore, the effluent of the mWWTP was pre-treated using a novel ultra-tight (4 kDa) UF membrane, an open NF membrane (1 kDa) and a commercial UF membrane (150 kDA) to prevent the subsequent RO from fouling.

The comparison of the pre-treatment membranes showed, that all membranes protected the RO as good from fouling as long biocide was dosed simultaneously. In terms of energy consumption and water recovery, the UF was suited best.

The study concluded that chemical parameters for cooling water can be easily met with the UF-RO treatment. As a result, the currently used Lake water/Tisso II water can be replaced with RO permeate, although a chemical stabilization is required being a mature process, that is easy to implement.

2.3.5. Kalundborg LCA (CS9)

Fabian Kraus, from KWB, explained the Life-cycle assessment conducted for the Kalundborg case study. The main objective focused on investigating the potential environmental impacts of different membrane schemes for Kalundborg utility for industrial water reuse as cooling water.

A Life Cycle Assessment (LCA) was conducted according to the standardized methods defined in ISO 14040/44, encompassing all components: direct emissions (on-site), indirect emissions, resource use (electricity, chemicals, waste), and credits for products (reclaimed water, nutrients in water for irrigation, heat). Different scenarios were evaluated, including the use of freshwater from Lake Tisso, freshwater from seawater desalination, and water reclamation from wastewater treatment plant effluent treated with various membrane processes. Data was estimated or calculated from pilot studies and literature.

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The LCA for CS9 indicates that water reuse increases greenhouse gas emissions compared to lake water but reduces the water footprint and nutrient release to the Great Belt. Conversely, water reuse decreases greenhouse gas emissions when compared to seawater desalination. However, if brine treatment towards Zero Liquid Discharge is necessary, the greenhouse gas emissions for water reuse increase significantly. Based on the results, the preferred treatment method involves conventional UF and Reverse Osmosis, with UV disinfection of RO feed water rather than biocide dosing, due to the lower environmental footprint.

2.3.6. Rosignano (CS3) and Kalundborg (CS9): Microbial Risk Assessments

Wolfgang Seis, from KWB, discussed the microbial risk assessments carried out for CS3 and CS9. According to the results for CS3, the current treatment scheme shows a high potential for achieving health-based targets for agricultural irrigation. However, a risk is identified due to the lack of local validation data for the implemented treatment train, so further monitoring is recommended. Additional RO units are expected to reduce the risk well below health-based targets.

Assessment results in CS9 indicate a low risk of *Legionella* contamination in cooling waters after UF/RO or NF/RO treatment. For car washing and street cleaning purposes, the risk remains below drinking water standards for NF, UF/RO, and NF/RO treatments. However, when using UF as a single pre-treatment prior to car washing, additional verification monitoring should be conducted to address remaining uncertainties regarding virus removal.

After secondary treatment, local measurements and literature information indicate an elevated risk from car washing activities, so it is not recommended without further treatment.

2.3.7. B-WaterSmart policy recommendations leveraging water reuse in the EU

Kristina Wencki, from IWW, explained main policy recommendation leveraging reuse in the EU from B-Watersmart project. Common issues regarding policy recommendations identified in B-Watersmart and its Living Labs include the need to increase treated wastewater quality requirements for discharge, as proposed by the UWWTD recast. This change can facilitate water reuse by reducing or eliminating the need for additional advanced treatments. Monitoring is crucial but often constitutes a significant portion of the direct costs of water reuse. Additionally, EU policies are needed to enhance public engagement, awareness, and communication to overcome negative perceptions and increase acceptance of water reuse.

Business models, funding, and pricing are critical factors for the successful implementation of water reuse systems. Engaging multiple users improves the technical and economic feasibility of water reuse. However, it is essential to clarify whether reclaimed water supply should be defined as an autonomous water service

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with clearly defined responsibilities. Water reuse typically requires dedicated treatment for reclamation, and direct reuse always necessitates a distribution network; production and distribution may not be managed by the same utility. There is also an urgent need for consistent guidelines for the water reuse licensing process to ensure effective practices.

Developing an EU strategic agenda on water reuse should cover all uses (non-potable and potable), indirect uses (including managed aquifer recharge), and direct uses. This agenda should include monitoring and enhancing the safety of current indirect reuse and facilitating the development of the circular water-energy-waste-food nexus. Member states should define priorities for reclaimed water use based on local environmental, technical, economic, and social circumstances, integrating reclaimed water into local/regional water balances without unnecessary investments unless needed for supply continuity. A uniform EU-wide position on accounting for indirect water reuse should be established, clarifying the boundaries between treated wastewater discharge and indirect water reuse, along with the necessary permits and treatments. The cost of additional treatments should reflect site-specific water resource management.

Environmental uses should be considered direct or indirect water reuse, including managed aquifer recharge, with clear guidelines for environmental impact and risk assessment. Future revisions of Regulation (EU) 2020/741 should establish minimum requirements for non-agricultural uses, provide clearer risk assessment instructions, and enhance monitoring. Research should be promoted to upgrade urban WWTPs to meet new UWWTD recast requirements. The beneficial use or recovery of phosphorus through irrigation with reclaimed water should be encouraged.

EU policies should promote public engagement and communication to improve water reuse acceptance. Coherent EU-wide guidelines for water reuse licensing and service provision, including treatment, storage, conveyance, and pricing, should be developed. Research and innovation should be encouraged to develop policies on water reuse business models, funding mechanisms, and pricing. Pilot projects for direct potable reuse should be supported to establish guidelines for water quality and treatment process reliability, addressing water scarcity, localized needs, emergency situations, and building societal trust in water reuse safety.

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2.4. Energy recovery: biogas related 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. Two follow-up workshops were conducted on May 30th, 2023, with 31 participants and on May 14th, 2024, with 22 participants. 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, 11 and 17.

Key lessons from the discussion:

Biogas production systems:

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.

4) Compared to an anaerobic fluidised bed reactor (AFBR), the electrostimulated anaerobic reactor (ELSAR) is less sensitive to variations in process conditions such as shock loads or biocides and contributes strongly to a stable biodegradation and biogas formation process.

5) The immobilised high-rate anaerobic system (AAT) is very well suited to treat olive mill wastewater and maintains a stable biodegradation and biogas formation process even though high variations in the loads occur.

6) The combination of an AAT with an AnMBR and activated carbon even increases the biodegradation efficiency and correspondingly its methane yield as well as its process stability compared to an AAT alone. The system can be applied to winery, dairy and olive mill wastewater.

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7) The ELSAR system uses activated carbon as fluidised anode. Considering the positive effect of the activated carbon in the AAT/AnMBR system, the ELSAR system is very likely also feasible to treat winery, diary and olive mill wastewater. Furthermore, the ELSAR system is capable to treat most (80-90%) of the industrial food and beverage wastewater.

CO_2e footprint

8) The CO_2e footprints of the AFBR and the ELSAR® are slightly negative and much lower than that of an aerobic system. The CO_2e footprint of the ELSAR® is even slightly lower than that of the AFBR due to the ELASAR®'s 10% higher methane yield. The main impact on the CO_2e-footprint has the dissolved methane in the reactor's effluent. Due to the 15 m height of the ELSAR®, a stripping process can be easily operated by gravity only and recover around 30% of the dissolved methane further reducing the CO_2e footprint. The recovery and reuse of heat after the stripping process can even further decrease the CO_2e footprint.

Solid oxide fuel cell

9) A solid oxide full cell was tested to valorise upgraded biogas and to produce electricity and heat as a by-product. The pre-treatment train was successfully validated showing that a dehydration step is not mandatory. One year of operation showed a reliable electricity production with a continuous electrical efficiency of around 56%.

Replication and EC support for biogas related technologies

10) To replicate biogas production and valorisation technologies in Europe, stable prices for upgraded biogas and electricity are needed at least for a period of five years to amortise the plant. Another five years would be beneficial, after an adaption on the energy market, to provide incentives to the investors. To bridge a potential gap between the guaranteed price and the actual market price, subsidies might be needed.

11) A minimum quota for upgraded bio-methane in the gas grid can further support the willingness of investors to implement biogas production technologies and upgrading units.

12) A simplification of administrative formalities and financial support related to the gas grid connection can highly accelerate the implementation of biomethane producing technologies.

13) A higher flexibility in the choice and combination of substrates will increase the replication potential of such technologies. Especially a regulation allowing the mixture of agro-industrial wastewater with domestic wastewater will support the application of such technologies in a wider field.

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2.4.1. Biogas production and valorisation in CS5 Lleida

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 electro-stimulated anaerobic reactor (ELSAR). 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 the heat values of the biogas streams resulting from both systems is uncertain until now. Those will be investigated in this case study.

In the follow-up meeting on May, 30th 2023, Antonio Giménez Lorang gave an update on the case study progress. The pilot-scale ELSAR was in operation, while the full-scale ELSAR was under construction. The ELSAR applies an anaerobic treatment combined with a cathode and a fluidised anode which consist of activated carbon. In this process, fermentative and methanogenic microorganisms biodegrade organic material and form biogas. Thanks to the electro-stimulating system, electroactive microorganisms oxidise organic material, release electrons to the anode and form hydrogen as well as carbon dioxide. Those substrates are used by other organisms to form gaseous hydrogen and methane. The electroactive microorganisms are less sensitive to variations in process conditions and contribute strongly to a stable process. The comparison of the ELSAR process with a conventional anaerobic fluidised bed reactor (AFBR) showed, that the ELSAR reached higher COD removal rates and correspondingly a higher methane production (Asensio et al. 2021). The comparison also confirmed that the ELSAR can better degrade shock loads (4- to 8-fold compared to the standard operation). The stable process behaviour was also observed in the presence of biocides and after starving periods.

An AnMBR is being investigated at the same case study treating brewery wastewater. It was successfully started-up reaching a stable process. The innovative idea in ULTIMATE is to connect both systems: the effluent of the ELSAR technology will be further treated using an AnMBR. The filtered water will be further treated to allow for water reuse.
To valorise the produced biogas, a solid oxide fuel cell was implemented at municipal WWTP of the case study. The solid oxide fuel cell produces electricity and heat as a byproduct. Five months of operation showed a constant electrical efficiency between

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55 and 59% and a produced power of 1.3 kW. Slight adjustments are still under progress such as further automatisation and certain measurements.

In the last meeting on May, 14th 2024, Antonio Gimenez Lorang presented the start-up of the full-scale ELSAR® system. Inoculum from another high-rate anaerobic reactor treating brewery wastewater was used to fill the ELSAR® with 2000 kg volatile suspended solids. Their specific methanogenic activity was test and showed very good results as well as their ability to settle corresponding to their good shape and size distribution around 1 mm. The start-up was done with a low organic loading rate (OLR) between 1 and 2 kg COD m^{-3} d^{-1} and an upflow velocity of 3.3 m h^{-1} in the first month. Extreme pH fluctuations required a decrease in the OLR. However, a high buffer capacity enabled a stable biogas formation process. COD removal rates of higher then 96% and a methane content of higher than 70% were successfully reached. As next step, the OLR will be increased to 25 kg COD m^{-3} d^{-1} and higher.

To valorise the produced biogas, a solid oxide fuel cell (SOFC) was tested. After a pre-treatment consisting of pressurisation, desulphurisation, cooling, dehydration, polishing to remove H_2S, water, siloxanes and volatile organic compounds, the SOFC used the upgraded biogas and produces electricity and heat as by-product. Compared to a combined heat and power unit, the SOFC produces electricity with a two-fold higher efficiency corresponding to around 56% of the total energy production. In CS5, the suitability of the pre-treatment train was successfully validated and one year of operation showed, that the electrical efficiency can be continuously achieved and that the dehydration process is not needed.

Lea Conzelmann presented the environmental impact of the anaerobic treatment of brewery wastewater compared to a baseline scenario involving an aerobic treatment. Compared to the aerobic system, the anaerobic system removes less nutrients and hence, its return load to the WWTP increases the nutrient load. However, still the anaerobic treatments (ELSAR® vs. AFBR) have a much lower CO_2e footprint compared the aerobic system. Both anaerobic treatments are roughly CO_2e neutral, even though the methane losses due to the dissolved methane in the effluent of the anaerobic treatment are the major factor to increase the global warming potential, while the produced biogas decreases it. The ELSAR® has even a slightly lower CO_2e footprint due to a 10% higher methane yield compared to the AFBR (also known as EGSB).
Recent investigations in CS5 have shown, that the 15 m height of the ELSAR system helps to easily recover dissolved methane from the effluent. This way, 30% of the dissolved methane can be recovered easily, decreasing significantly the CO_2e-footprint. This will be considered in the final update of the life-cycle assessment in D2.2.

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2.4.2. 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 pretreating 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.

In the follow-up meeting on May, 30th 2023, Isam Sabbah presented the progress of the Israeli case study. In Karmiel, the AAT system successfully reduced COD and TSS loads for the further treatment in a conventional activated sludge (CAS) system. In addition to the load reduction, biogas was produced and hence, with the utilisation of the biogas and the reduced energy demand in the CAS, a promising basis for an energy-efficient water reuse was reached. During one year of operation, the COD concentration in the AAT effluent remained successfully on a stable level despite fluctuations in the influent as a result of OMW discharges. Correspondingly, biogas was produced throughout the entire year. In summer, the biogas production rate reached its maximum dependent on the organic influent load and high temperature accelerating the microbial biogas production process.
In Shafdan, the combination of an AnMBR based on an AAT combined with activated carbon for a higher biogas yield and to reduce biofouling was tested. To the knowledge of the authors, the use of an immobilised biomass in an activated carbon fixed foam instead of granular biomass is unexplored within AnMBR technologies until now. First results from laboratory experiments showed for the digestion of phenol-containing substrate higher biogas yields were achieved resulting from the new combination compared to that without activated carbon addition.

In the last meeting on May, 14th 2024, Katie Karbaby presented the effect of differently pre-treated substrate regarding the biogas production in the AAT, which as investigated in Karmiel. On one hand biogas was produced from wastewater mixed

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with OMW and on the other hand, the polyphenols were removed via extraction from the same mixture. The biogas production rate was with roughly 9 m^3 d^{-1} on a very similar level for both cases, while the methane yield was slightly higher with 6% only. In Shafdan, two lab-scale systems were investigated and compared: 1) AAT containing activated carbon in combination with a subsequent AnMBR and 2) AAT without activated carbon and a subsequent AnMBR. On average, both systems reached very similar COD removal rates. It was concluded that the share of OMW was still too low to see any effect of the polyphenols, since their concentration was obviously too low to inhibit the methanogenic microorganisms. Hence, their removal did not show any effect in the biogas production process.

2.4.3. 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.

2.4.4. 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 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.

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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).

2.4.5. 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.

2.4.6. Wider-Uptake: Utilizing biogas from sludge digestion in a natural gas energy grid in Norway

Lene Beadle from IVAR (Norway) talked about a society, where nothing goes to waste. IVAR is a municipality owned utility that supplies drinking water for 360 000 people, treats wastewater of 12 municipalities and produces biogas. IVAR operates two biogas plants treating sludge from wastewater treatment and food waste. Before digestion, the sludge is hygenised in a thermal hydrolysis process at 160 °C and 5 bar. The digested organic matter is reused as organic fertiliser on the agricultural fields. The biogas is upgraded since 2011 using an amine scrubbing process. After the addition of propane, it is sold to the company “Lyse”. Lyse established a gas distribution pipe for natural gas, which is use to distribute the biogas over a distance of 600 km. The biogas is valorized as fuel for vehicles and district heating.

2.4.7. ULTIMATE: Replication and EC support of biogas production and valorisation technologies

In the final ULTIMATE meeting for energy recovery, the replication potential as well as the barriers for their market uptake and potential support coming from the EC were discussed, after the Spanish and Israeli cases studies had presented their final results.

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Those results can be found in the corresponding paragraphs of the case studies in this chapter.

The weakness of biogas production system is the high content of dissolved methane in the effluent increasing the CO_2e footprint of the technology significantly, leading to an almost neutral CO_2e-footprint. Therefore, innovative technologies are needed to remove the dissolved methane from the effluent. In the case of the ELSAR® system, the reactor's height of 15 m is beneficial, because the effluent can be disposed at this height to a subsequent stripping column using gravity only without additional energy consumption. This way, 30% of dissolved methane can be recovered. The same is true for an AFBR, but different for an AnMBR, which height is usually around 5 m only. Here, additional energy would be needed to lift the effluent to the inlet of a stripping column. A further CO_2e footprint reduction might be achieved with heat recovery and reuse after the stripping process.

Further research and especially demonstration projects are needed for SOFCs, since they are rarely used in the context of biogas valorization and reported demonstrations usually relate to other sectors. Furthermore, the materials used for the SOFC's production are expensive and hence, the product is still very expensive and not attractive for inexperienced customers.

The price for upgraded methane and/or produced electricity from bio-methane has fluctuated highly in recent years. To further accelerate the market-uptake of biogas technologies, securities for the return of investment would be very beneficial. This might be achieved via a guaranteed and stable price for the upgraded biogas or the produced electricity for at least five- or ten-years Europe-wide. If the price falls below the guaranteed price, subsidies would be necessary to finance the gap. After the first five years, an adaptation of the price depending on the energy market could be conducted for the next period of five years.

In addition, a minimum quota for each European country regarding upgraded bio-methane can highly support the uptake of biogas production and upgrading technologies. In some European countries such as Denmark and France already very high quotas are achieved between 50 and 100%, while Spain for example is only aiming for 1% currently. Furthermore, a simplification of administrative formalities and financial support related to the gas grid connection can highly accelerate the implementation of biomethane producing technologies.

To achieve a higher flexibility of biogas production systems, a regulation allowing the mixture of agro-industrial wastewater with domestic wastewater is very important not only for the European countries, but also for Israel, where one of our case studies is

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located and would profit very much from it to further replicate its innovative technologies.

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2.5. 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. Follow-up meetings were conducted on March, 30th 2023, in which 41 persons participated and the sister project WaterMining shared its insights and on May 14th, 2024, with 22 participants. 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, 12 and 17.

Key lessons from the discussion:

Low-grade heat recovery from AnMBR effluent

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.

3) The operation of the reverse osmosis at different temperatures of 20 °C, 30 °C and 40 °C revealed a higher flux with increasing temperature resulting in similar permeate qualities. Due to short term investigations, the fouling potential resulting from the higher temperature was not investigated so far. However, the higher temperature leads to a higher solubility of some mineral products and is assumed to be helpful for reducing scaling processes.

4) The operation of the struvite formation process at a temperature of 35 °C, which leads usually to a higher solubility of struvite, had for the AnMBR effluent of treated distillery wastewater no disadvantageous effect, so that the conditions for struvite formation were still favourable. Hence, the heat can remain in the effluent in order to use it for the subsequent stripping process.

5) The operation of the stripping process at 35 °C instead of 30 °C had no positive impact on the ammonia removal rate. Therefore, higher temperatures need to be

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tested in order to enable a pH decrease, while maintaining the same ammonia removal rate.

Heat recovery from washing water of waste incineration

4) An incineration line of hazardous waste has usually a furnace with quenching to cool the flue gas. The gaseous effluents from incineration are washed to eliminate gases and dust. The washing water has a high temperature and seems to be feasible for heat recovery. However, investigations showed, that high contents of salts lead to scaling and clogging and hence, the washing water is not suited for heat recovery via heat exchangers.

Brine treatment with waste heat

5) Waste heat from a power plant is very suitable for further brine treatment such as multiple effect distillation.

High temperature - aquifer thermal energy storage (HT-ATES)

6) When planning an HT-ATES, it is very important, that every stakeholder is on board already at the beginning of the project, especially persons involved in the ownership of the system and other people that might have decision power should be engaged. It takes usually three to four years from the initial idea until the system operates.

7) Social perception regarding HT-ATES was in the case of Rotterdam very positive, because people see it as a contribution to a more stable, robust and green heating supply.

8) The combination of a geothermal doublet with an HT-ATES decreases the geothermal capacity of the doublet, increases its lifetime and reduces investment costs.

9) To gain geo-hydrological data for a subsurface exploration, it can be combined with a geothermal conductor drilling what is very cost-effective being three to six times cheaper than a dedicated test drilling.

10) The bigger the storage is and the better the layer to the upper subsurface isolates, the higher the heat or cold recovery efficiencies are.

11) 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.

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12) 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.

Global warming potential

13) The global warming potential of a geothermal well and an HT-ATES system depends mainly on the electricity consumption to operate both systems. Compared to heat generated from natural gas, the heat originating from a geothermal well and an HT-ATES have a 60% lower global warming potential considering the Dutch power mix in 2019. The greener the power mix will become in the future, the lower the global warming potential will be of such systems.

Replication and EC support for HT-ATES

14) Test drillings to characterise the subsurface are expensive and time consuming. They are considered as a barrier for an easy market uptake of this technology. Hence, more research and demonstration projects are recommended to establish inexpensive, reliable and innovative technologies and their combinations in order to avoid uncertainties during planning of an HT-ATES and to accelerate the planning process.

15) The highest risks are considered to be uncertain permit procedures and public perception. Furthermore, the permit procedure for a HT-ATES requires usually several years. We strongly suggest accelerating this procedure and to promote the demonstration of full-scale pilot systems in order to develop suitable policies and to show in practice that HT-ATES is a renewable, clean and safe technique.

2.5.1. 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

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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 needs to be assessed in order to choose the most beneficial scenario.

Marc Pidou gave an update of CS7 in the follow-up meeting on March 30th 2023. A boiler was installed successfully to produce heat from the biogas resulting from the AnMBR for the Glenmorangie's buildings. Furthermore, the recovery of heat is studied in the pilot system, because it delivers several advantages: extracting the heat before the AnMBR effluent reaches the struvite formation unit, decreases the struvite solubility and thus, enhances its recovery due to a lower process temperature (Ariyanto et al. 2015). Reusing the heat for the air stripping process to recover ammonia allows to operate the process at a lower pH and hence, saves sodium hydroxide. Also, for the reverse osmosis treatment, a higher temperature can be an advantage in terms of the viscosity as already explained before. Therefore, at CS7 a flexible system consisting of two heaters was integrated in the pilot system, where heat can be transferred to the water upstream of the air stripping unit and upstream of the reverse osmosis. Experiments to operate the reverse osmosis at different temperatures of 20 °C, 30 °C and 40 °C showed, a higher flux with increasing temperature from 7.3 L/(m² h) to 8.2 L/(m² h) with similar permeate qualities.

On May 14th 2024, Marc Pidou presented further results from CS7. Again, according to Ariyanto et al. 2015, a lower process temperature decreases the solubility of struvite and might enhance its formation process. The highest solubility was observed at 35 °C. Therefore, the removal of phosphate from the AnMBR effluent was investigated at temperatures of 20 °C, 30 °C and 40 °C. However, the removal rates were for all temperatures very high between 95% and 93% and showed no clear impact of the temperature on the struvite formation process. The reason therefore might be the complex composition of the wastewater contributing to favourable conditions for struvite precipitation. Hence, for this wastewater, higher temperatures around 35 °C can be tolerated without the risk to decrease the struvite precipitation potential.
Regarding the ammonia stripping, the highest removal rates between 53% and 85% ware reached at a pH of 9.8. As already described, the removal rate of ammonia through air stripping increases with increasing temperature. Hence, a higher process temperature can enable a pH decrease, while maintaining the same removal rate. Therefore, different temperatures at different pH values were tested: 30°C at pH 9; 35 °C at pH 9; 30°C at pH 10 and 35 °C at pH 10. Also in this case, the removal rates ranged between 68% and 72% and no clear impact of the temperature could be revealed. However, the temperature difference of 5 K was not very high and thus, as a next step, higher temperatures (e.g. 60 °C) will be tested, after the maximum potential for a temperature increase in the system will have been determined.

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2.5.2. 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, Suez 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 vapour on-site from the hot washing water for a local use. The pH is around 5 and the water contains high salt concentrations.

In the follow-up meeting, Anne Reguer presented the results of the feasibility study. The technical risk assessment revealed a high risk for clogging events and corrosion processes during heat recovery resulting from the high salt content in the washing water, so that cooling water as a second source for heat recovery was chosen. Data referring to one year of operation were analysed and showed a potential of 10 MW for each incineration line. However, the assessment of the energy consumption revealed that self-consumption scenarios are not sufficient to reach the 25% energy recovery target and hence, additional consumers would be necessary. Applying a heat pump for simultaneous heating and cooling and a vapour-compression heat pump in series using heat showed for different capacities high operational expenditures with an unsatisfying overall energy performance and high capital expenditures resulting in a non-competitive steam price even with a depreciation period of 20 years. Applying the Organic Rankine Cycle instead to produce electricity using the energy from the cooling water or from the flue gas also revealed for both an insufficient return of investment. The system might have been rewarding for temperatures of 90 °C and higher instead of the available 87 °C. Hence, other options must be considered for the future.

2.5.3. 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 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

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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.

Martin Bloemendal from KWR (NL) reported in the follow-up meeting the outcome of the feasibility study about CS2 “Heat storage in aquifers: Symbiosis between geothermal heat and heat storage”. In the feasibility study, the combination of a geothermal doublet with an HT-ATES was considered for the potential implementation at CS2. The potential to use HT-ATES to store excess heat from a geothermal plant during the summer and recover it to supplement the heat supply from this source during the winter was characterised by analysing the actual supply and demand, studying the geohydrology at the site to determine the suitability of the subsurface for HT-ATES and predict the performance, assess the financial feasibility and map the local governance situation with regards to permits. To gain geo-hydrological data, the subsurface exploration was combined with a geothermal conductor drilling what was very cost-effective being three to six times cheaper than a dedicated test drilling. The assessment concluded that the present aquifer is very suitable for the installation of HT-ATES wells and that there is potential to increase the efficiency of sustainable heat delivery from the geothermal wells to the greenhouses in a cost-efficient manner.

Stjin Beernink also from KWR (NL) presented in the final energy recovery meeting, the potential to reduce of CO_2 emissions with a large scale seasonal subsurface heat storage. The feasibility to store between 57-107 TJ/a, which are available in summer and demanded in winter, in a yearly storage volume of 0.31-0.52 Mm^3/a, was shown. The local subsurface conditions are also suitable and enable a thermal recovery rate between 65-80% depending on the actual demand. A simulation of the maximal thermal effects after 20 years for the Middenmeer HT-ATES system showed a good result supporting the intention to establish an HT-ATES in the Westland area. The depth of the storage aquifer is supposed to be over 200 m deep containing saline groundwater. Because no other systems are close by, which interests might be harmed, a pilot license for should be very likely possible to be gained. Therefore, the next step is to conduct an impact study and a corresponding monitoring.

Christian Remy from KWB (DE) presented the life-cycle assessment for the planned HT-ATES system using the produced heat from a geothermal well in summer for energy storage. In winter the stored thermal energy is supplied to the heating network in addition to that from the geothermal well. Besides the baseline scenario (natural gas as energy source for district heating), two HT-ATES scenarios were defined: 1) max thermal energy input (105 TJ/a) and output (73.5 TJ/a) in and from the HT-ATES with a heat loss of 30% and 2) min thermal energy input (92 TJ/a) and output (59.8 TJ/a) in and from the HT-ATES with a heat loss of 35%. The global warming potential of both HT-ATES scenarios are highly dependent on the electricity consumption to operate the

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geothermal well as well as the HT-ATES. Compared to the baseline, the global warming potential of the HT-ATES scenario corresponds to roughly 40% of that of the baseline considering the power mix of the Netherlands from 2019 with 505 g CO_2e/kWh. In the future however, when the power mix will contain more green generated energy such as 250 g CO_2e/kWh (estimated for 2030), the global warming potential will further decrease to approximately 20% of that of natural gas. In this case, more than 1000 t CO_2e/a can be saved using the geothermal well in combination with the HT-ATES.

2.5.4. 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.

2.5.5. 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

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

2.5.6. WaterMining: Heat recovery for brine treatment

Dimitris Xevgenos from the TU Delft (NL) and Alessandro Trezzi a saline water specialist from SOFINTER SpA (IT) presented the Italian case study on Lampedusa in Italy, where 3500 m^3/d are desalinated to cover the entire drinking water demands of the island. In the frame of WaterMining, a sister project to ULTIMATE, waste heat driven desalination and a suitable brine management shall be investigated. Therefore, seawater is desalinated using nanofiltration. Two streams are produced, one containing monovalent ions and one containing multivalent ions. The monovalent ion containing stream is further treated by a multiple effect distillation, a thermal crystallizer and a dryer to produce NaCl. Hereby, all three units produce high quality water, which can be reused in industry. From the stream containing multivalent ions, $Mg(OH)_2$ and $Ca(OH)_2$ are recovered via a multiple feed plug flow reactor for industrial reuse. The residual stream is further treated in Eutectic freeze crystallizer to recover Na_2SO_4. Using an electrodialysis with bipolar membranes, NaOH as well as H_2SO_4 are recovered for internal recycling. The targets of the pilot operation are exploitation of low temperature waste heat from a power plant, low temperature vacuum operation, achieve a high recovery rate of the NF on feed water, gain a high distilled water quality and allow for a self-adjusting process.

2.5.7. ULTIMATE: Replication and EC support for heat storage, recovery and reuse technologies

In the final ULTIMATE meeting for energy recovery, the replication potential as well as the barriers for their market uptake and potential support coming from the EC were discussed, after the Scottish and Dutch cases studies had presented their final results. Those results can be found in the corresponding paragraphs of the case studies in this chapter.

The low-grade heat recovery and reuse technologies are usually applied directly in combination. Hence, recovery and reuse usually take place internally in a company applying all processes at the same time and therefore, no special form of cooperation or partnership is needed to exchange the heat.

This is different for the application of a HT-ATES system, which needs heat to store it and provides heat on a seasonal demand, for example to a heating network. Here are usually different companies or entities involved and certain forms of corporations and partnerships, such as an industrial symbiosis, are necessary to guarantee the delivery of heat and the demand for it.

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Bloemendal et al. (2015) created a map showing the potential for replication of HT-ATES in terms of favourable subsurface conditions in Europe and worldwide. In Europe, especially northern France, the Netherlands, Germany, Denmark, Norway, Poland, Lithuania, Latvia and Estonia are having and will have a high potential based on their geo-hydrological conditions and the climate in the future.
However, to determine in detail the suitability of the subsurface for a HT-ATES system, usually expensive and time-consuming test drillings are conducted. Those are considered as a barrier to an easy market uptake of the technology. More research and demonstration projects are needed to establish inexpensive, reliable and innovative combinations of technologies to characterise the subsurface (e.g. geophysical investigation methods (sounding, seismic reflection), etc.) in order to avoid uncertainties during the planning of HT-ATES systems and to accelerate the planning process.

Fleuchaus et al. (2020) showed in a survey among 38 experts, that technical risks are less critical than legal, social, organizational and political risks. They see the highest risk in uncertain permit procedures and public perception.
Also, in the Netherlands in practice, the time frame, from application submission to receive an outcome or in the best case a permit, needs for a LT-ATES currently roughly 3 months. However, the same procedure for a HT-ATES requires usually several years. It would be very helpful to strongly accelerate this procedure. Currently the aim is to reduce the duration to one year.
For the further uptake of HT-ATES in the coming years, we suggest promoting the demonstration of full-scale pilot systems in order to develop suitable policies and to show in practice that HT-ATES is a renewable, clean and safe technique.

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2.6. 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. A follow-up meeting was conducted on May, 2nd 2023, in which 20 people participated and the sister projects B-WaterSmart, REWAISE and WATER-MINING shared their insights. 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 and 13.

Key lessons from the discussion:

1) Different innovative technologies for the recovery of nutrients have been successfully implemented and applied for wastewater, sludge, kitchen waste and/or non-hazardous organic liquid wastes:
- advanced biodrying and composting,
- bioelectrochemical systems and
- ultra-low flush toilet coupled with (hyper-)thermophilic anaerobic digestion.
- electrodialysis,
- fluidized bed reactor (FBR) for struvite precipitation
- stripping columns.
- adsorption columns.
- Aerobic Granular Sludge (AGS) systems.
- Anaerobic membrane biroeactors (AnMBRs). These systems are not aimed to recover nutrients efficiently but produce nutrient-enriched effluents that facilitate their recovery in downstream processes.

2) Nutrient recovery is possible in different forms: struvite, ammonium sulphate, phosphorus as $CaPO_4$ compounds, biofertilisers, phosphoric acid, solid NPK fertiliser and within reclaimed water through fertigation.

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

4) Future research lines of the tested technologies and processes are mainly related to process optimization and technological implementation at full-scale.

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2.6.1. Nutrient recovery: 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, with the ambition of reaching zero liquid discharge. 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 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.

The treatment scheme of the CS2 includes prefiltration, coagulation, sand filtration and activated carbon and the final discharge is the sewer system. The proposed system is circular to enable water and fertiliser reuse by removal of concentrated sodium and recovery of nitrogen (N), phosphorus (P), and potassium (K). The new flow-scheme includes the addition, after the existing treatment train, of electrodialysis (ED) for nutrient recovery followed by disinfection for water reuse. The main advantages of ED are the potential for ion-selective recovery, the prevention of sodium accumulation in the final effluent and the ion concentration allowing to reach the needs of greenhouse horticulture, whereas the main challenge is the process optimisation for nutrient recovery. The initial results showed at EC of 1.9 mS/cm a recovery of K^+ up to 250 mg/L, a recovery of NO_3^- up to 450 mg/L and a recovery of $H_2PO_4^-$ up to 50 mg/L, while with EC of 3 mS/cm the recovery of K^+ was up to 300 mg/L, the recovery of NO_3^- was up to 650 mg/L and the recovery of $H_2PO_4^-$ was up to 100 mg/L. In addition, the dilute produced had acceptable water quality for irrigating greenhouses. The work is still in progress and further testing with additional technologies (mono-selective electrodialysis, ion exchange and donnan dialysis) as well as long term pilot testing will be done until the end of the project.

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2.6.2. 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 (CS7). Particularly, in the current situation the wastewater produced by the Glenmorangie whisky distillery is treated via AnMBR, which allows to remove 98% of COD and produces an effluent with very high total ammonia nitrogen (TAN) 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 CO_2 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.

After a review of the existing technologies, the selected process scheme includes struvite precipitation and a stripping column with scrubber. Struvite precipitation is obtained through a fluidized bed reactor (FBR) composed of four different sections with a volume that becomes greater from the bottom to the top. The velocity is reduced by moving to the larger sections, larger particles precipitate to the bottom in the narrowest part, while smaller particles arrive at the largest section at the top, together with the effluent. Key results are: 62±15% PO_4-P removal and 18.6 kg struvite/d (theoretically) with no significant contamination by metals. For what concerns the stripping process, in the first column the wastewater is fed at the top while the air moves in the opposite direction. In this way the ammonia passes from the liquid to the gas phase. Then the air, rich in ammonia, is passed through another column where the ammonia is re-solubilised in the liquid phase, in different forms depending on the type of acid used. Key results are 69±16% TAN removal. In conclusion, more than 75% of P and N removal was obtained with the combined FBR/stripping processes where the FBR effectively protects the stripping unit from scaling.

2.6.3. Smart-Plant: Bio-based fertiliser recovery from wastewater and sewage sludge

Sergio Ponsà is the leader of the BETA Technology Centre. His research group is involved in different projects where nutrient recovery is investigated. Within the Smart-

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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:

- 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.

2.6.4. 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.

2.6.5. 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

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

2.6.6. B-WaterSmart: Venice Case Study

Patrizia Ragazzo from VERITAS S.p.a. presented nutrient recovery in B-WaterSmart and, in particular, in the Venice Living Lab. The Living Lab includes two pilot plants for N-recovery by stripping and salt production and two decision support system (DSS) tools supporting the decision-making process regarding the reuse opportunities of the final effluent and the sludge management. The N-recovery was performed with two stripping columns using two different substrates: liquid fraction from the anaerobic digestion process and the liquid fraction of OFMSW (organic fraction municipal solid waste) from the anaerobic co-digestion. Two different technologies are studied.

- The first one includes a traditional stripping packed column to facilitate the transfer of ammonia from the liquid to the gaseous phase. The column is sensitive to clogging and scaling, so a pre-conditioning of the matrix is required: heating up to 60 °C and pH=11 and dosing chemicals in a flocculation process to remove solids. After the stripping column, there is an adsorption column to produce ammonium sulphate. The technology usually allows for high removal efficiencies, but the preliminary flocculation process determines the production of sludge.
- The second technology is simpler. There is no need of pre-treatment and no sludge production but has a lower yield and longer retention time.

2.6.7. REWAISE: Vigo Case Study

Jose R. Vázquez-Padín from Aqualia presented nutrient recovery in the REWAISE project by comparing different technologies.

- Anaerobic membrane bioreactor (AnMBR): associating the anaerobic process with membrane allows for lower energy demand, lower sludge production, lower CO_2e emissions, high quality permeate. In addition, the process allows to obtain high quality treated water rich in nutrients, which could be used for fertigation.
- Decentralised AnMBR: separation at source of blackwater (BW), kitchen waste (KW) and greywater (GW), allowing to reach high COD removal (Run4Life project).

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- Memb-raner: the Rewaise Case Study regards a car factory where a pilot plant treating 10 m^3/d of urban wastewater has been implemented including anaerobic digestion, ultrafiltration membrane and dissolved methane recovery. The methane recovery unit is necessary because the permeate is saturated with CH4 causing potential loss of energy and greenhouse gasses (GHG) emissions, results showed 80% methane recovery at -625 mbar and 90% methane recovery at -760 mbar. The study for the recovery of nutrients from the permeate is ongoing at laboratory scale.
- Urban wastewater treatment plant: combined treatment of wastewater and biowaste in small populations (LIFE ZERO WASTEWATER project).
- OFMSW leachate treatment: new sustainable and circular economy-oriented treatment including stripping and membrane contactors to recover ammonium in the form of biofertilisers and thermophilic AnMBR (55 °C) the purge as organic fertiliser (LIFE INFUSION project).

2.6.8. WATER-MINING: Future scheme of aerobic granular sludge WWTPs

Nouran Bahgat gave a presentation about nutrient recovery in the Water Mining project and, in particular in the Case Study 4 (P-removal to ultra-low levels and P-recovery) and Case Study 3 (extracellular polymeric substance (EPS) (Kaumera) Valorisation). The technology is based on Aerobic Granular Sludge (AGS), which is composed of granules formed by several layers depending on the level of oxygen penetration inside. In the CS4, a pilot plant, BioPhree, was developed including different adsorption columns to remove the phosphate. The iron oxide-based adsorbent goes to a regeneration cycle to separate the phosphorus obtaining a liquid flow rich in phosphorus. In the CS3, the biopolymer Kaumera Nereda® gum (Kaumera) is extracted from AGS. The main objective is to recover the EPS, additionally nitrogen and phosphorus is partly recovered as integral part of the polymer. The extraction process includes an alkaline reactor followed by an acidification tank and an anaerobic digester for sludge treatment. For the P recovery a decanter is added with the alkaline reactor and a disc centrifuge is added with the acidification tank. From the mass balance, recovery is under evaluation considering, together with the phosphorus in the final polymer (19%), also acid-Orthophosphate from the acidification tank (27%) and the PO_4-P in the digestate effluent from the anaerobic digestor (11%). Phosphorus effect on Kaumera properties and potential applications (ex: flame retardants). Finally, for the nitrogen, the mass balance shows a possible recovery in the polymer (7%) and as NH_4-N in the digestate from the anaerobic digestor (5%). Possible future scheme may include alkaline hydrolysis and acidic precipitation with anaerobic digester and P-chemical precipitation.

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2.7. 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. Two follow-up workshops were conducted: the first one on November, 22nd 2023 with 25 participants and the second one on June, 4th 2024 with xx participants. In these workshops, apart from some updates of the aforementioned ULTIMATE’s case studies, others were presented, i.e., CS7 (Tain), CS8 (St. Maurice l’Exil, France). In addition, sister projects WIDER-UPTAKE and WATER-MINING also participated, as well as Circular Biocarbon project. 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, 14 and 18.

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 key steps for the implementation of recovery process of added-value compounds.

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 criteria).

6) Different technologies for the sustainable recovery of materials from diverse water streams and/or non-hazardous organic liquid wastes have been implemented:
- Hydrothermal carbonization (HTC),
- Adsorption columns,
- Absorption columns,
- Solar desalination
- Aerobic Granular Sludge (AGS) systems.
- Alternative biocomposite production.

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- Advanced oxidation process (AOP)
- Struvite crystallization.

7) Material recovery is not normally the only approach in all the case studies presented. For instance, in Rosignano (CS3 of ULTIMATE), they tried to increase the quality of water reuse by reducing the salt intrusion in the reclaimed water. In addition, CS1 of WATER-MINING focused on increasing the yields of seawater desalination.

8) All the cases focused on recovering materials from liquid streams, except for CS8 of ULTIMATE that works with flue gases.

9) The materials to be recovered are diverse: hydrochar, coagulant and softening agents; limestone; polyphenols; NaHSO3, biocomposites; magnesium and sodium chloride; biostimulant, water absorbent or coating binder; struvite; cellulose, alternative construction materials.

10) Apart from the potential barriers in the previous workshop (points 4 and 5), others were detected: competition with conventional unsustainable products; low production to significantly enter in the market; lack of successful large-scale case studies.

11) The replication of the technology of CS8 is challenging as different incineration plants present significant variability from each other.

12) In general, the quality of the fertilisers obtained in CS7 was high, with limited organics and metal contamination, also negligible risks of chemical contamination.

13) The producers of wastes (potential material recovery) are not generally interested in the production of renewable materials for several reasons: lack of knowledge on material recovery processes, scarce introduction on the market of renewable products, low incomes from the by-products, etc.

14) Material recovery is even more challenging from urban wastewater. In fact, it is barely mentioned in the new wastewater treatment directive. Industries can be more relevant actors to exploit the high potentiality of material recovery from industrial wastewaters as they can be associate more efficiently (industrial symbiosis).

15) With respect to end-of-waste criteria, it is hard to demonstrate all the conditions that need to be accomplished, especially with certain products such as alternative building blocks.

16) Great challenge on obtaining feedstocks with enough quality to obtain products with enough quality (and stable characteristics) to be competitive in the market.

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17) Public-private collaboration is necessary. Facilitating and accelerating the permission and authorization procedures is also important.

18) It is also essential to obtain subsidies in terms of grants, loans or other forms to promote high investments in circular technologies.

2.7.1. 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 (Greece), 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 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-H_2O 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.

In the first follow-up meeting, the outcomes of CS4 and CS6 were updated. In CS4, results showed maximum adsorption capacity of 22.78 g of polyphenol per kg of resin. This means 60% of recovery in 30 min and 95% in 60 min (yield of 130 g of polyphenol per m^3 of wastewater). Results on dynamic adsorption showed that the adsorbent can recover polyphenols for at least 10 regeneration cycles, implying that 1.7 m^3 of wastewater can be treated per kg of resin per cycle. Regarding the recovery of the resin, optimal results were obtained when using MeOH-H_20 (70% of recovery from the resin). It must be noted that the final product consists of a mixture of polyphenols. Their separation is not efficient enough in this system to produce pure polyphenols.

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Regarding CS6, they need much more methanol to reuse the resin (up to 1L MetOH/L water), although the recommended solvent ratio was 1 liter of methanol per 4 liters of wastewater.

In the second follow-up meeting, Myrto Touloupi (GTG) updated the results from CS4. For the resin selected (amberlite TM FPX66), 85% of polyphenol were adsorbed: i) orange by-product (4.7 g polyphenols/(kg product)); ii) olive by-product (23.7 g polyphenols/(kg product)).
For the extraction, conventional solvents were tested (H_2O, methanol, ethanol). Better results with MetOH, but it is toxic and expensive. Hence, different dilutions were tested aiming to find a good balance between high extraction and low toxicity and costs.
They also performed supercritical CO_2 extraction, obtaining better results without adding extra solvents.
Further research will focus on trying to replace resins, as they are expensive, i.e., cost 2500 €/20 kg. This is expected to reduce costs by 90%.

2.7.2. 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 wastewater reuse plant (WWRP) which is a tertiary plant aiming at refining the quality of the effluent water from the municipal WWTPs 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). 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 Aretusa 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, UV radiation and fluorescence. The latter two variables are surrogate parameters for the determination of organic pollutants.
- 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 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 good hardness removal in the tested wastewater with reductions ranging between 46% and 87%.

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In the follow-up workshops, Massimiliano Sgroi from UNIVPM updated the results obtained in this Case Study 3. The potential materials to be recovered in this CS are:
i) Hydrochar from hydrothermal carbonization (HTC) of sewage sludge to be used as soil amendment, adsorbent (in GAC process) or for energy production. With respect to the hydrochar, the pilot plant was designed according to laboratory data. Lab-scale results also showed the need of activating the char to be able to adsorb the pollutants. To activate the char, the following was needed: i) Mixing of char pellets with KOH in flakes (KOH to char ratio: 1:1); ii) heating up to 600°C (5°C/min), isotherm for 1 h and cooling (5°C/min) with N2 purging; iii) washing with 5M HCl and demi water (up to pH 7); iv) drying at 105°C until constant weight. This activation improved the adsorption capacity significantly.
ii) Soda (Na_2CO_3) from Solvay production line ("Soda Solvay light"), which is out of specification. Hence, it is tested as coagulant and softening agent.
iii) Granulated limestone rocks ("precotto") which are only Partially calcinated and slacked, with $Ca(OH)_2$ content of around 9%, i.e., not accomplishing the requirements for commercialization (out of specification). Hence, it can be reused in alternative applications such as in the construction section, ceramic production or as coagulant and softening agent.
iv) Solvay also produces H_2O_2. This compound is a promoter of OH radicals when coupled with UV radiation, so this H_2O_2/UV technology has been tested as improved advanced oxidation process (AOP). In addition, digital tools (UV and fluorescent sensors) have been tested as surrogate parameters to monitor the quality of the effluent water. The fluorescent sensors 275/354 nm showed to be more accurate to monitor the presence of emerging contaminants than UV sensors.
The UV/H_2O_2 showed relevant removal of CECs, which confirms the potential of this technology to use the H_2O_2 from Solvay industry.
This technology was proved with municipal wastewater but has the potential to be used in other water media such as industrial wastewater. In these cases, another emission wavelength would be probably needed.

The coagulation-flocculation process, that mainly aimed to remove COD and hardness (Ca, Mg), showed better results using Soda Solvay than Precotto or their mixes. These results (jar-tests) were used to design the pilot plant that is currently under operation.

2.7.3. Material recovery and reuse in ULTIMATE CS8: Chemical platform of Roussillon (France)

This presentation was carried out by Rodolphe Vautherin from Suez (3S) and consisted of the recovery of sulfur and metals at the chemical platform of Roussillon (France). In this platform, liquid hazardous wastes (mainly from chemical industry with high salt and sulfur content) are incinerated at 1100 ºC. Flue gases are then efficiently desulfurized, but the sulfur was not recovered. Within the framework of ULTIMATE project, the sulfur aims to be recovered in the form of a marketable solution ($NaHSO_3$).

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To do so, a lab-scale pilot process has been developed to study the impact of certain operating conditions on the absorption of SO_2.
As main conclusions from the batch tests:
i) SO_2 is absorbed in high yields when the ions required for absorption are present in the solution.
ii) Absorption efficiencies do not depend on the concentration in the liquid phase.
iii) the lower the temperature, the higher yield of reaction.
Regarding the second phase, i.e., pH control tests, at pH 8, absorption yields reached values over 96%; whereas at pH 5 yields were around 70%. As main conclusion, pH control was possible and showed good results, but they have to be confirmed in real flue gases as they can produce secondary reactions that decrease the absorption yields.
Finally. CS8 aims to create a model that represents the industrial pilot mathematically (using MatLab). This model is expected to: i) predict the pilot behavior and estimate interesting configurations to be tested; ii) better understanding of the mechanisms of SO_2 absorption; iii) better analyse the impact of secondary reactions.

In the final Material recovery workshop, Anne Reguer presented the updated results of CS8. Pilot tests carried out with 4 different wastes from diverse customers, with percentages of sulfur concentrations in variables ranges within 12-49%.
Some of the improvements made are:
- Reduction of washing water volume in scrubber
- Avoiding condensation and water accumulation.
- Continuous operation during sulfur waste incineration.

Results obtained so far (still in progress) showed concentrations of $NaHSO_3$ in the range of 83-216 g/L, whereas for $NasSO_3$ the concentration is in the range of 0.1-7.4 g/L and for Na_2SO_4 is 0.4-3.3 g/L. These yields are lower than expected, but optimization is foreseen.
About 40% of SO_2 is captured by the washing process. To improve this yield, it is necessary to remove basic waste from the furnace inlet and reduce the pH of the first washing steps.
The overall yield of the industrial pilot is around 99%, being most of it removed in the second step (sulfite production), rather than the first step (bisulfite production).
The results from the developed model suggest that the process can be improved if the temperature is reduced to 50-60ºC. They will probably need a third column to obtain the targeted pH.
They also obtained promising results in terms of metal composition.
Additionally, Stephane Deveughele (3S) explained their approach related to IT tools applied to CS8. Their approach is configuring a single IT application that carries out technical and economic studies in the CS8, based on the software WasteAdvanced®.

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2.7.4. Material recovery and reuse ULTIMATE CS 7: Tain (UK)

In the final workshop of material recovery, Marc Pidou (UCRAN) explained the results obtained in CS7: Glenmorangie distillery. They treat the distillery wastewater using AnMBR system, which effluent contains high nutrient concentrations (795 mg N/L; 236 mg P/L; 43 mg Mg/L). These nutrients are aimed to be recovered by two technologies: i) struvite crystallization process to recover phosphorus as fertiliser; and ii) stripping column to recover ammonium sulfate (fertiliser or other potential applications). After recovering these nutrients, water can be also reuse onsite (after reverse osmosis post-treatment).

One difficulty in struvite precipitation is the low amount of magnesium (below the molar ratio needed: $NH_4/PO_4/Mg=1/1/1$). Consequently, they add Mg to the water to increase the removal of PO_4 (NH_4 is in excess). They tested different operating pH values (7.4-9.4) in a reactor with different sections to facilitate the crystal formation and their precipitation. As results, P-removal increased (around 80%) with higher pH (over 8.9). At the highest P-removal, PO_4 concentration in the effluent accounted for 45-53 mg P/L. Higher removal could be achieved by increasing the Mg/P ratio (0.5-1.1). However, the type of product also changed with pH, being more pelleted under lower pH conditions and more soluble at a higher pH. Understanding how the product is structured with pH values is important from the commercialization point of view, as the product will need to present certain characteristics.

With respect to N-recovery, it increases with pH, obtaining the highest at pH 9.8 (69%). Under pH values of 9 the recovery is quite low (around 10%).

In general, the products' quality was high, with limited organics and metal contamination.

Despite the promising results, for the distillery company, the recovery of nutrients is not a priority for their business. They generally focus on their production process and subcontract the waste management. This is also related to the low profit that can be obtained from the final products. On the other hand, there is significant symbiosis with local farmers in terms of recovering the sludge from AnMBR directly in land.

The interest of the company in the technology would be avoiding treatment costs rather than producing valuable products. This lack of interest in the market is a clear barrier in the development of circular and symbiotic technologies and processes.

Material recovery can be even more challenging in urban wastewater rather than industrial wastewater. The moderator Francesco Fatone believes that companies can associate more efficiently between them to move the material recovery sector forward.

Afterwards, Johannes Koslowski (KWR) presented some results about the quantitative chemical risk assessment (QCRA) of CS7. More specifically, he analyses the environmental effects of adding the fertilisers produced by the aforementioned technologies.

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The methodology implemented used Monte Carlo simulation to evaluate different scenarios and concentrations of potential pollutants throughout the time. The methodology also defines the negligible, acceptable and unacceptable level of risks.
The CS7 struvite contains significant amounts of Ni, Zn and Cu. Due to the high variation of the concentrations of these metals, two scenarios were defined (high and low concentration of each metal). The CS7 struvite always showed negligible risks, assuming that the fertiliser would be applied for 100 years.

2.7.5. 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 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.

2.7.6. 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

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and building blocks have been produced and already been applied in real environments.

2.7.7. 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.

2.7.8. WIDER-UPTAKE: CS 1 (Netherlands case study)

Peter van Gilst (NPSP) introduced the Dutch case study of the H2020 project WIDER-UPTAKE. This case study aims to produce biocomposite materials and prototype products from water-embedded resources, focusing on the application of raw materials, not the recovery and production of the raw materials themselves. From raw materials such as (cellulose, calcite, vivianite, biochar, bio-based resins and fillers and others), products are obtained to be applied in façades, bank protection, construction materials, signing and design products.

As main challenges of these sustainable products, raw materials require availability in enough quantities, proper specifications (mechanical and chemical properties,

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processing, and storage conditions), supply consistency (quality and economics), marketable materials (not treated as mere wastes). However, waste-based materials tend to present variable properties according to their place of origin and seasonal influences. Minimum processing and ordering volumes combined with best-before dates can create barriers for scaling up new materials. With respect to bio composites requirements, main issues are related to mechanical and esthetical fits for applications, the market competitiveness with conventional products and the reproducibility of their quality. Policies and regulatory issues have been also detected in the framework of this CS. In this respect, national implementations of the Waste Directive are needed. Moreover, true pricing may stimulate competitiveness of new sustainable material as it is unclear if renewable bio-based materials are fairly valued.

2.7.9. WATER-MINING: Demonstration of renewable desalination and sustainable brine management. CS 1 (Italy case study)

Rodoula Ktori (TU Delft) gave a presentation about material recovery in the WATER-MINING project and, in particular in the Case Study 1 (Italy), which focuses on “sea-mining”, i.e., renewable desalination and sustainable brine management. Its main objective is to demonstrate the compelling advantages of advanced desalination combined with renewable solar energy and waste heat, while softening pre-treatment and improving water and other value-added resource recovery.

In the Italian case study (Lampedusa island), the desalination plant fully covers the total drinking water needs of the island. Its energy consumption accounts for around 10% of the total energy of the island. The main targets of this CS is to cover 50% of the total energy by renewable energy and waste heat, reduce the energy consumption by 10%; increase water recovery to at least 80%; and obtain magnesium and sodium chloride purity higher than 90%.

2.7.10. WATER-MINING: CS 3-Faro/Olhao Nereda WWTP. Kaumera results overview

Philipp Wilfert (TU Delft) presented the main results of the CS3 (Portuguese case study) of the WATER-MINING project. This CS expects to obtain valuable polymer out of WWTP sludge (with local use), as well as involve local stakeholders. Faro/Olhao WWTP is a large facility with 113200 pe. The “Kaumera” prototype implemented in this study is based on aerobic granular sludge (Nereda®), which helps to reduce the area of reaction, thus decreasing the energy consumption. These sludge-based granules with bacterial EPS can be used on agricultural soils as biostimulant, water absorbent or coating binder. Preliminary results are promising, but the product must adapt to customer needs and not the other way around.

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2.7.11. CIRCULAR BIOCARBON: Industrial-scale biorefineries from OFMSW and sewage sludge

Placido Auresanz (URBASER) presented the H2020-Circular Biocarbon project, which is related to the development of industrial-scale biorefineries from the organic fraction of municipal solid wastes (OFMSW) and sewage sludge (SS). More specifically, two biorefineries are being built: one in Zaragoza (Spain) and another one in Sesto San Giovanni (Italy).

Expected products of Circular Biocarbon include coating of direct consumer products, coating of mechanical moving parts, of plastic molding tools, biodegradable waste bags, graphene-based products, biodegradable soil mulch films, organo-mineral fertilisers, and liquid biostimulants.

With respect to end-of-waste criteria in the framework of this project, they find difficulties demonstrating all the conditions that need to be accomplished, especially in the case of the production of alternative building blocks. As currently there is not significant market or demand for these products, the potential of this technology is underdeveloped.

The main challenge in this case study is related to ensuring the supply of raw feedstock with enough quality to be introduced in the anaerobic process. They suggest the selective collection of OFMSW to achieve this goal. The micro-pollutants contained in sewage sludge are also a major issue that complicates the anaerobic digestion process. These issues are also related to obtaining low-quality products, thus making the biorefineries unfeasible.

To tackle these challenges, they indicate that public-private collaboration is necessary. Facilitating and accelerating the permission and authorization procedures is also important. It is also essential to obtain subsidies in terms of grants, loans or other to assume the high investment in circular technologies.

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2.8. 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. A follow-up workshop was conducted on Sept. 26th 2023 with 27 participants. The sister project B-WaterSmart contributed with a presentation to the workshop and shared its insights. 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 and 15.

Key lessons from the discussion:

1) For all digital tools, the main work is the model and its validation. 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. A very big challenge is not having direct access to the data. Then, a very good communication/connection to the operator needs to be established to receive the data in time.

2) Systems, that rely on publicly available data, face a huge challenge, because not only internally the data types vary, but also already on a national level, they vary from region to region. To have access to the same data types (e.g. same time periods) and to recent data nationally and internationally, can highly boost the replication of such systems as e.g. the water demand forecasting tool.

3) Personal data protection has to be considered, when meters and sensors need to be installed household-wise. Agreements/contracts have to be made with the households with the permission of the owner to use such data. This is very time consuming and should be considered in the planning of such a system.

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

2.8.1. 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

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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 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.

2.8.2. 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 was 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 are screened regarding the highest admissible chloride content. These potential uses will be integrated in a data-driven matchmaking platform for water reuse.

In the follow-up meeting Cecilia Bruni presented the early warning and matchmaking system. Therefore, a model for the sewer networks in Rosignano and Cecina was developed using geometric information and data from pumping stations, sampling campaigns, flowmeters and electrical conductivity meters, sanitary flow and rainfall. The model was calibrated using data from the wastewater treatment plant. For the early warning system, sensors were installed along the coastline for the electrical conductivity, the water level, flowrates and precipitation. The early warning system is based on a recurrent neural network to predict the chlorine concentrations. For the smart equalisation, an equalisation tank is used as entering point to the water reclamation plant. Both WWTPs in Rosignano and Cecina deliver their effluents to the

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equalisation tank. The set-point which regulates the pumps of the effluent coming from the WWTPs is controlled by the water level in the equalisation tank and the effluent quality. The match-making platform decides the reuse purpose of the water depending on its quality, determined by the electrical conductivity. The reclaimed water can be used directly in industry, when the electrical conductivity is below 2000 µS/cm or for agricultural irrigation, when it is even higher than 2000 µS/cm. To allow for an industrial reuse at an electrical conductivity higher than 2000 µS/cm, the water is further treated using reverse osmosis.

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

The 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 is treated in an 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.

Ángel Robles from the University of València presented the software Lodif Biocontrol for the control of ultrafiltration membranes, which shall be tested in Lleida. The aim is to avoid/reduce fouling processes and thus, to save energy during the filtration process. The software is under continuous development, incorporating improvements and configurable, to facilitate the implementation of control systems and optimization algorithms in a WWTP. To control the filtration process, knowledge-based controllers for biogas sparging, the sludge recycling flow and back-flushing initiation are used to minimize the fouling rate. Hereby, the set-points of the biogas recycling flow rate for gas sparging is controlled to scour the membrane depending on the permeate flow. In addition, a model-based supervisory controller is used to minimize the operational expenditures and to control the modification of the set-points of the knowledge-based controllers. It uses the filtration model as a basis considering cake layer formation and irreversible fouling. The input parameters are the biogas recycling flow rate, the sludge recycling flow rate, the duration of the filtration, relaxation and back-flushing, the frequency of back-flushing initiation and the transmembrane flux during back-flushing. The control of the membrane fouling allowed in a pilot investigation to save 35% of energy in membrane operation.

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

Anne Kleyböcker from Center of Competence 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 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 model is currently developed in order to investigate different scenarios to define corresponding set-points for the oxygen concentration in the aerated tanks and for the mixed liquor suspended solids (MLSS).

Jan Schütz from KWB presented the model in the follow-up meeting. The model was created with the Software SIMBA#. The challenge was, that the software is designed for municipal WWTPs and had to be adapted for the wastewater in Kalundborg having a high fraction of non-degradable organic matter resulting from the industry. The model is based on the activated sludge model 3 (ASM3) and was successfully calibrated with an overall model efficiency of 74%. The model was used to investigate the reduction of direct discharges of untreated wastewater to the recipient through the implementation of an additional upstream buffer tank. The model showed, that the implementation of a buffer tank with a volume of 5000 m³ enables the reduction of overflows by 99%. In addition, for the joint control system, a TN predictive equation was derived from historic data. The equation allows a prediction of the TN concentration 36 h before the TN load enters the municipal WWTP.

2.8.5. 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.

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2.8.6. 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 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.

2.8.7. B-WaterSmart: The short-term water demand forecasting tool & the regional demand supply matching GIS tool

Katharina Gimbel from the IWW Zentrum Wasser (Germany) presented two tools developed in the frame of the German living lab East Frisia in B-WaterSmart. Due to climate change, raising water demands and salt water intrusion into the groundwater in coastal areas, a regional demand-supply matching GIS tool is being developed. In this tool, open data and an open GIS platform are used to match demands and alternative sources for the regional water supply. Results of a UWOT model for different scenarios are integrated and hence, possible alternative water resources are suggested by the tool such as the potential for rainwater harvesting and water reuse. The second tool forecasts the short-term demand in the region. Due to increasingly extreme weather conditions (e.g. droughts) the water demands are growing and peak loads become usual with the risk of water shortages. Already existing forecast tools often consider the whole water supply network. The complex network makes it difficult to identify the individual water consumers and the demand of smaller supply areas. To gain additional information, the B-WaterSmart tool generates 24 h water demand forecasts based on small meter data. It provides different spatial resolutions and thus, produces a comprehensive knowledge base contributing to manage the water supply system efficiently and sustainably.

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2.9. 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.

2.9.1. 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.

2.9.2. 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.

2.9.3. 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 m^3 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

2.9.4. 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.

2.9.5. 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

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analysed the aspects for success of industrial symbioses in different projects. Those 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, eighteen 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 (i) at an early stage, an intermediate stage and at the end of the project together with experts from other Horizon2020 projects such as NextGen, Smart-Plant, Run4life, Sea4value, Digital-water.city, Fiware4water, Water2Return and Aquaspice, Sludge 4.0, and Circular Biocarbon. In addition, the partners from our sister projects B-WaterSmart, Water Mining, Rewaise and Wider Uptake participated to share their opinion with us and to derive together recommendations for European policy makers to boost the market-uptake and replication of our ULTIMATE solutions.

To establish a successful WSIS, we identified the most important factor to be the commitment and willingness to act together of the WSIS partners 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. In addition, lighthouse cases such as the WSIS in Kalundborg, Tarragona and Rosignano are extremely helpful for WSIS newcomers to learn from them for their own WSIS establishment. All potential stakeholders, including administrative actors, should be part of the establishment already from the very first idea onwards.
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, was seen as a crucial step towards the successful project execution to inform and involve all project partners even those, who were not directly involved case study specific tasks. Furthermore, the technology evidence base (Kleyböcker et al. 2021a, Kleyböcker et al. 2024b; https://mp.uwmh.eu/teb/) contributed to an open and evidence-based communication about the outcomes of our project for spreading the successful circular economy solutions in Europe and worldwide. Our technological workshops were mainly dedicated to three topics: water reclamation, energy recovery and material recovery.

Water reclamation

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 standard reverse osmosis. In general, the adsorption technology is very versatile in terms of inorganic and organic pollutants

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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.
Currently, there are successful examples of symbiosis between wastewater treatment plants and water treatment facilities, with ample opportunities for further enhancement and optimization, particularly in promoting the reuse of regenerated water in various industries. Several ULTIMATE case studies (CS1, CS2, CS3, and CS9) have demonstrated the technical feasibility of various membrane-based technologies for industrial water treatment at the pilot plant scale. These technologies have successfully produced water that meets the required quality standards for reuse in different applications, such as industrial processes and irrigation, validating the collaboration between water treatment plants and industrial sectors. On the other hand, technical feasibility studies for treating industrial water and obtaining water for reuse have been complemented with LCA and Microbial Risk Assessment to evaluate the environmental impact and human health effects.

Energy recovery
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 in wastewater treatment plants 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. Systems, that rely on publicly available data, face a huge challenge, because the data types often vary and cannot always be used without further processing. For data, which refer to private households for example, personal data protection has to be considered. Agreements/contracts have to be made to receive the permission of the data owner to use such data. This is very time-consuming and should be considered in the planning.

We learned that biogas technologies involved in wastewater treatment can contribute to a lower CO_2 footprint of a WWTP, because anaerobic treatment processes allow for a decrease in the organic loading rate to the downstream activated sludge process and hence, for a lower CO_2e footprint of a WWTP. The comparison of three WWTPs configurations applying (i) a conventional activated sludge (CAS) system, (ii) an anaerobic fluidised bed reactor (AFBR) combined with an CAS, and (iii) an electrostimulated anaerobic reactor (ELSAR®) combined with an CAS, revealed the lowest CO_2e footprint for the configuration involving the ELSAR® system. Recovering the dissolved methane from the reactor’s effluent is crucial to obtain a low CO_2e footprint. Besides the AFBR and the ELSAR® systems, an immobilised high-rate anaerobic treatment system (ATT) was investigated. The AFBR and the ELSAR

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treated brewery wastewater. Compared to the AFBR, the ELSAR is less sensitive to variations in process conditions such as shock loads or biocides and contributes strongly to a stable biodegradation and biogas formation process. The AAT is very well suited to treat olive mill wastewater and maintains a stable biodegradation and biogas formation process even though high variations in the loads occur. The combination of an AAT with an anaerobic membrane bioreactor (AnMBR) and activated carbon even increases the biodegradation efficiency and correspondingly its methane yield as well as its process stability compared to an AAT alone. The system can be applied to winery, dairy and olive mill wastewater. Considering the positive effect of the activated carbon in the AAT/AnMBR system, the ELSAR system is very likely also feasible to treat winery, diary and olive mill wastewater, because it uses activated carbon as fluidised anode. Furthermore, the ELSAR system is capable to treat most (80-90%) of the industrial food and beverage wastewater.

For two of our ULTIMATE processes, low-grade excess heat can 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. Short-term investigations at different temperatures showed no effect on fouling so far, but a higher flux with increasing temperature as expected.

When planning a high temperature - aquifer thermal energy storages (HT-ATES), it is very important, that every stakeholder is involved already at the beginning of the project. Social perception regarding HT-ATES was in the case of Rotterdam very positive, because people have seen it as a contribution to a more stable, robust and green heating supply. The HT-ATES is very well suited to be operated in combination with a geothermal doublet. The combination increases the doublet's lifetime and reduces investment costs. To gain important data for the planning phase of the HT-ATES, the subsurface exploration can be combined with a geothermal conductor drilling to deliver geo-hydrological data. The conductor drilling is three to six times cheaper than a dedicated test drilling. When starting the operation of a HT-ATES, temperature shifts occur at the warm and cold wells. Temperature shifts in an 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

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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.
The global warming potential of a geothermal well and an HT-ATES system depends mainly on the electricity consumption to operate both systems. Compared to heat generated from natural gas, the heat originating from a geothermal well and an HT-ATES have a 60% lower global warming potential considering the Dutch power mix in 2019. The greener the power mix will become in the future, the lower the global warming potential will be of such systems.

Material recovery
In terms of nutrient recovery, different innovative technologies have been successfully implemented and applied for material recovery from wastewater, sludge, kitchen waste and/or non-hazardous organic liquid wastes. Some of these technologies are advanced biodrying and composting; bioelectrochemical systems, ultra-low flush toilet coupled with (hyper-)thermophilic anaerobic digestion, electrodialysis, fluidized bed reactor (FBR) for struvite precipitation, stripping columns, adsorption columns, aerobic granular sludge (AGS) systems, anaerobic membrane biroeactors (AnMBRs).
Those technologies enable to recover various valuable materials as struvite, calcite, ammonium sulphate, CaPO4 compounds, biofertilisers, phosphoric acid, ferric (hydr)oxide pellets, solid NPK fertiliser, nutrients within reclaimed water through fertigation; hydrochar, coagulant and softening agents; limestone; polyphenols; NaHSO3, biocomposites; magnesium and sodium chloride; biostimulants, water absorbent or coating binders.
The technologies tested in ULTIMATE project, as well as in its sister and invited projects generally showed promising results in terms of percentage of recovery and quality of the materials obtained. For instance, the electrodialysis process of CS2 showed a recovery of K^+ of 250-300 mg/L, a recovery of NO_3^- of 450-650 mg/L and a recovery of $H_2PO_4^-$ of 50-100 mg/L. In CS7, the AnMBR system coupled to a fluidized bed reactor (FBR) for struvite precipitation and ammonia stripper obtained more than 75% of P and N removal from distillery wastewater. CS4 and CS6 recover high-added value polyphenols (market value ranging from 1620 €/g to 7240 €/g). CS3 reused by-products from Solvay industry (i.e., soda out of specification; partially calcinated granulated limestone rocks, H_2O_2). In CS8, the sulfur contained in flue gases is recovered in the form of a marketable solution ($NaHSO_3$).

The workshops delivered valuable information for the participants and identified important topics for further cooperation and discussion among the ULTIMATE partners and the other projects. 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) was established, where those projects also

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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 profited from the lessons learned and discussions about their concepts in order to set up, operate and optimize their demo cases properly. This contributed to the successful implementation of thoughtful ULTIMATE solutions and provided 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 ULTIMATE 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. However, the workshops still revealed the demand for **EU policy support in order to boost the market-uptake and replication of the ULTIMATE technologies**:

- **Water recovery and reuse**

It should be highlighted that policy recommendations are vital. Increasing treated wastewater quality requirements under the revised Urban Wastewater Treatment Directive (UWWTD) can simplify water reclamation processes, potentially eliminating the need for advanced treatments. While monitoring is essential, it can be costly, affecting the economic feasibility of water reuse. Public engagement and awareness are crucial to overcoming negative perceptions and increasing acceptance of reused water. Business models, funding, and pricing are key to successful implementation, with multi-user systems enhancing technical and economic viability. Clarifying responsibilities and developing consistent guidelines for water reuse licensing and service provision across the EU are essential for effective practices.
The strategic agenda should encompass all types of water reuse, emphasizing safety, environmental impact assessment, and the integration of reclaimed water into local water balances based on regional circumstances. Future regulations should set minimum standards for non-agricultural uses, improve risk assessment protocols, and encourage research on innovative water reuse technologies and practices.

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- **Digital technologies such as early warning and control systems**

Providing access to publicly available data (historical and real-time) being digital and of a uniform data type, e.g. same time periods for different regions and countries, can highly boost the replication of such systems such as the water demand forecasting tool. The requirement to develop digital solutions based on FIWARE architecture and publishing them open access can contribute to a better compatibility of different solutions and strongly helps to replicate such solutions.

- **Biogas related technologies**:

To replicate biogas production and valorisation technologies in Europe, stable prices for upgraded biogas and electricity are needed at least for a period of five years to amortise the plant. Another five years would be beneficial, after an adaption on the energy market, to provide incentives to the investors. To bridge a potential gap between the guaranteed price and the actual market price, subsidies might be needed. A minimum quota for upgraded bio-methane in the gas grid can further support the willingness of investors to implement biogas production technologies and upgrading units. A simplification of administrative formalities and financial support related to the gas grid connection can highly accelerate the implementation of biomethane producing technologies.

- **Heat recovery and reuse**

Test drillings to characterise the subsurface are expensive and time consuming. They are considered as a barrier for an easy market uptake of this technology. Hence, more research and demonstration projects are recommended to establish inexpensive, reliable and innovative technologies and their combinations in order to avoid uncertainties during planning of an HT-ATES and to accelerate the planning process. The highest risks are considered to be uncertain permit procedures and public perception. Furthermore, the permit procedure for a HT-ATES requires usually several years. We strongly suggest accelerating this procedure and to promote the demonstration of full-scale pilot systems in order to develop suitable policies and to show in practice that HT-ATES is a renewable, clean and safe technique.

- **Material recovery and end of waste status**

The implementation of technical solutions for material recovery in the case studies have detected certain barriers and gaps:

i) the quality of the final product is fundamental for the market accessibility, but in the current market it is often complicated to introduce circular products due to the competition with conventional products, low production of circular products that avoids having significant impact in the market, and scarce social acceptance.

ii) The end-of-waste criteria as defined nowadays is often unclear, especially for certain by-products obtained from emerging technologies. In this

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respect, it is often hard to demonstrate all the conditions that need to be accomplished, especially with certain products such as alternative building blocks.

iii) Scarce successful large-scale case studies.

iv) Low interest in waste producers to adopt circular processes, and variability of byproducts' characteristics were also some detected barriers for the recovery of materials.

v) Material recovery is even more challenging from urban wastewater. In fact, it is barely mentioned in the new wastewater treatment directive.

vi) Low social acceptance.

vii) Low production of circular by-products to significantly enter in the market.

The implementation of successful industrial symbiosis cases (at demonstrative scale), together with improved public-private collaboration are expected to improve the current situation on material recovery. In this respect, it would be expected that industries could be more relevant actors to exploit the high potentiality of material recovery from industrial wastewaters as they can be associated more efficiently (industrial symbiosis) than wastewater and waste treatment facilities that are often managed by public entities.

It is also essential to obtain subsidies in terms of grants, loans or other to assume the high investment in circular technologies.

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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

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Annex 1-18 are attached as extra files:

Annex 1: Presentations – Membrane technologies_2021

Annex 2: Presentations – Adsorption technologies_2021

Annex 3: Presentations – Biogas technologies_2021

Annex 4: Presentations – Heat recovery_2021

Annex 5: Presentations – Nutrient recovery_2021

Annex 6: Presentations – Material recovery_2021

Annex 7: Presentations – Digitalisation_2021

Annex 8: Presentations – Success secret of WSIS_2022

Annex 9: Presentations – Membrane technologies_ 2023

Annex 10: Presentations – Adsorption technologies_2023

Annex 11: Presentations – Biogas technologies_2023

Annex 12: Presentations – Heat recovery_2023

Annex 13: Presentations – Nutrient recovery_2023

Annex 14: Presentations – Material recovery_2023

Annex 15: Presentations – Digitalisation_2023

Annex 16: Presentations - Water recovery_2024

Annex 17: Presentations - Energy recovery_2024

Annex 18: Presentations - Material recovery_2024

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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

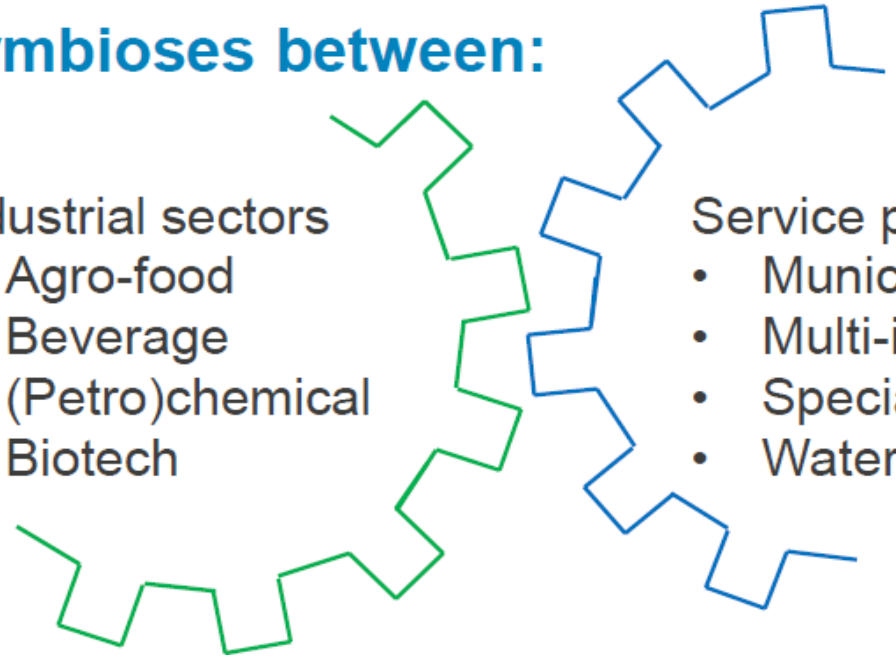


Ultimate (June 2020 – May 2024):

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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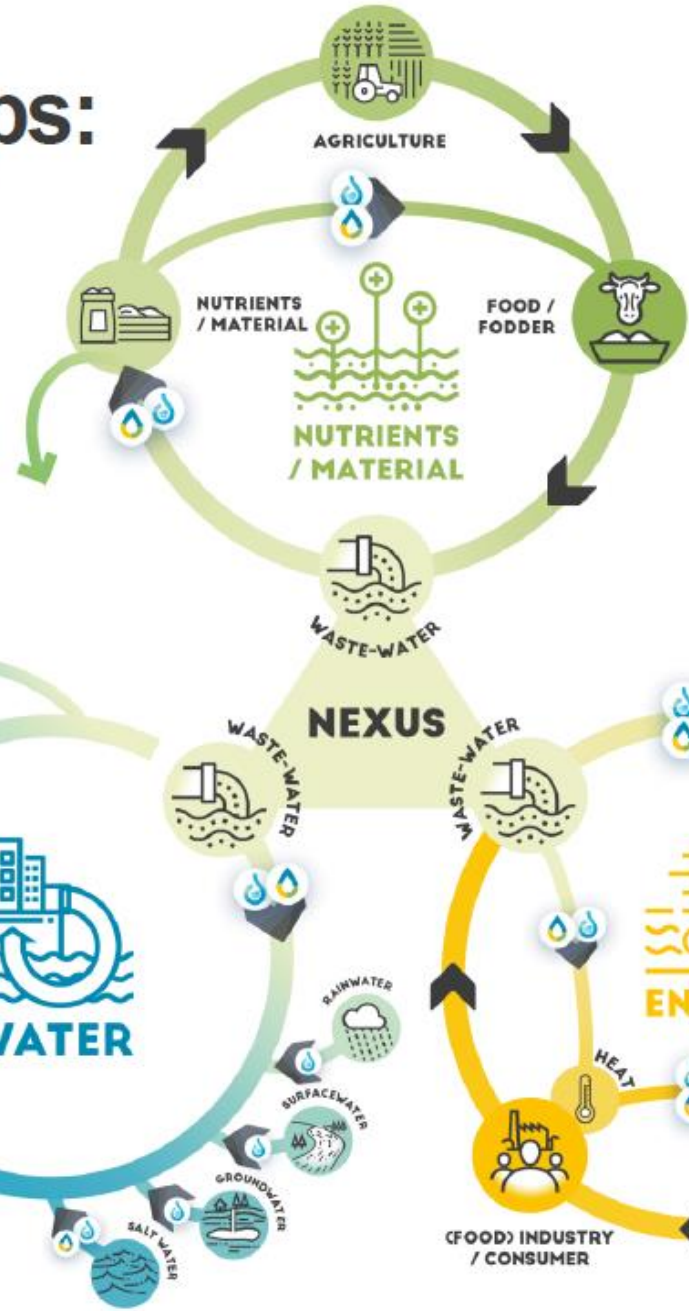
3 Cross-cutting Technology Groups: 9 Topics







F. Fatone C. Bruni

UNIVERSITÀ POLITECNICA DELLE MARCHE

- Nutrient recovery
- High added value products
- Metal recovery

eurecat
Centre Tecnològic de Catalunya



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

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)
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11:20	**Open discussion**
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 Hm³ / year

Direct jobs:17

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Camp de Tarragona WRP

Industrial water reclamation for cooling towers, boilers and demineralized uses

6,8 hm³/year capacity for urban wastewater reclamation



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 Oxígeno (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:

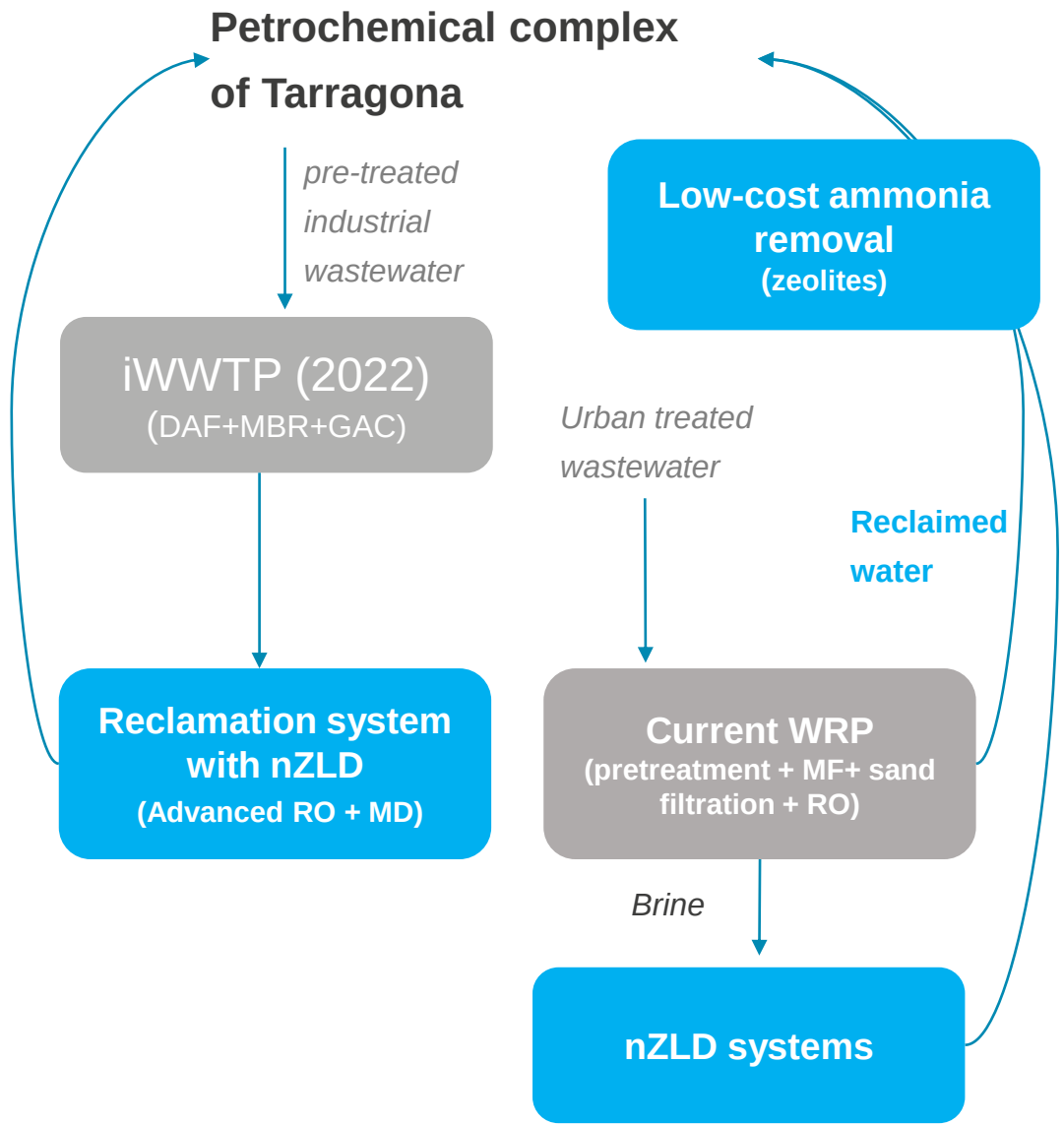
eurecat Centre Tecnològic de Catalunya

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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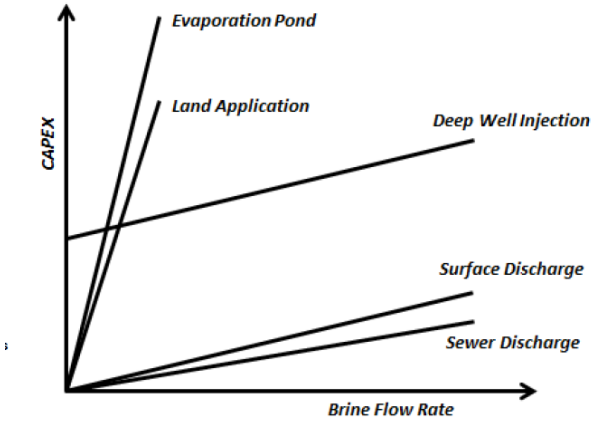
nZLD systems

Optimize water production and minimize 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

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

60-80% Water recovered

Evaporation
Membrane Crystallization
Solar ponds
Advanced Solar Evaporation

Water

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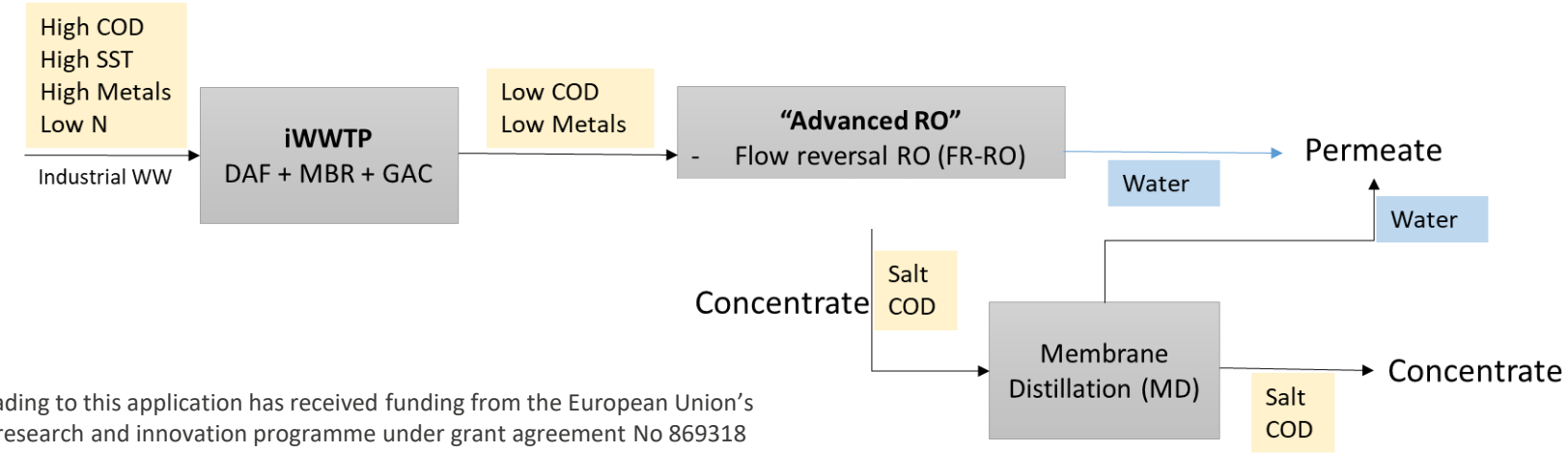
nZLD concentration

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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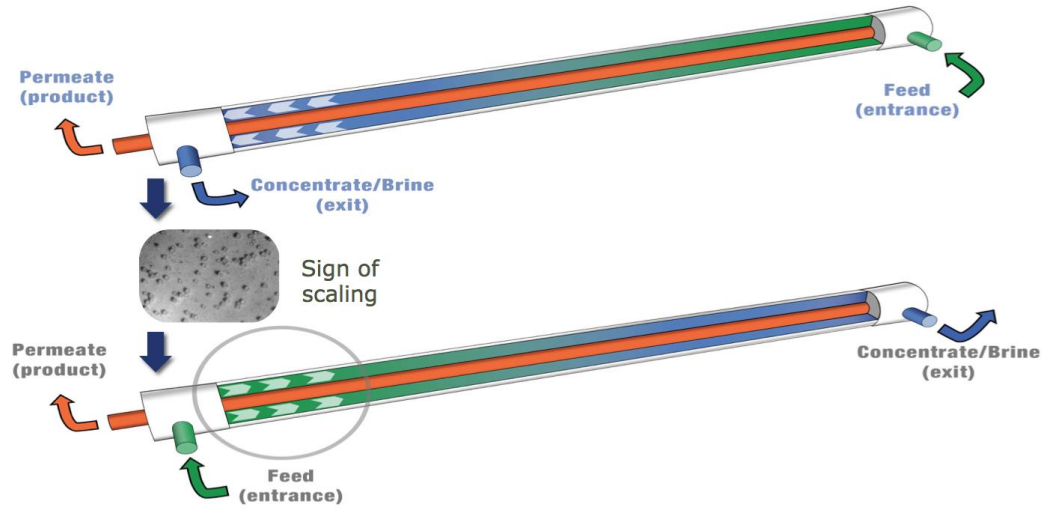
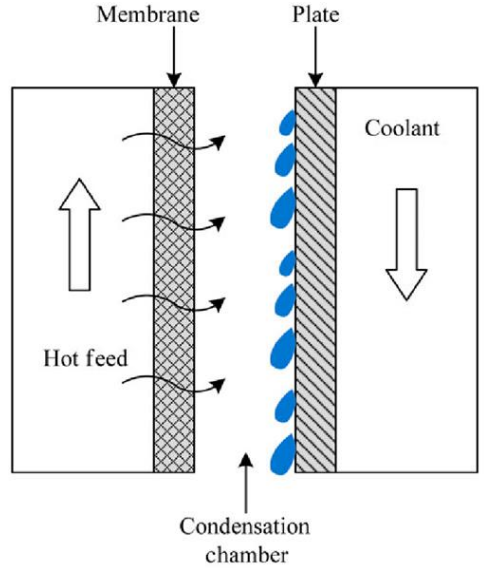
nZLD technologies proposed in CS1

Flow reversal RO (FR-RO)



- 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.

Membrane distillation



- 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

ELSEVIER

Application of feed flow industrial wastewaters

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

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

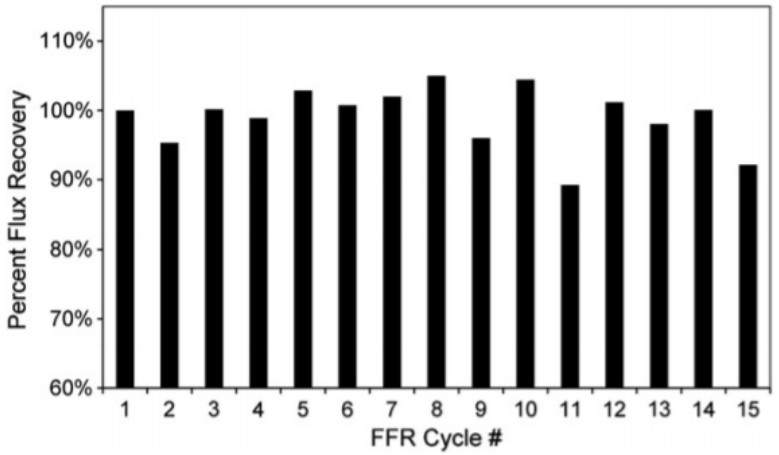

Fig. 10. Percent recovery for the tail element (PV6) permeate flux for the series of FFR cycles for Test #2 (69% recovery for period of 88 h, $SI_{gm} = 2.76$; Table 3).

Desalination 308 (2013) 63–72

Contents lists available at SciVerse ScienceDirect

Desalination

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

ELSEVIER

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

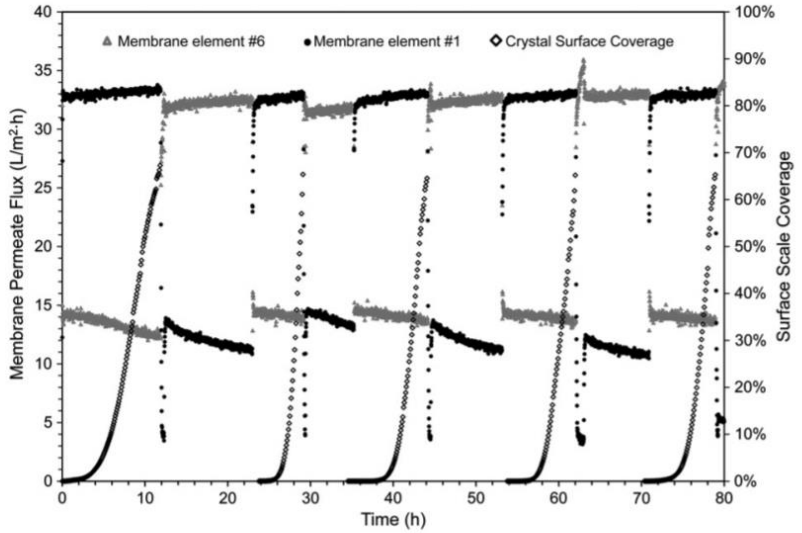

Fig. 12. Permeate flux (normalized) for membrane elements PV1 and PV6 during NFF and FFR periods, along with percent surface crystal coverage in the MeMo cell monitored area (M3 operation at 81% recovery with $SI_{gm} = 3.45$, with the FFR trigger set to 65% surface scale coverage in the MeMo monitored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

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MD

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

DCMD

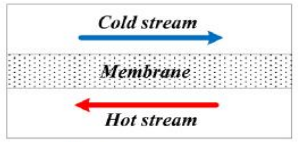

Figure 4.3 Direct contact membrane distillation.

AGMD

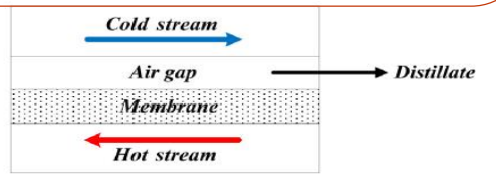

Figure 4.4 Air gap membrane distillation.

SGMD

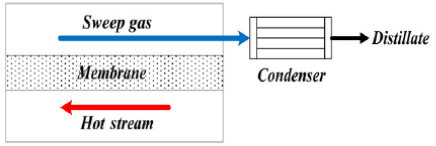

Figure 4.5 Sweep gas membrane distillation.

VMD

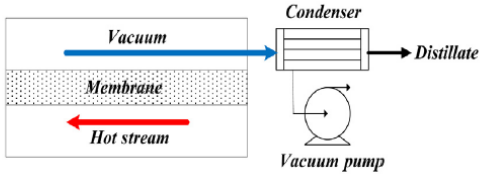

Figure 4.6 Vacuum membrane distillation.

Selection of MD:

- **Operation modes**
- **Materials available for membranes**

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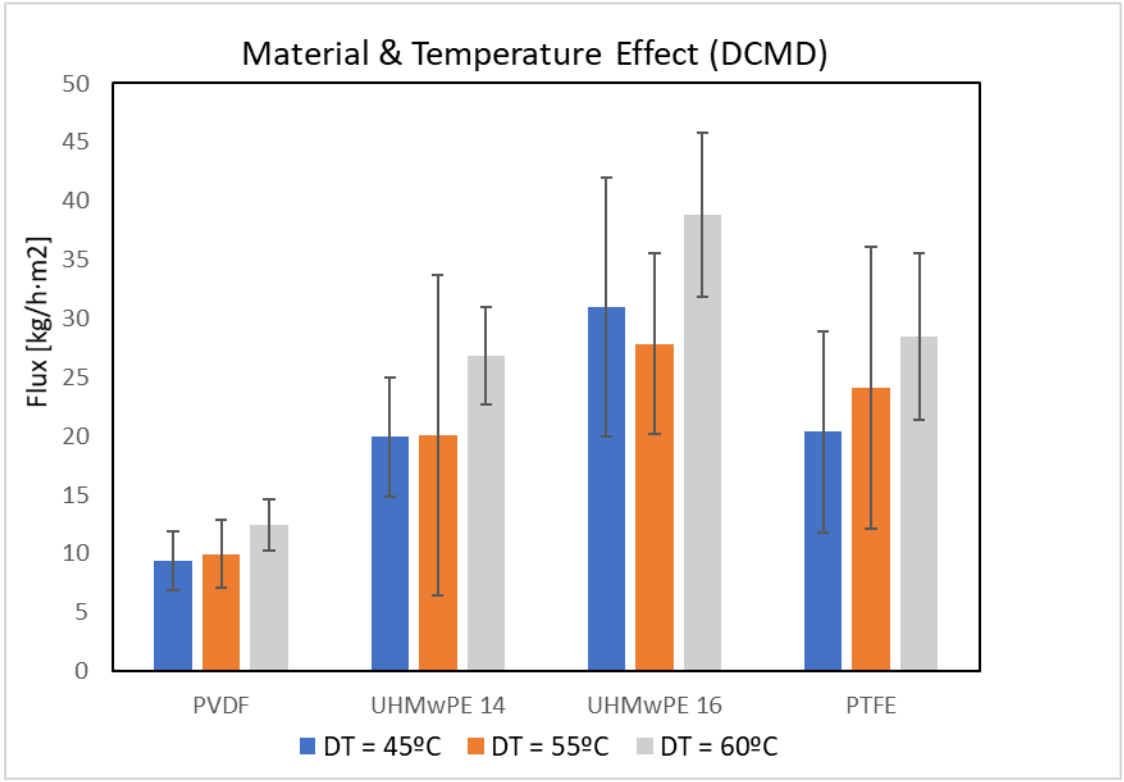
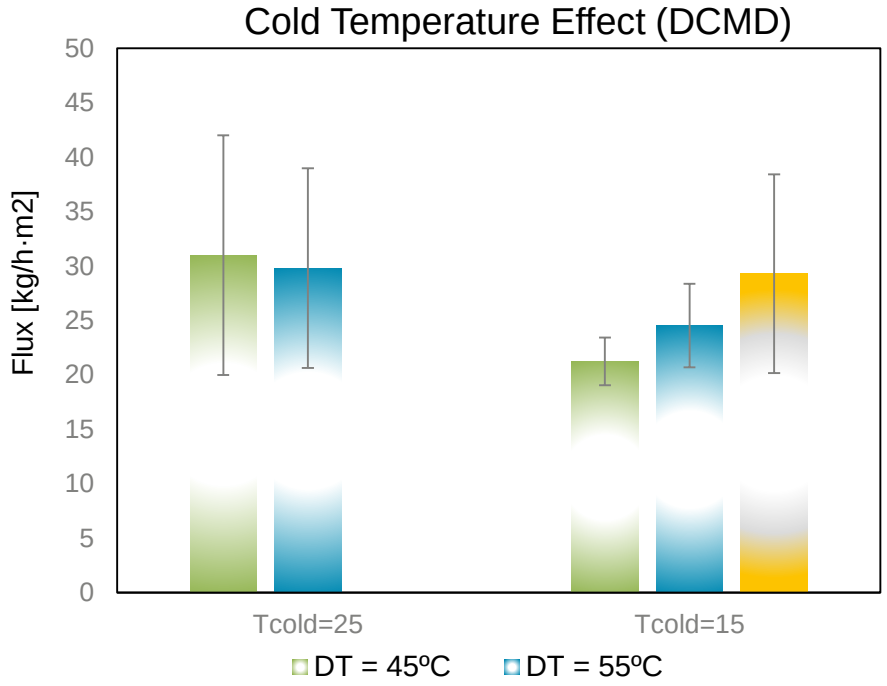
MD preliminary results

UHMwPE16 material is the most promising material for the application

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





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

Next steps in CS1

Internal milestones:		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
		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																															

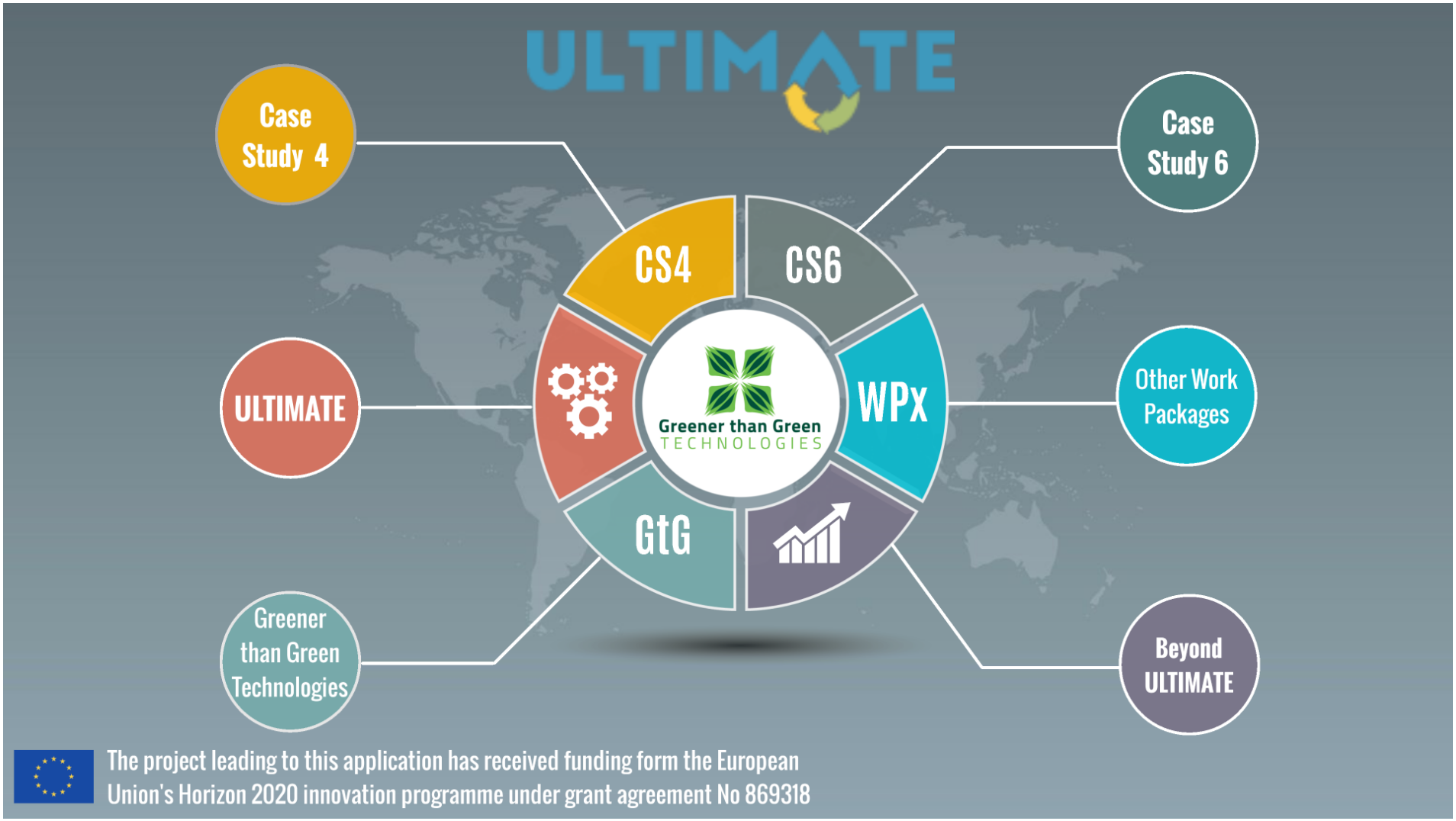
The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

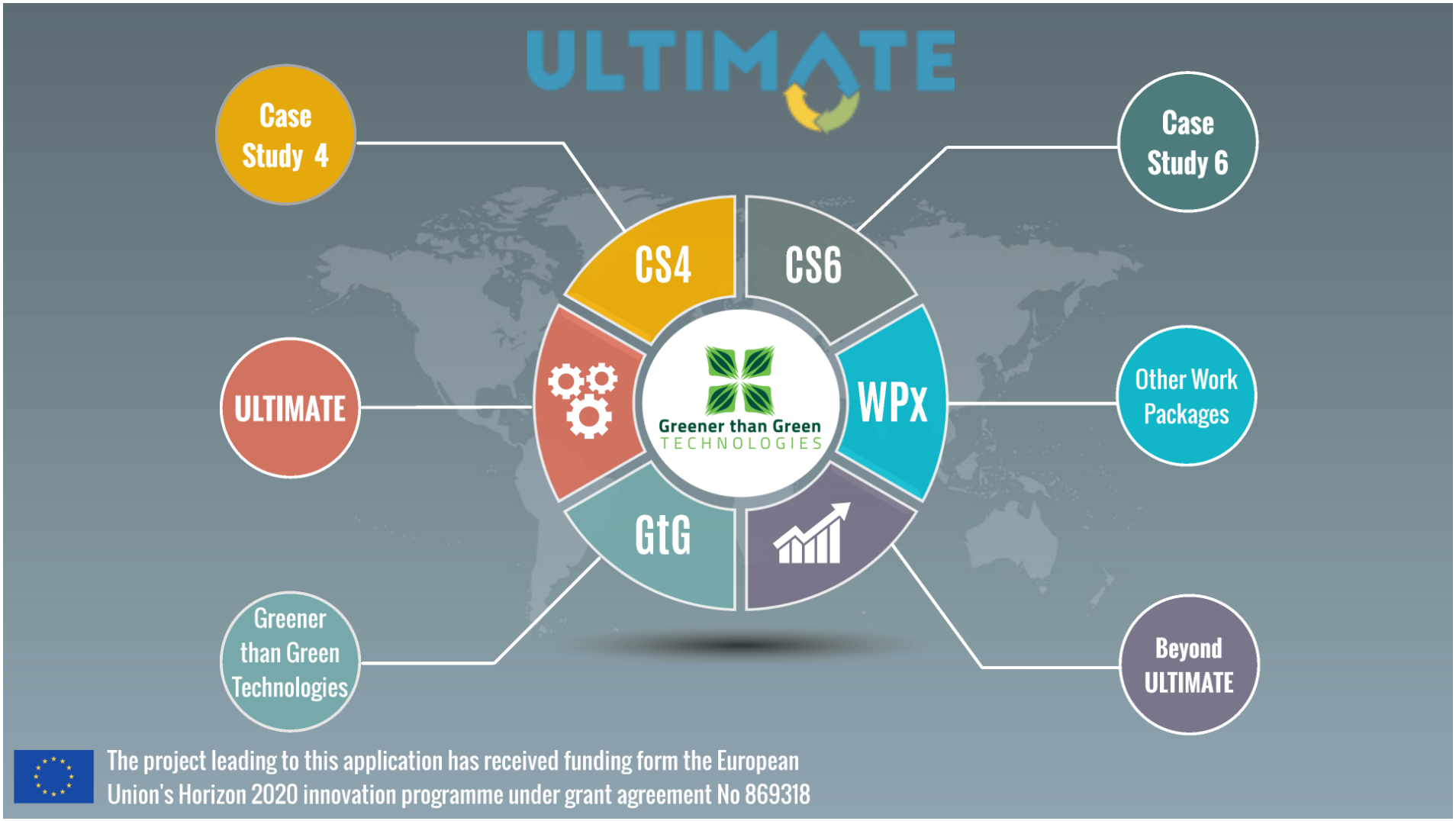
Conclusions

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)

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
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
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

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.

The team

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The team



Myrto Touloupi
Chemist BSc MSc



Christophoros Christophoridis
Chemist BSc MSc PhD

Haris Magonis
Environmental Engineer
MEng MSc



Charalampos- Philip Iossifidis
Chemist BSc MSc MBA



Dimitri Iossifidis
Chemist BSc MSc PhD



Eri Bizani
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

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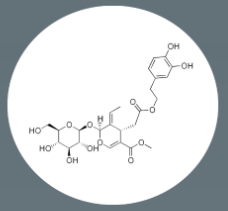
Case Study 4 Goals

- 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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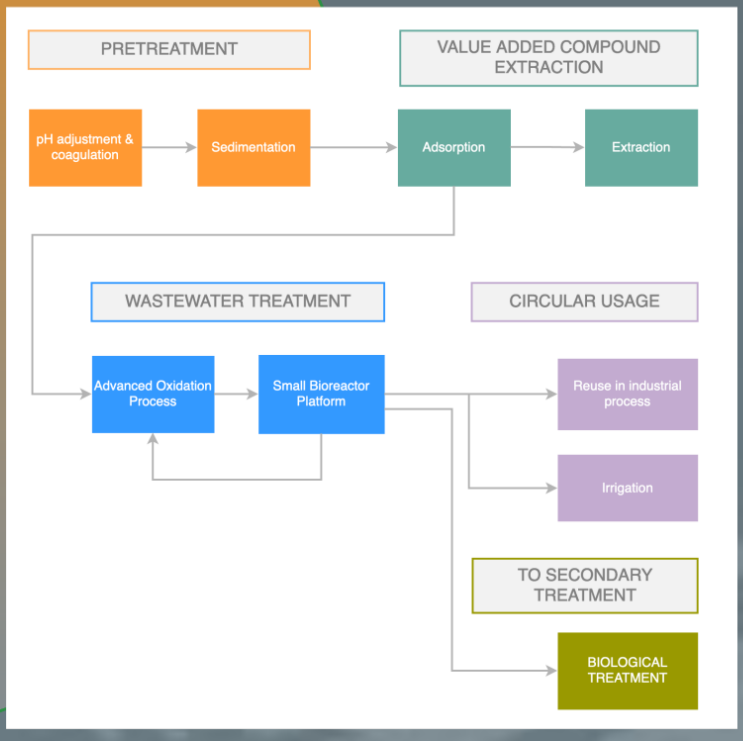
Unit Design



Cross-section



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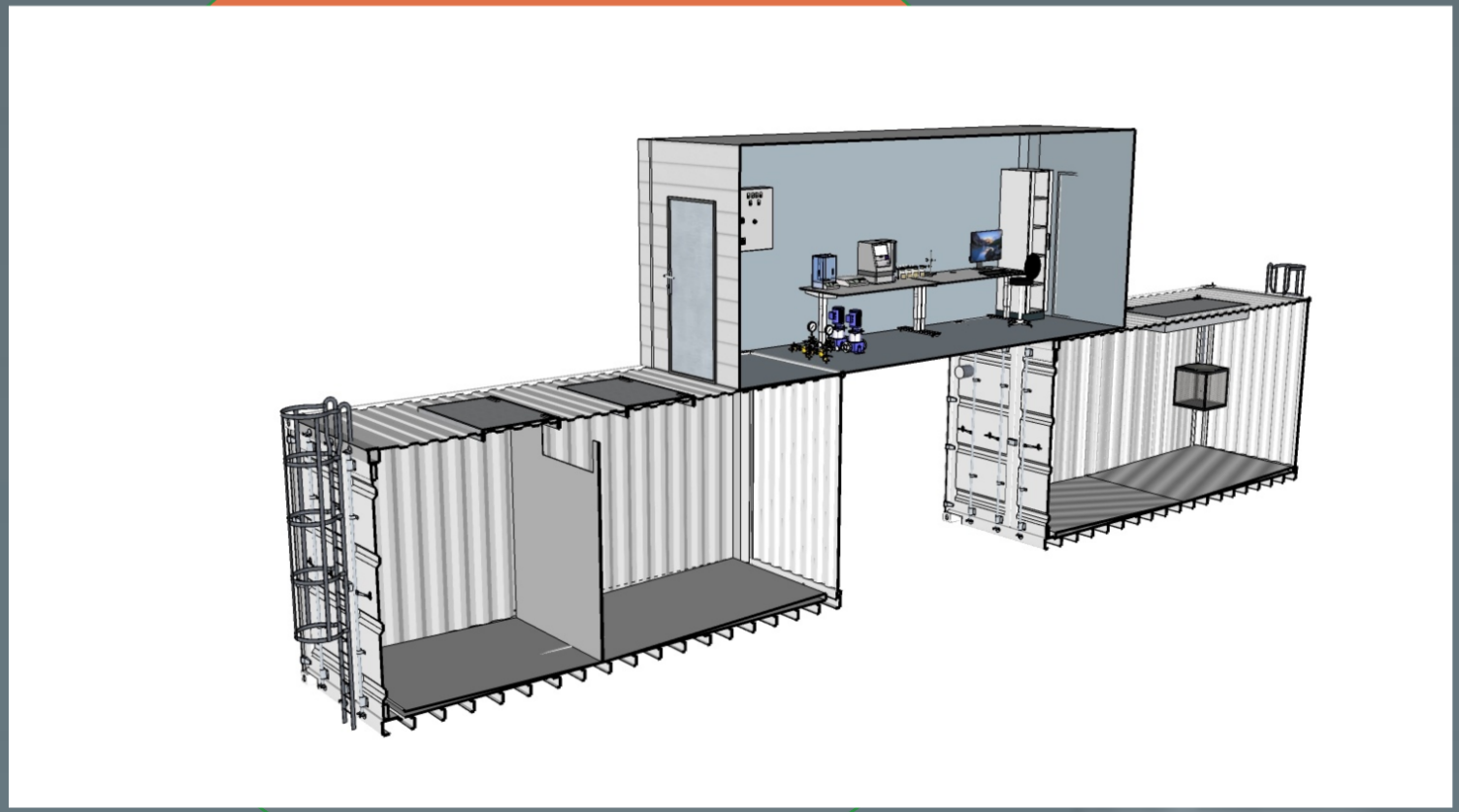
Unit Cross-section



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Small Bioreactor Platform

BioCastle
Nature open-code inspired



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

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

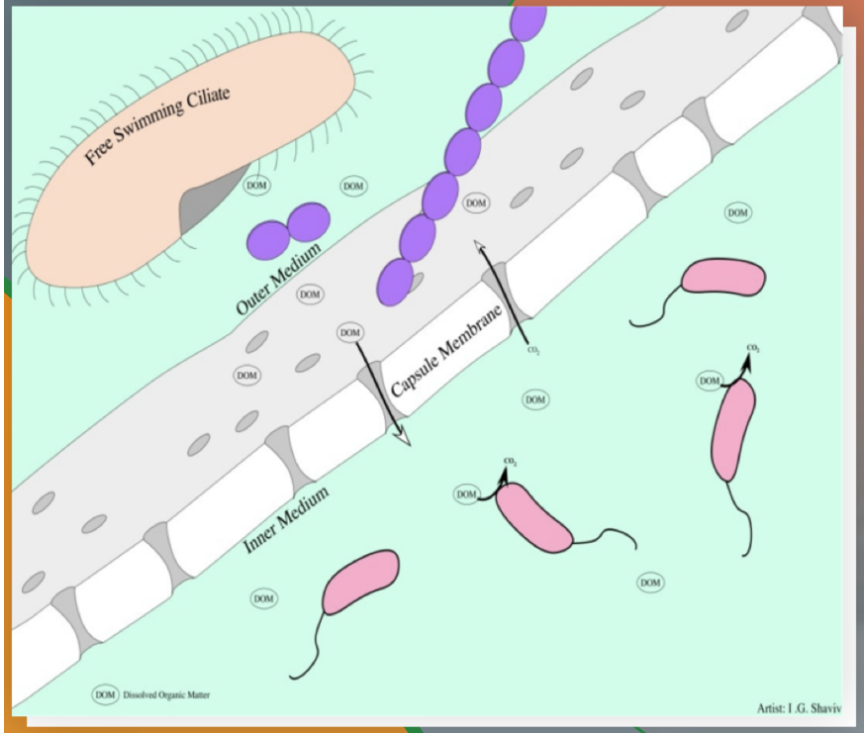
Applications

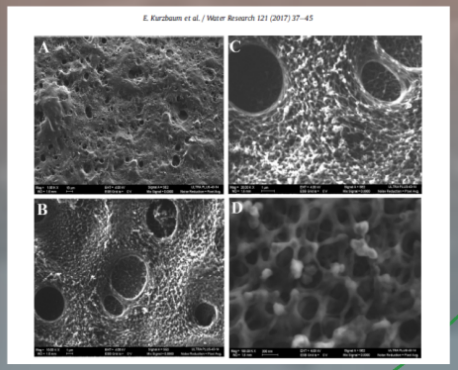
ULTIMATE

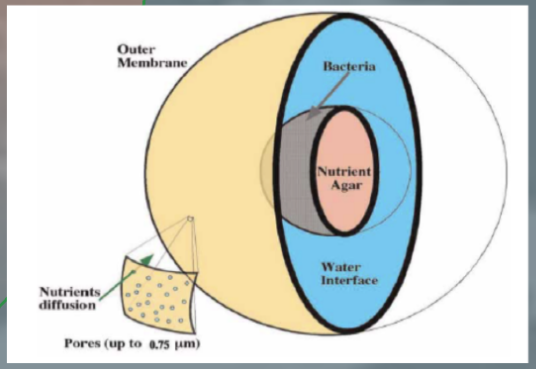
The project leading to this application has received funding form the European Union's Horizon 2020 innovation programme under grant agreement No 869318

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

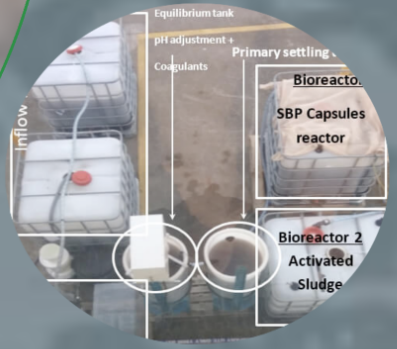
SBP technology addresses certain biological treatment problems:

- 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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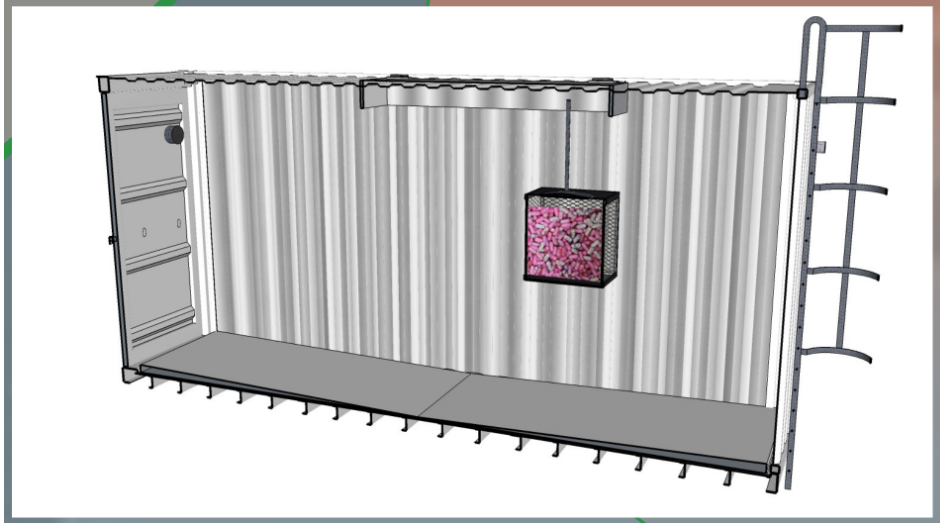
SBPs application in ULTIMATE

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

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WATER SMART INDUSTRIAL SYMBIOSIS

CS7 – Tain (Glenmorangie distillery)

Cranfield University

Aquabio

Meeting: November, 25th 2020



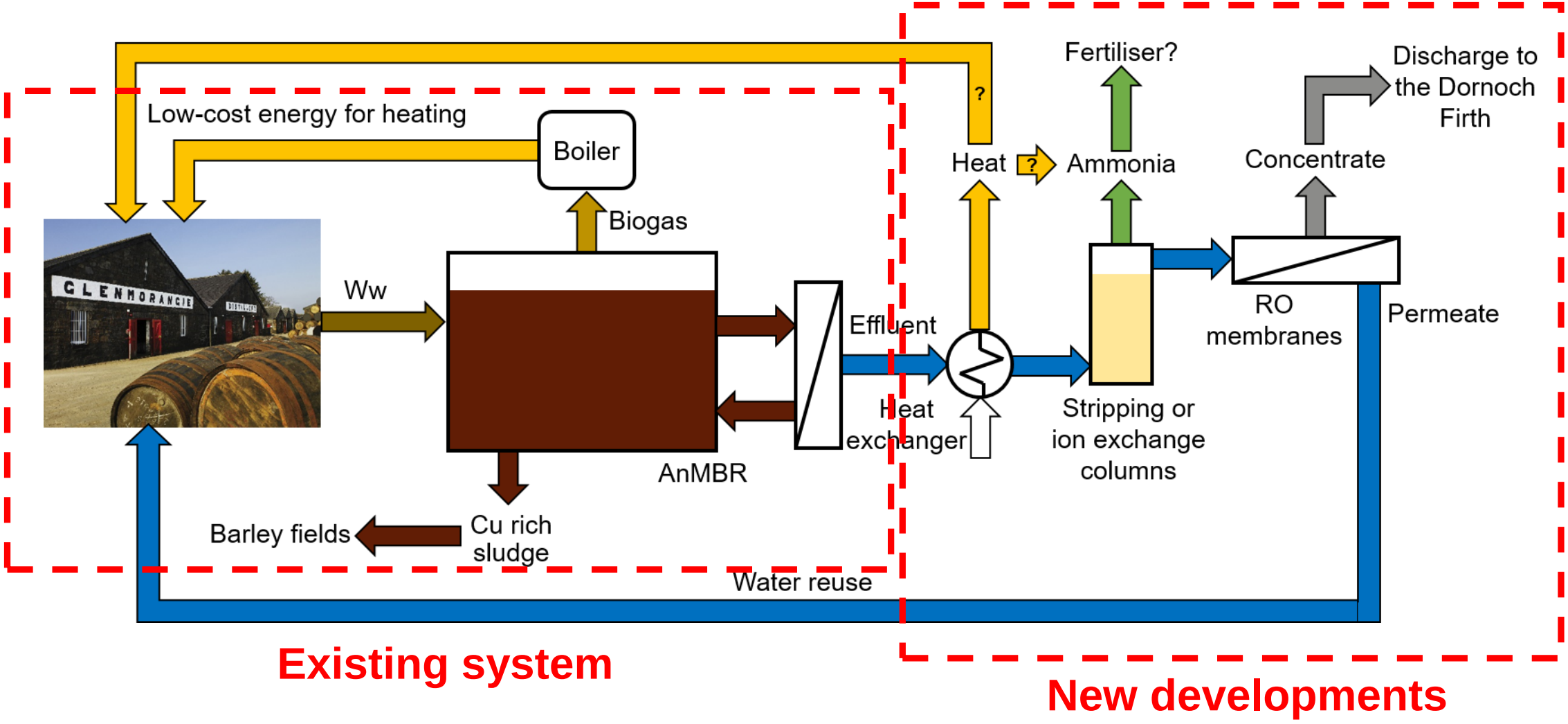
CS7


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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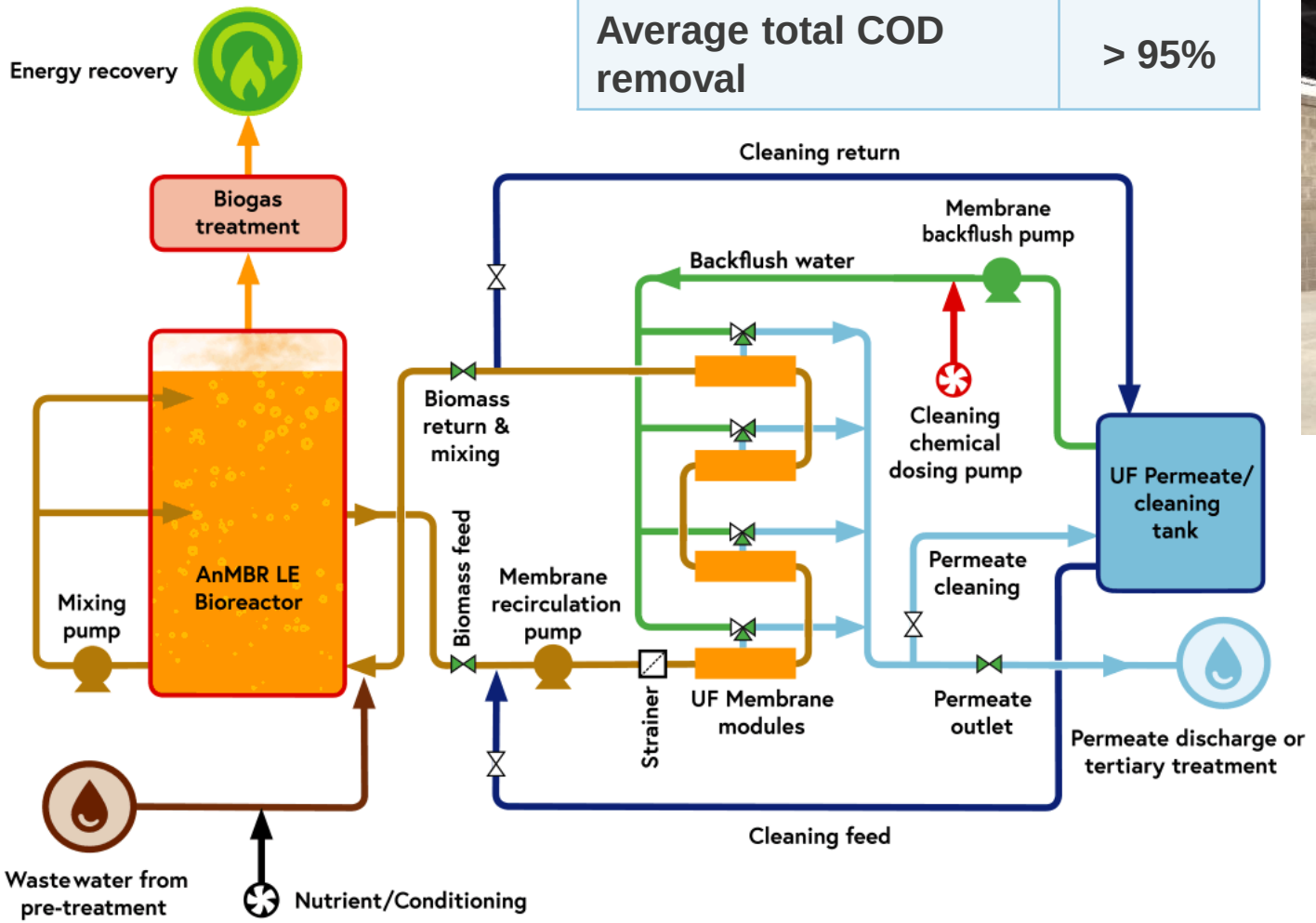
AnMBR LE™

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)

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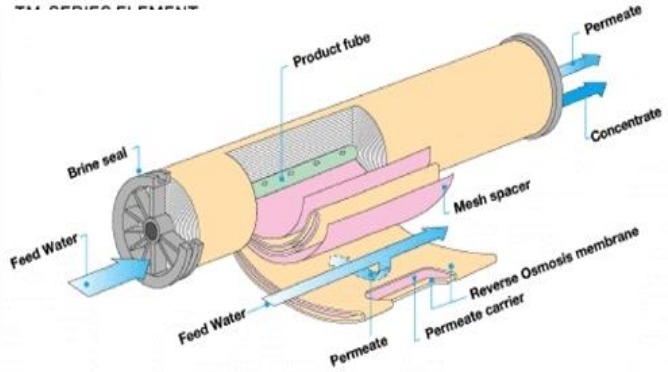
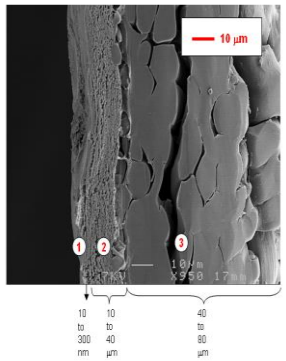
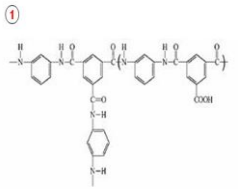
Reverse osmosis

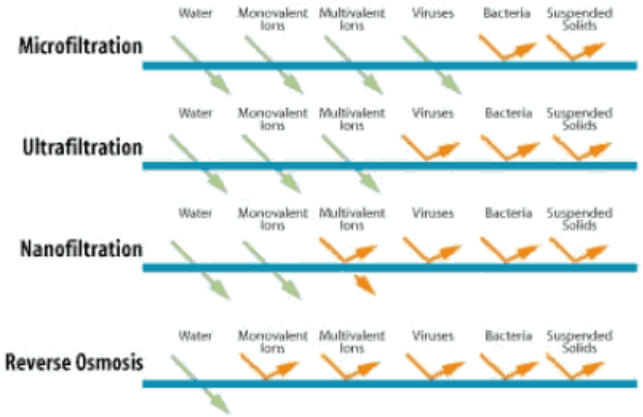






1. Polyamide (PA)
2. Poly (ether sulfone) (PES)
3. Polyester







Demonstration of the application:

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

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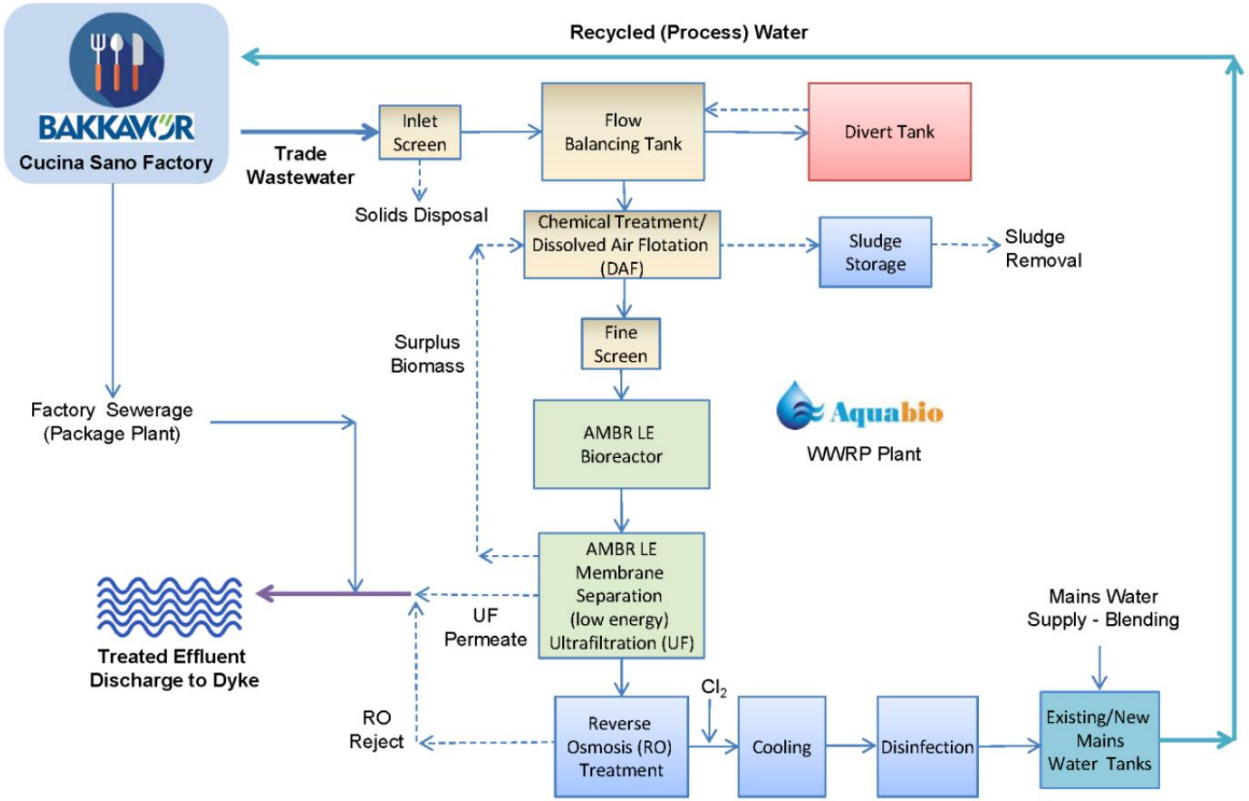
Previous experience – food processing

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%

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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																																															

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ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

Thank you!

ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

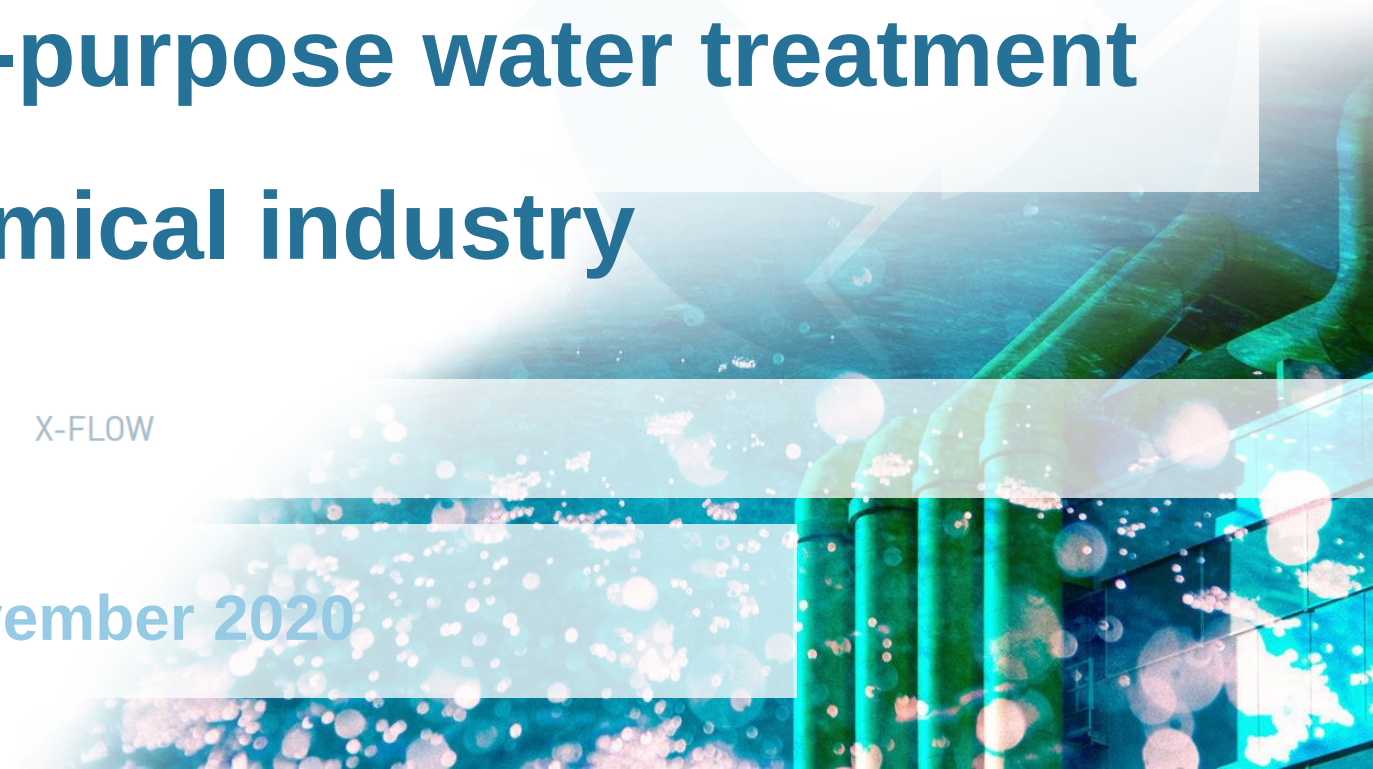
CS9 Kalundborg

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

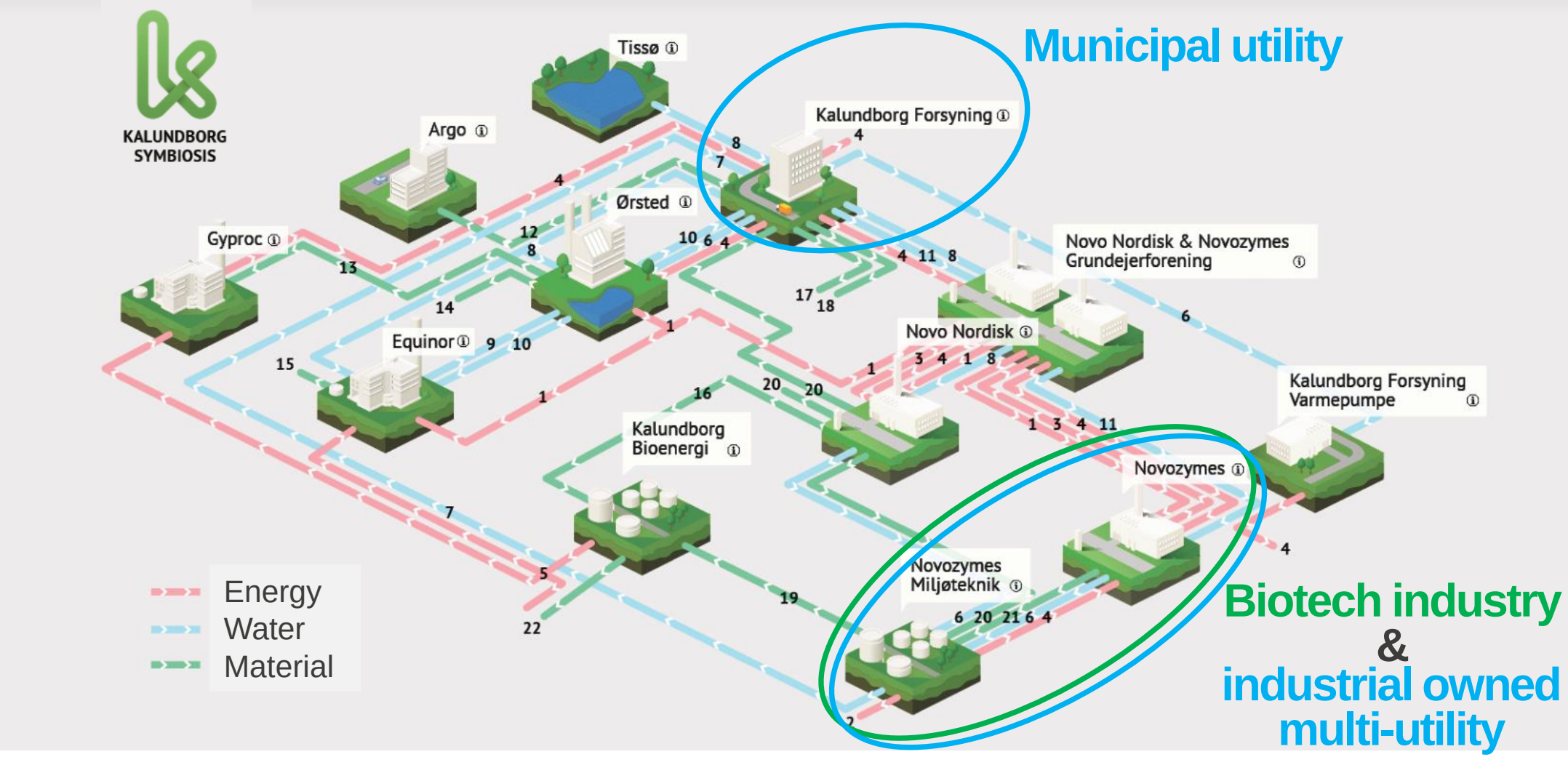
Leo Vredenbregt

PENTAIR X-FLOW

CTG Membranes meeting: 25 November 2020



Kalundborg Symbiosis since 1972:



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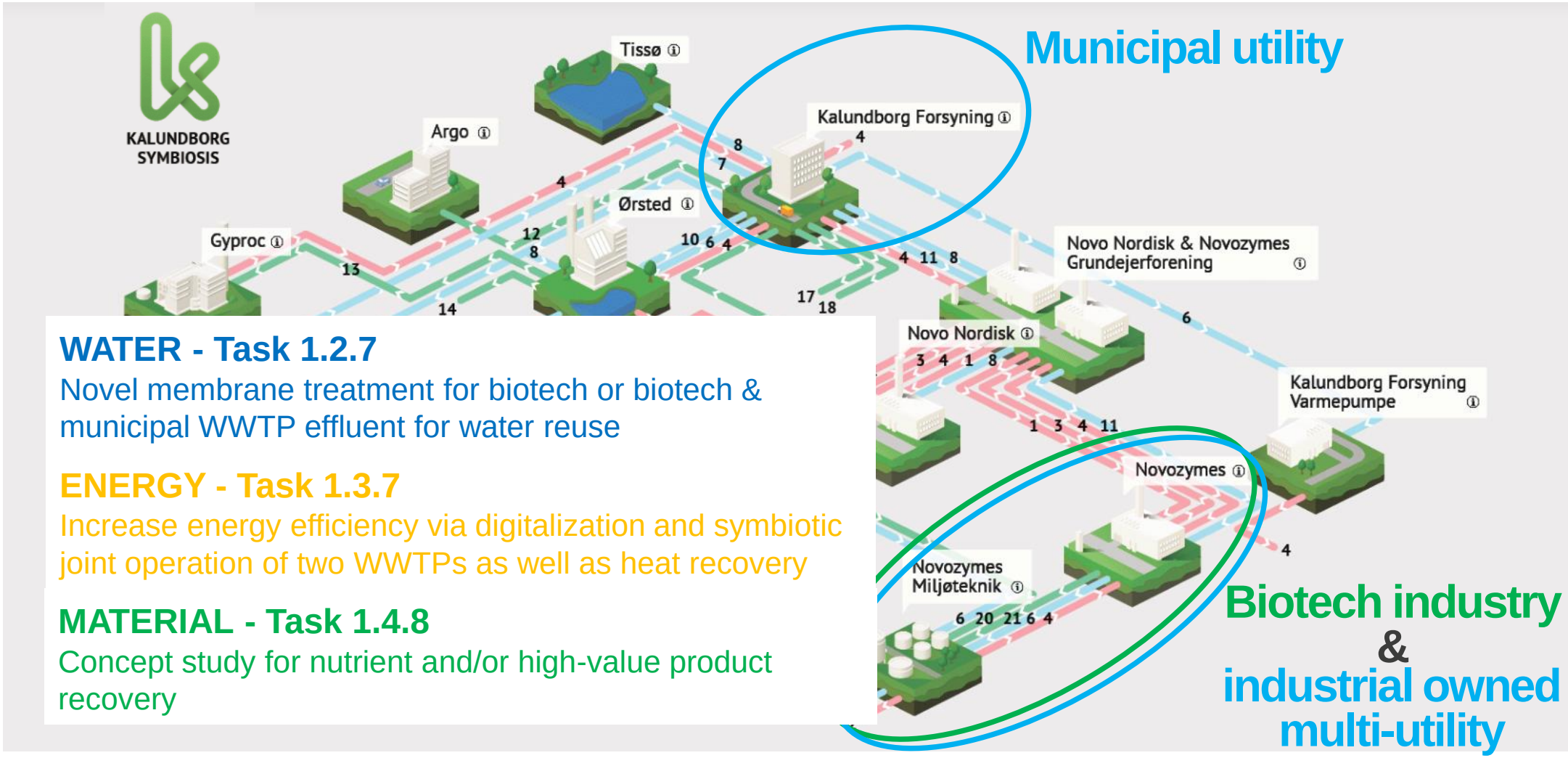
Kalundborg Symbiosis since 1972:



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

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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

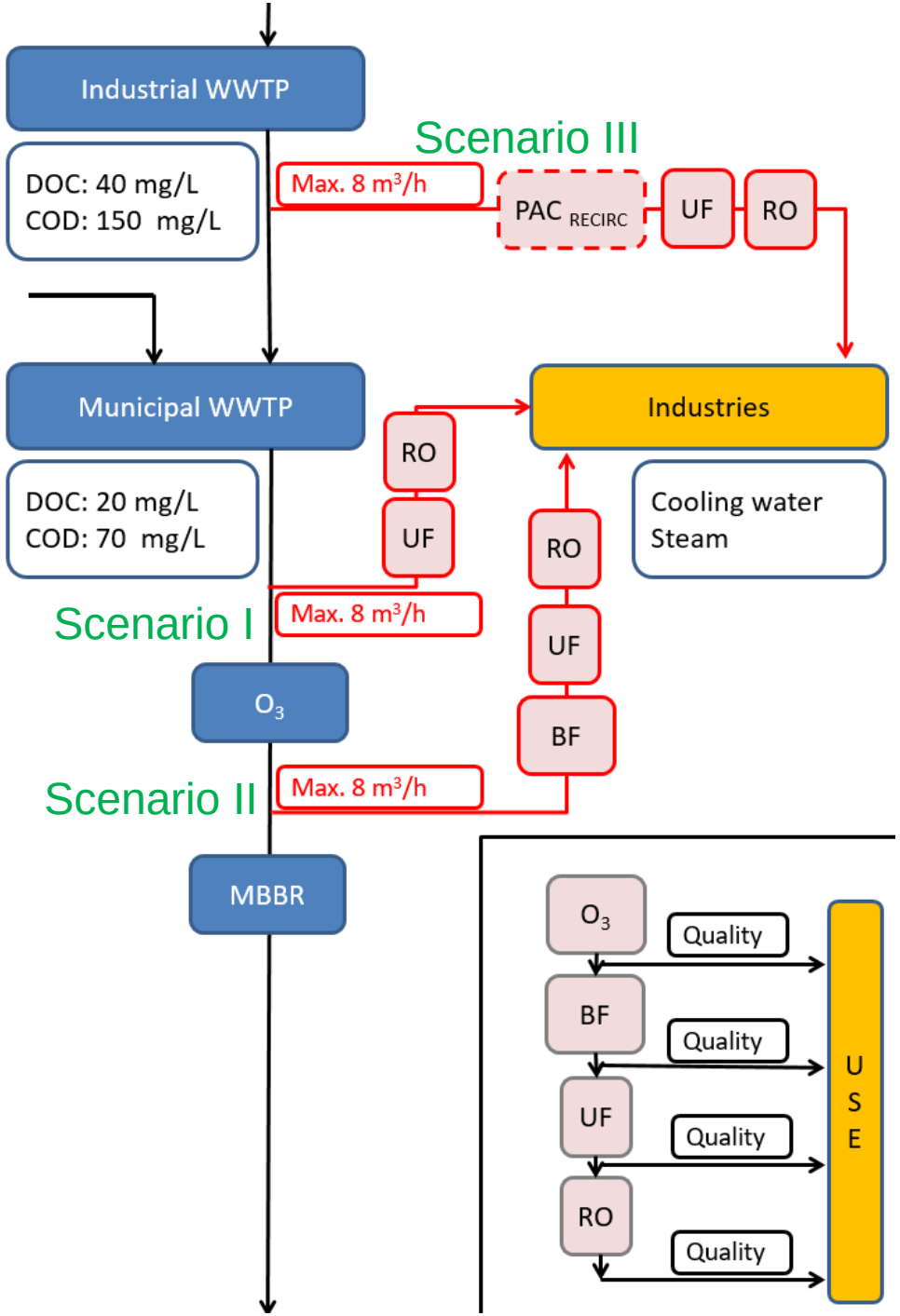
KOMPETENZZENTRUM Wasser Berlin

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



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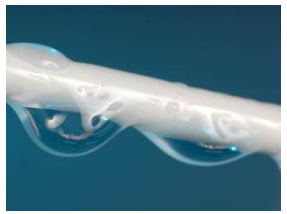
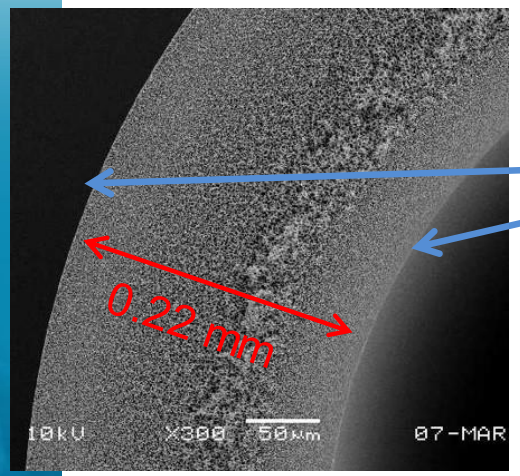
Hollow Fiber Ultrafiltration

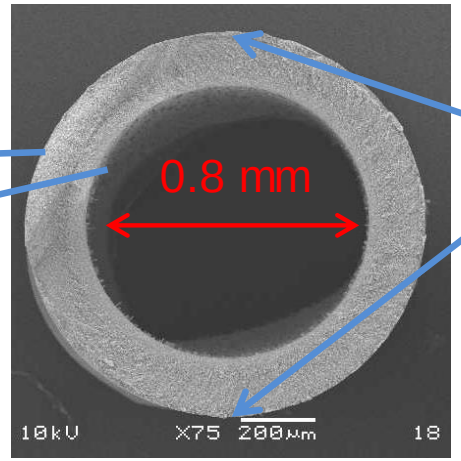
PENTAIR X-FLOW

- 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)

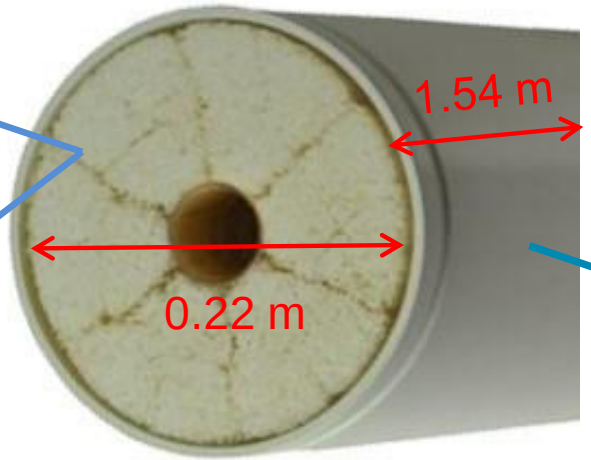




Fibre wall



Fibre



Module head



Skid with modules

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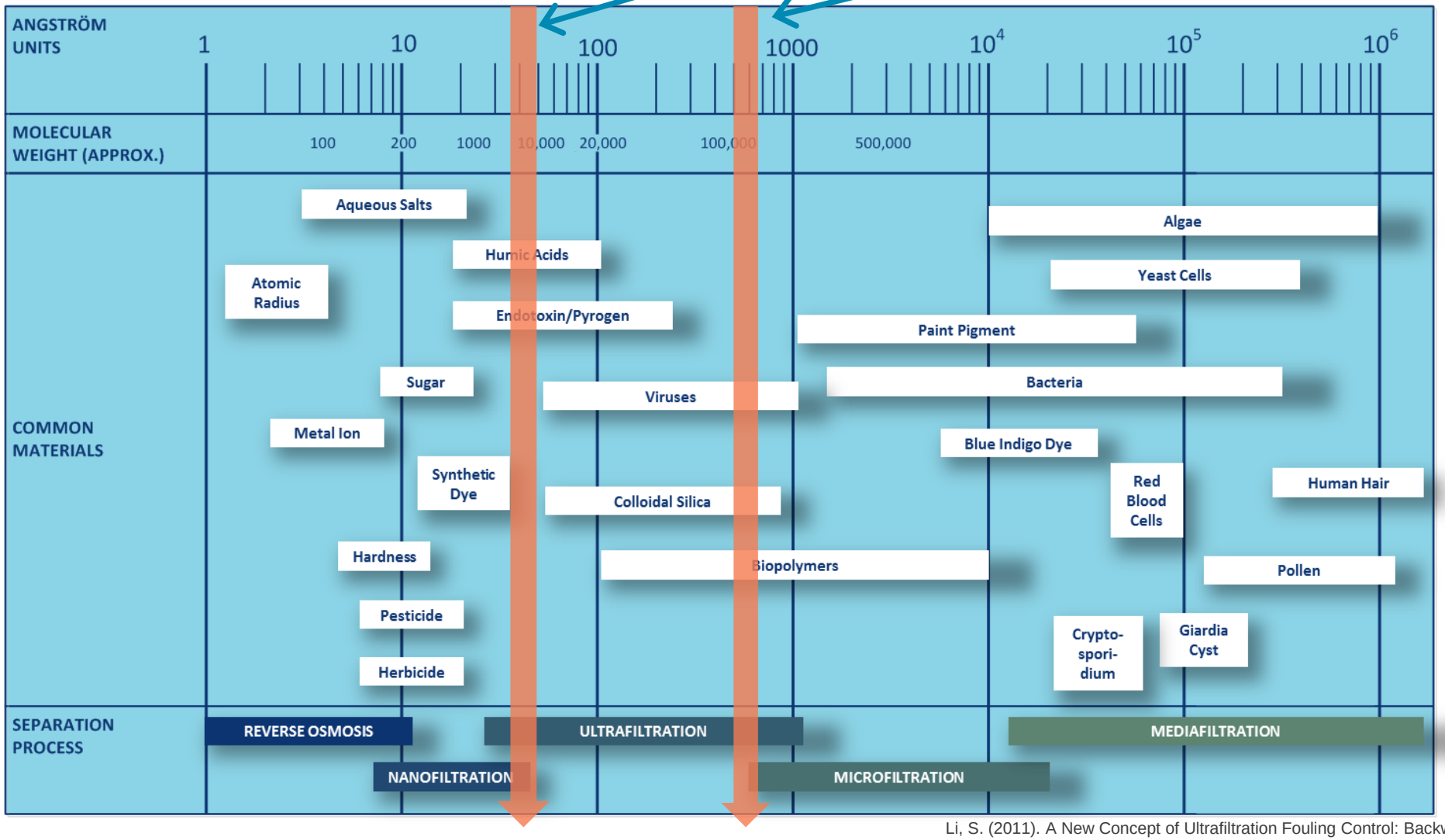
The Filtration Spectrum

Novel (ultra tight) UF membrane (~4 kDa)

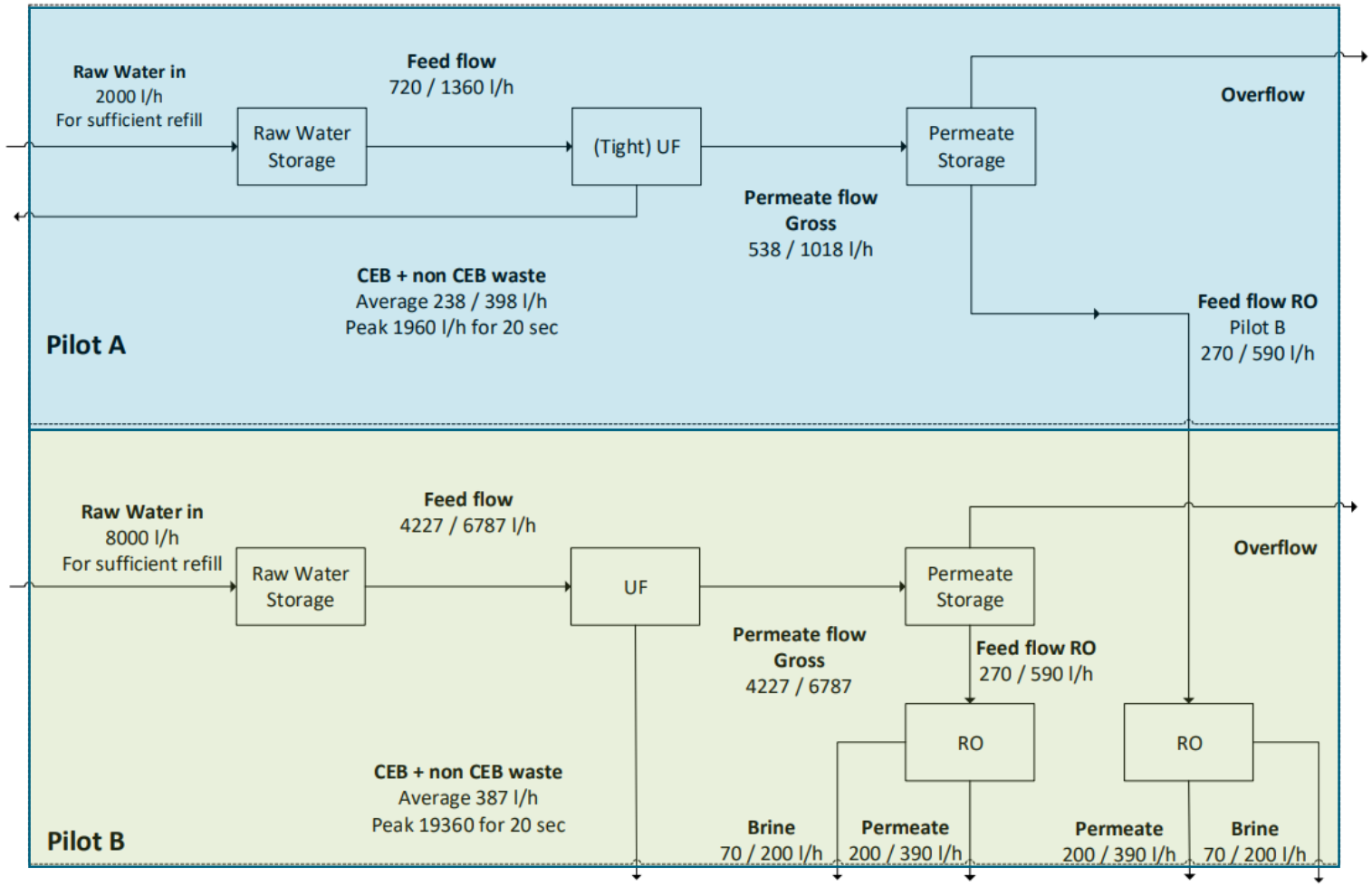
Conventional UF (MWCO 150 kDa)



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

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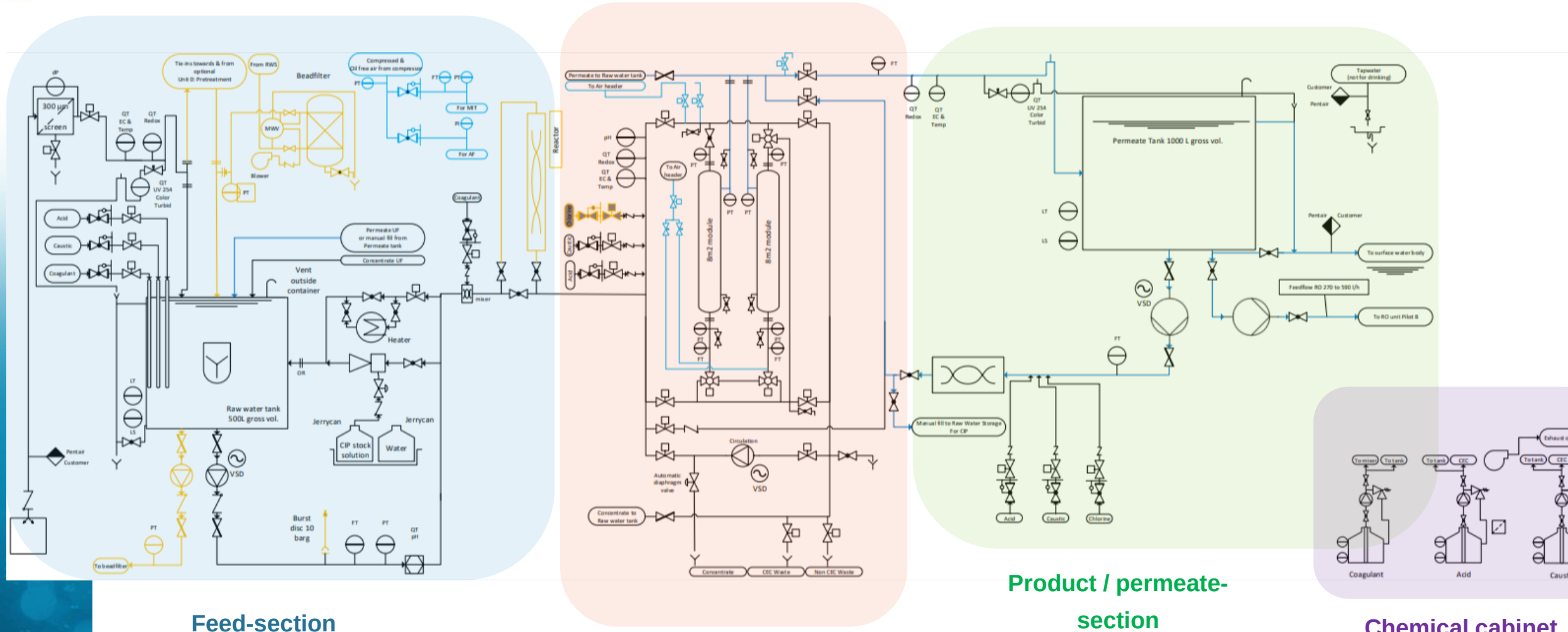
Li, S. (2011). A New Concept of Ultrafiltration Fouling Control: Backwashing with Low Ionic Strength Water. Delft, The Netherlands, Technische Universiteit Delft.

Flow diagram pilot A (tight UF)



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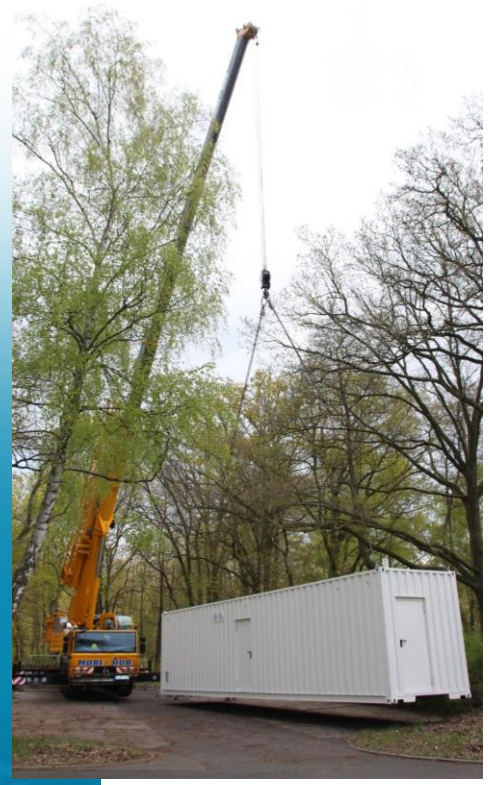
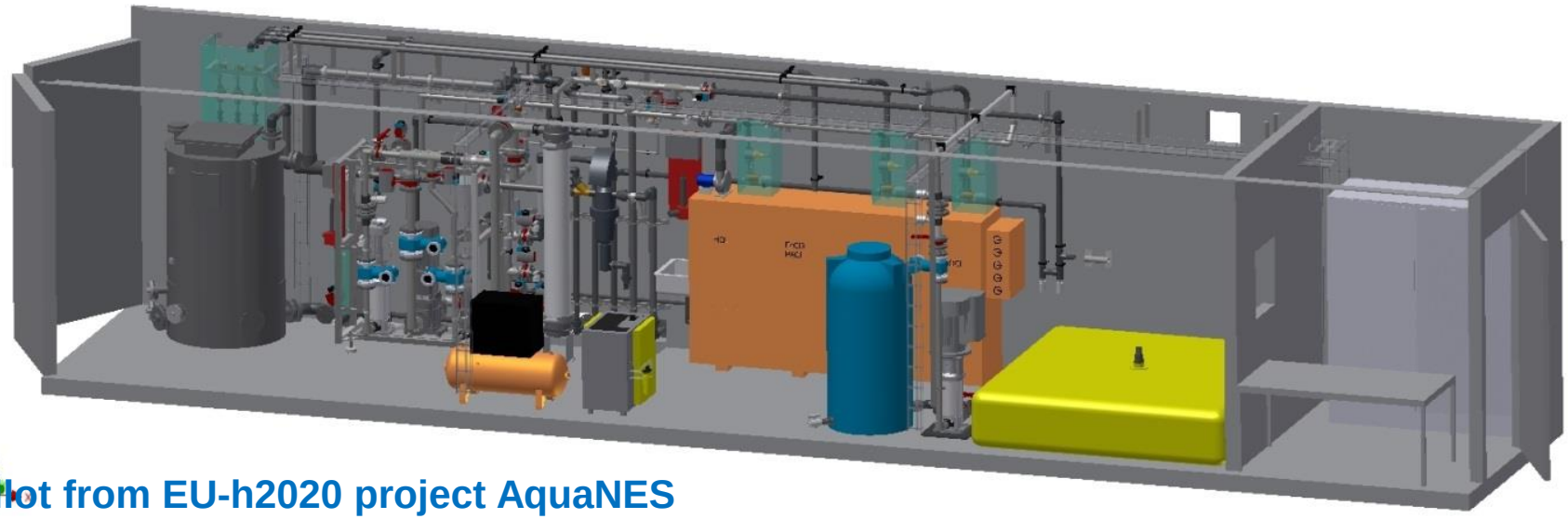
Pilot B from previous EU-h2020 project will be refurbished





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)

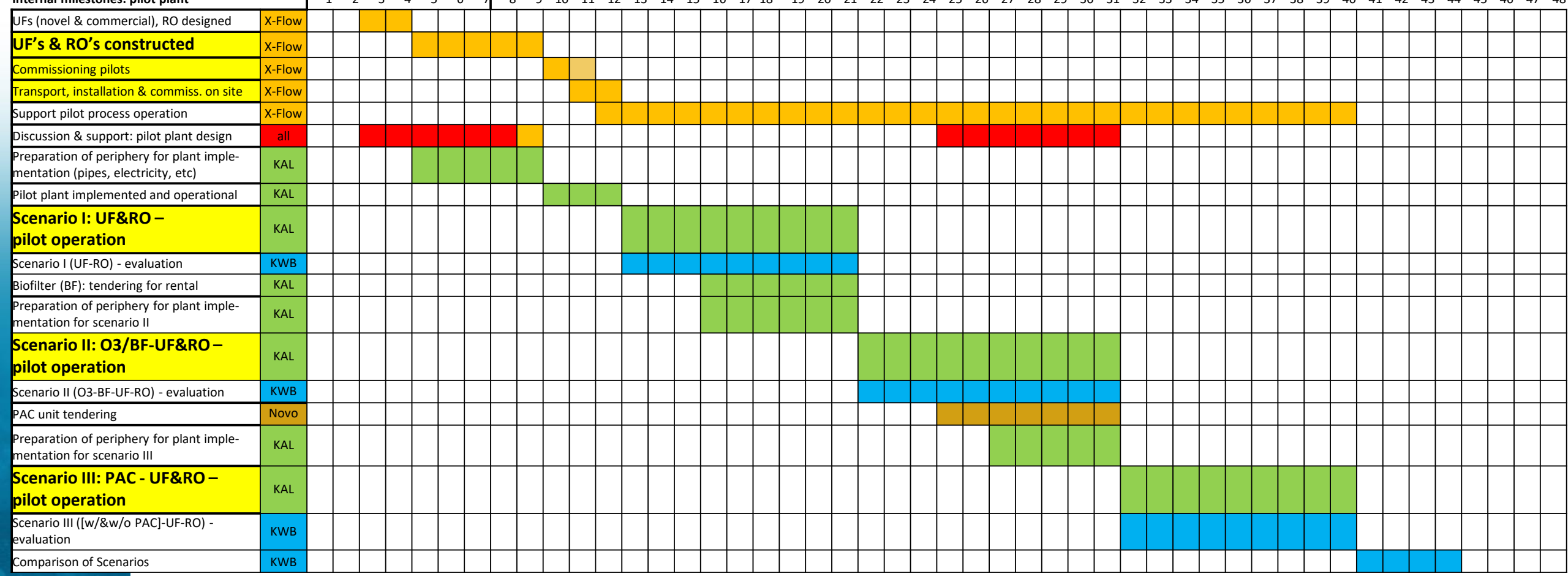
WATER - Task 1.2.7

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)



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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

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

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

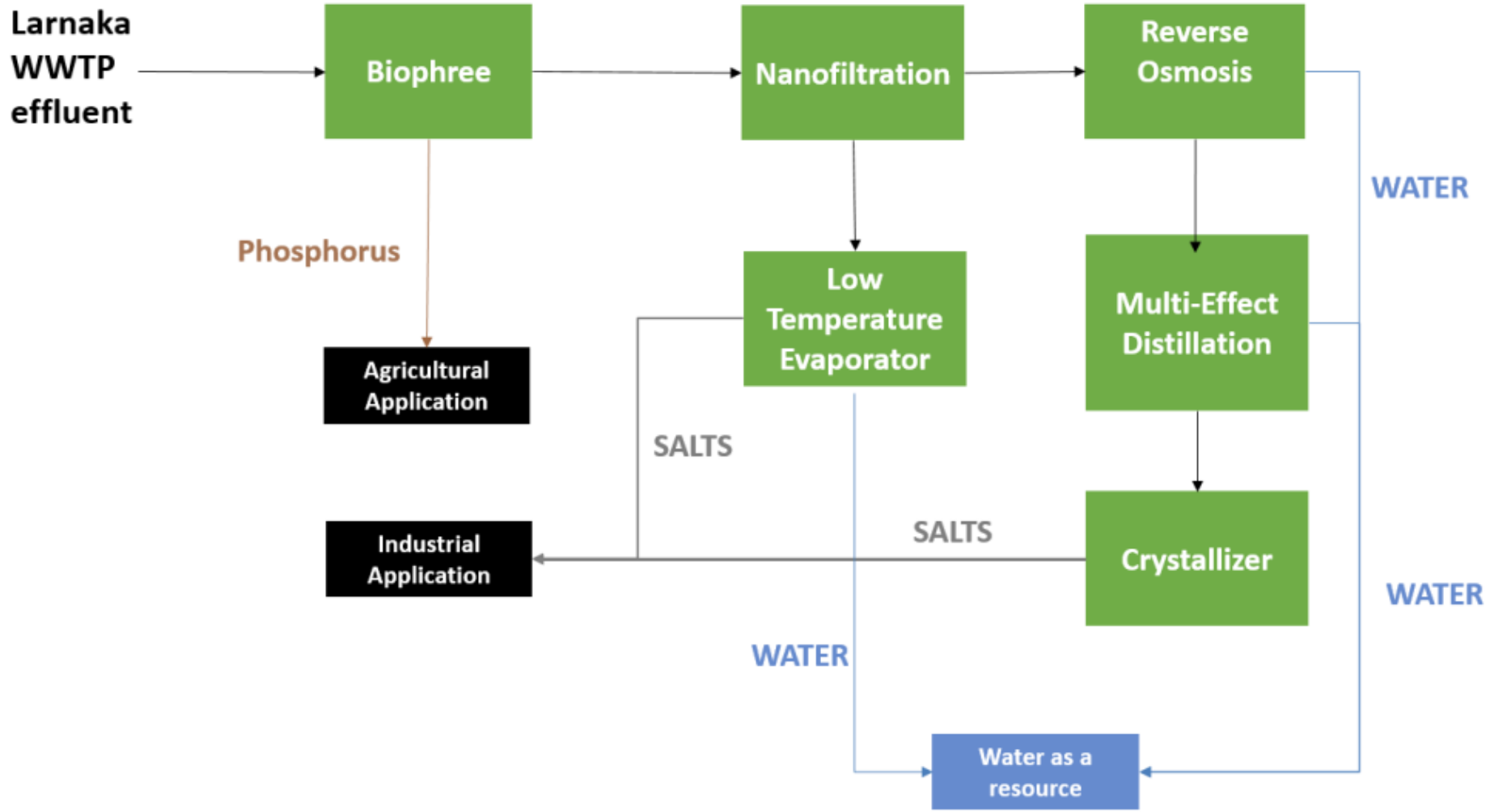
Water of high salinity→ salt accumulation will cause problems to land and cultivations

Pilot Objectives

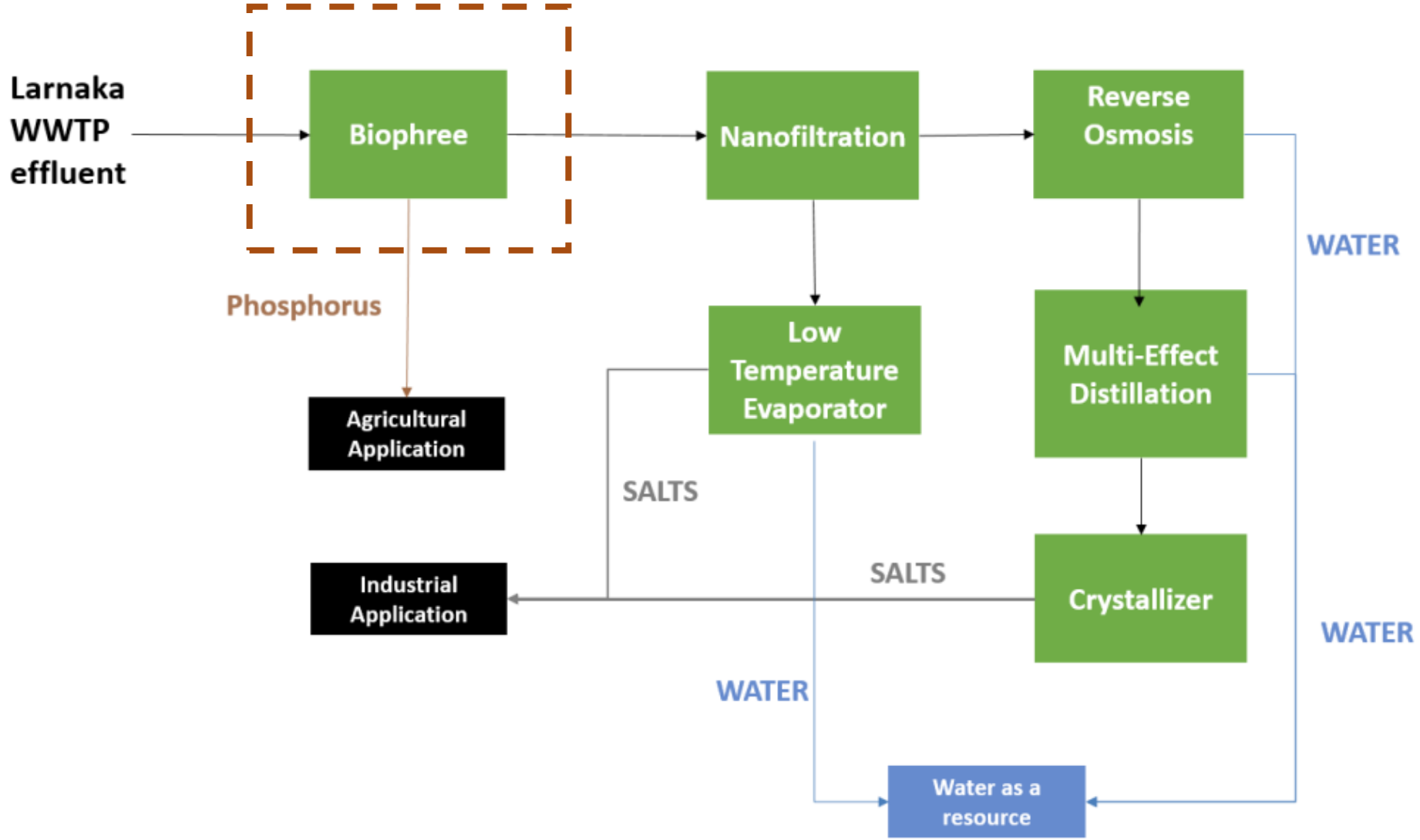
- Ultra low phosphorus concentration in the effluent (<0,05 mg/L)
- Recovery of phosphorus
- Recovery of NaCl
- Recovery of water

water mining

Process flow diagram of pilot



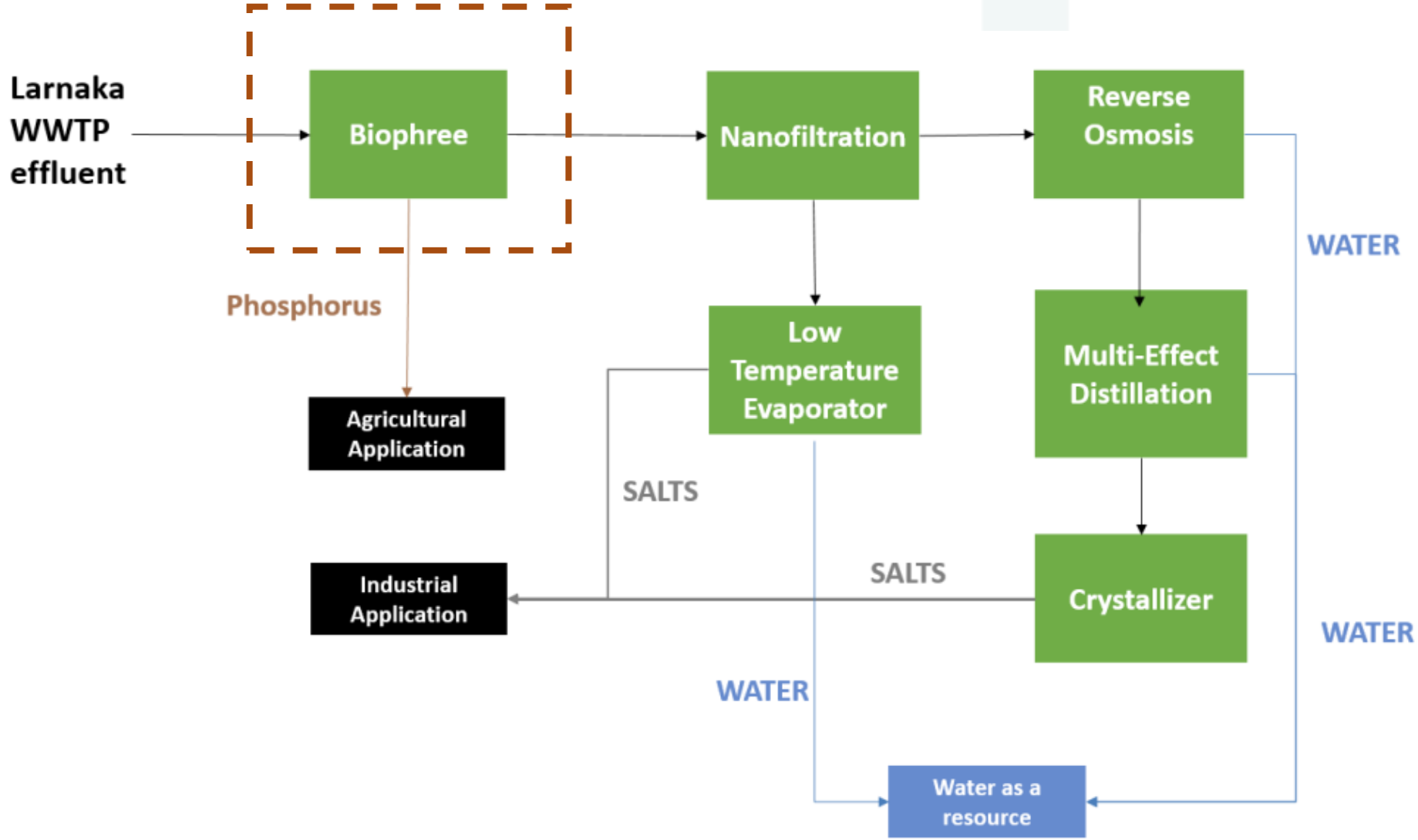
Process flow diagram of pilot



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.

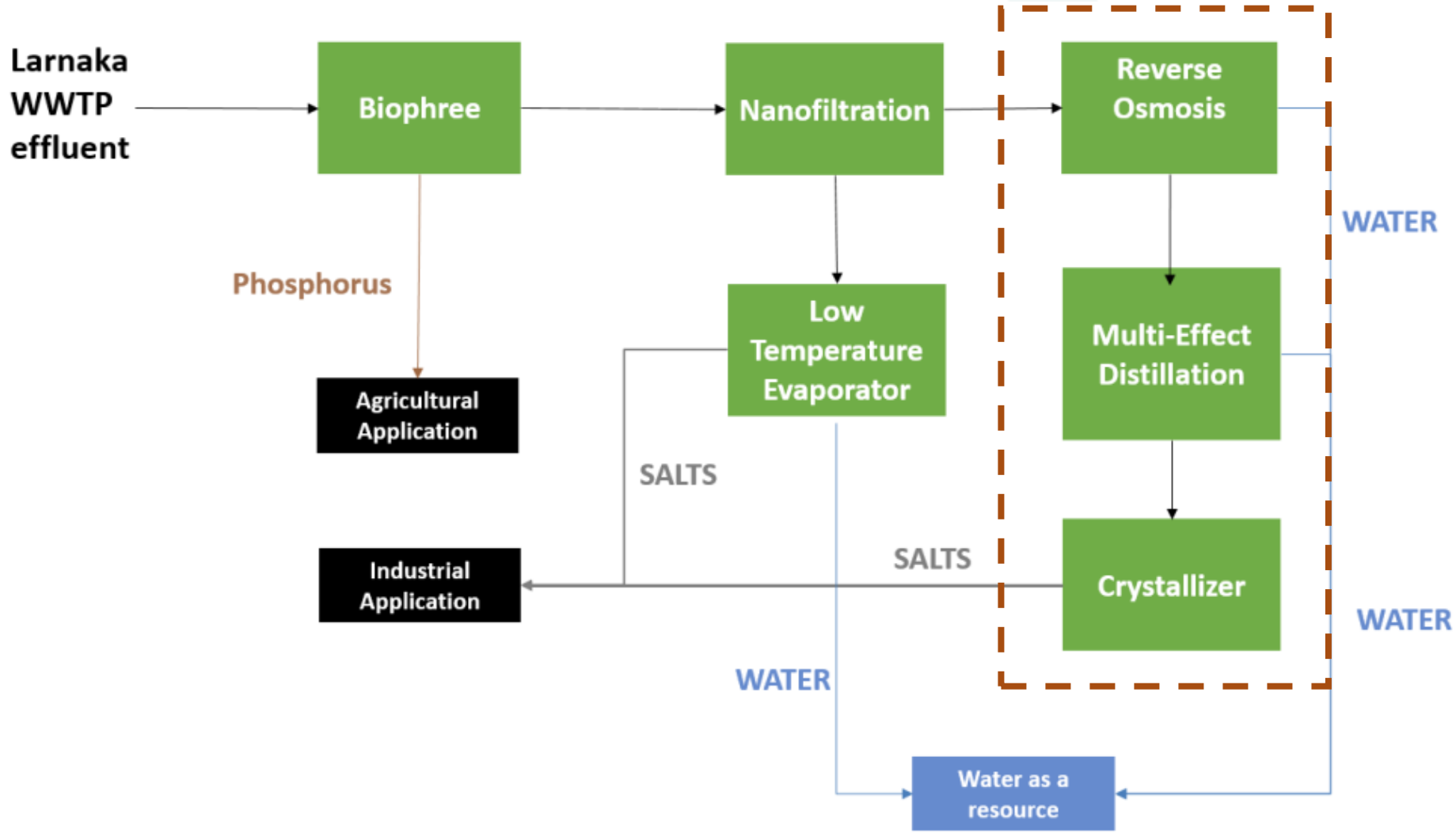
Process flow diagram of pilot



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.

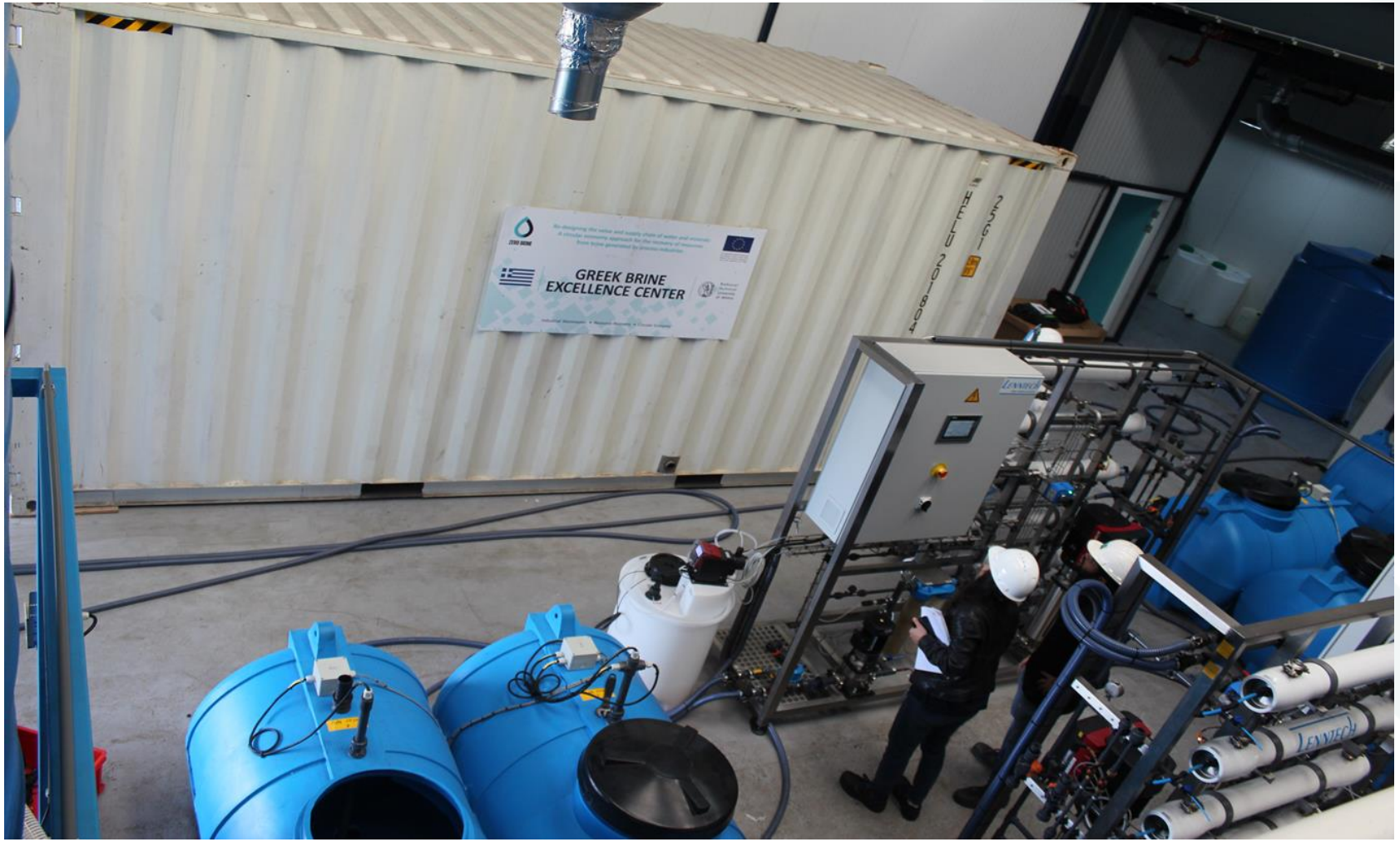
Process flow diagram of pilot



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.

water mining



water mining





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!!!

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!

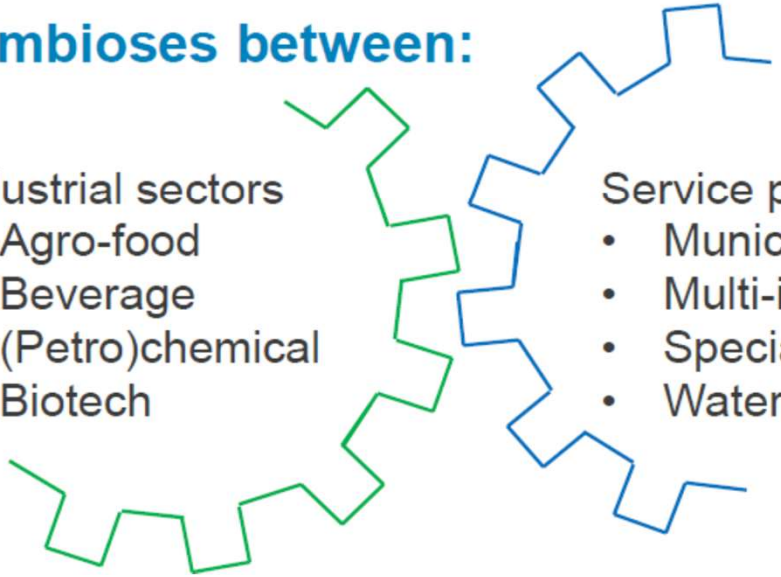
The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

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

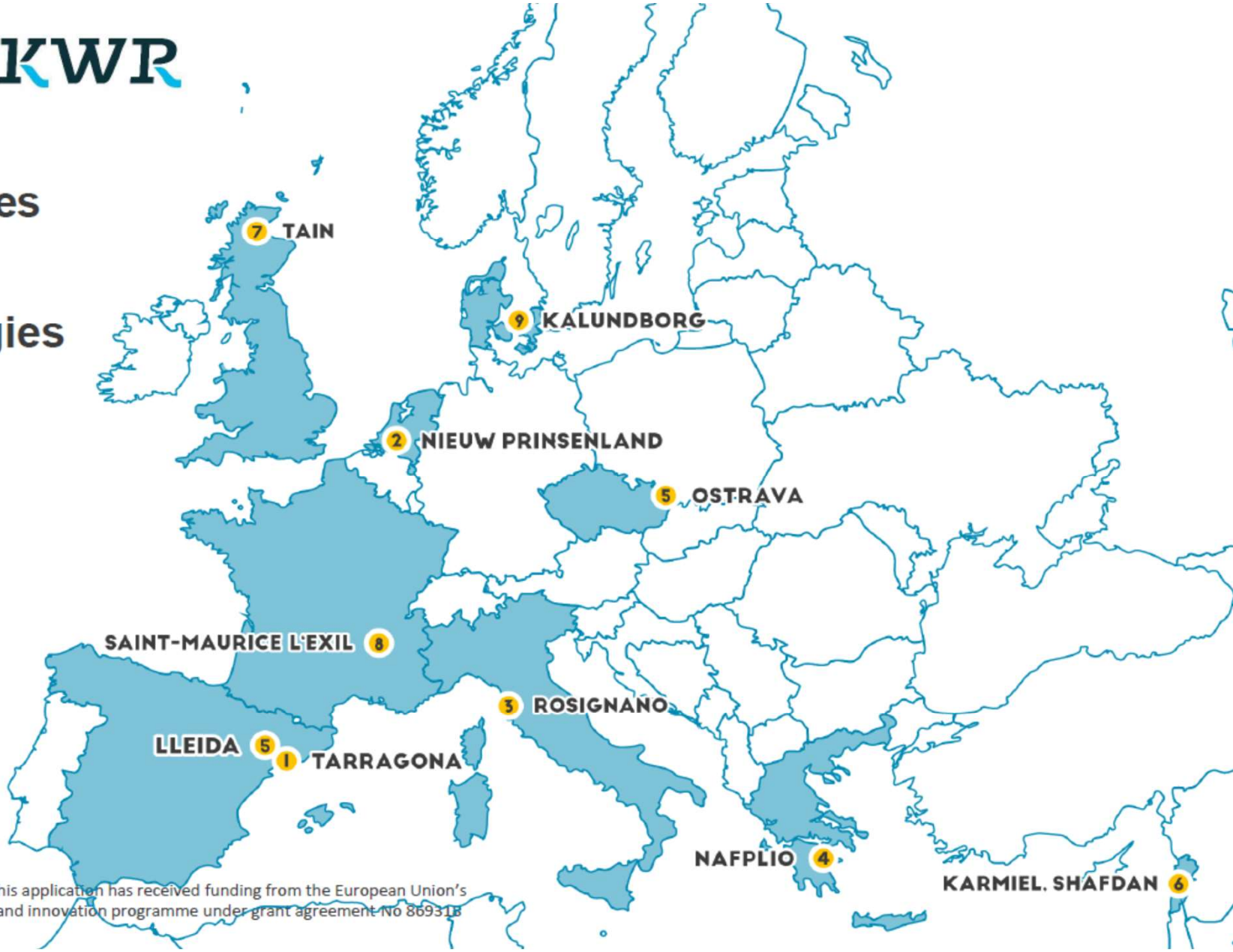
Service providers
- Municipal utility
- Multi-industry utility
- Specialized SME
- Water services provider

Coordinator: KWR

9 Case Studies

27 Partners

37 Technologies



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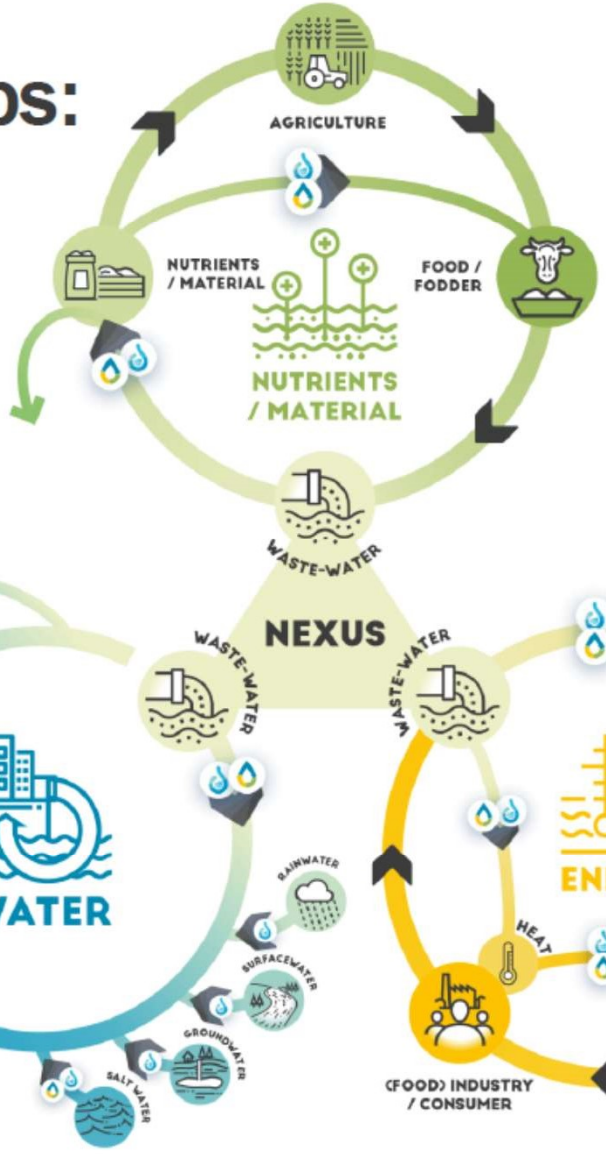
3 Cross-cutting Technology Groups: 9 Topics





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

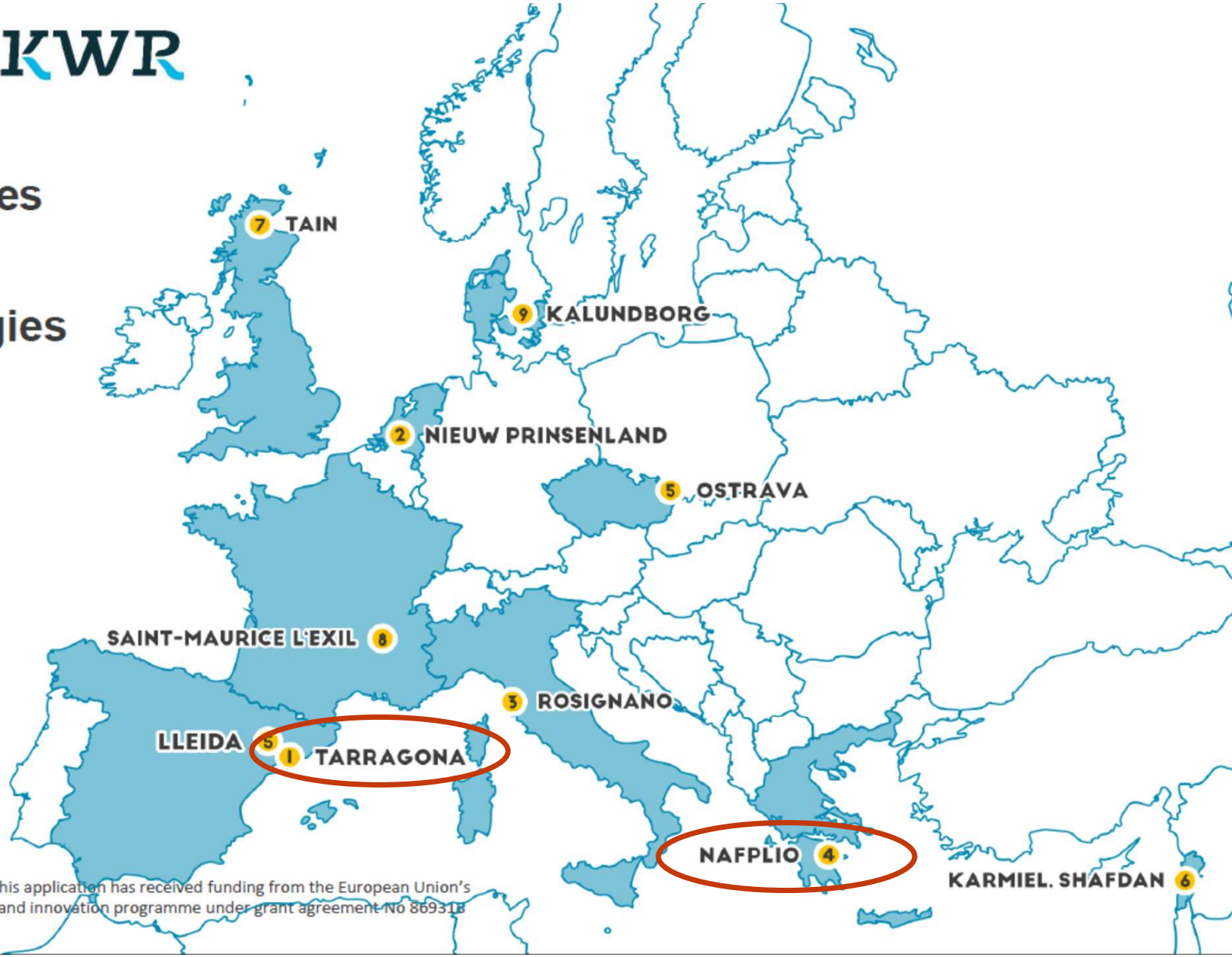
- Biogas technologies
- Heat recovery
- Digitalization

Coordinator: KWR

9 Case Studies

27 Partners

37 Technologies



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Agenda

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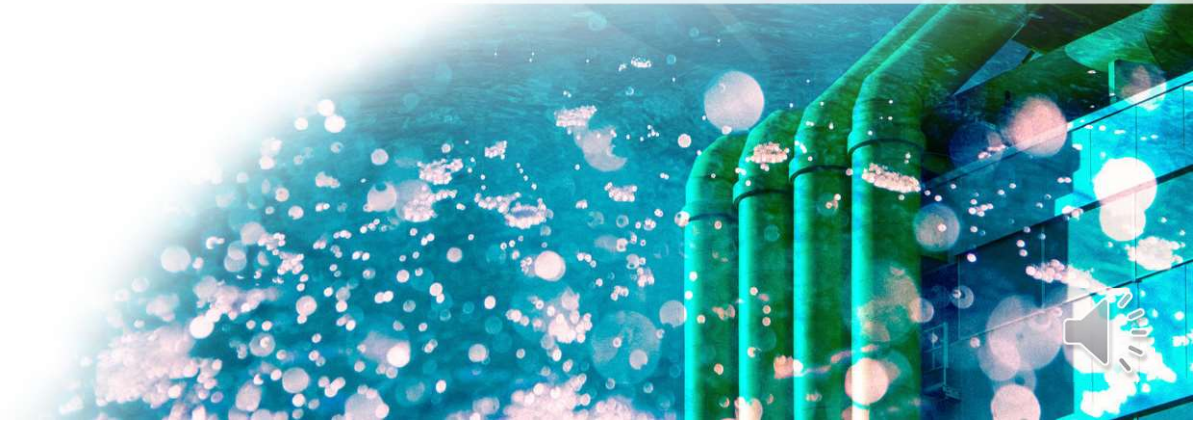
ULTIMATE

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.

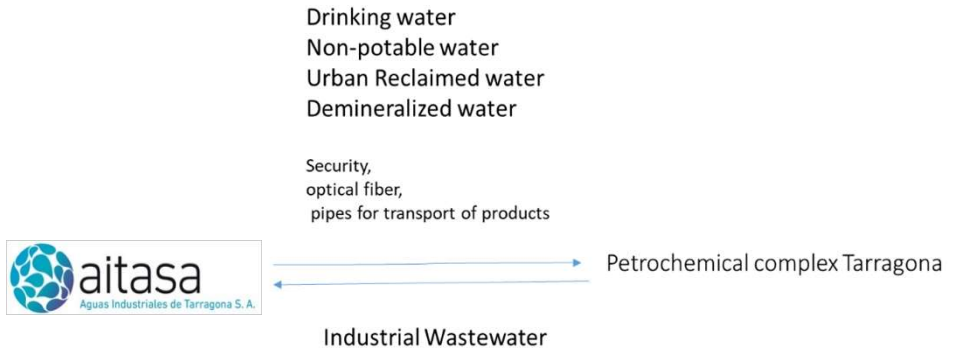
More than 30 companies operate in the petrochemical complex focusing on production of chlorine, alkaline salts, oxygen gas, fertilizers, insecticides, fuels, plastics and synthetic essences.

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 Aguas Industriales de Tarragona S. A.





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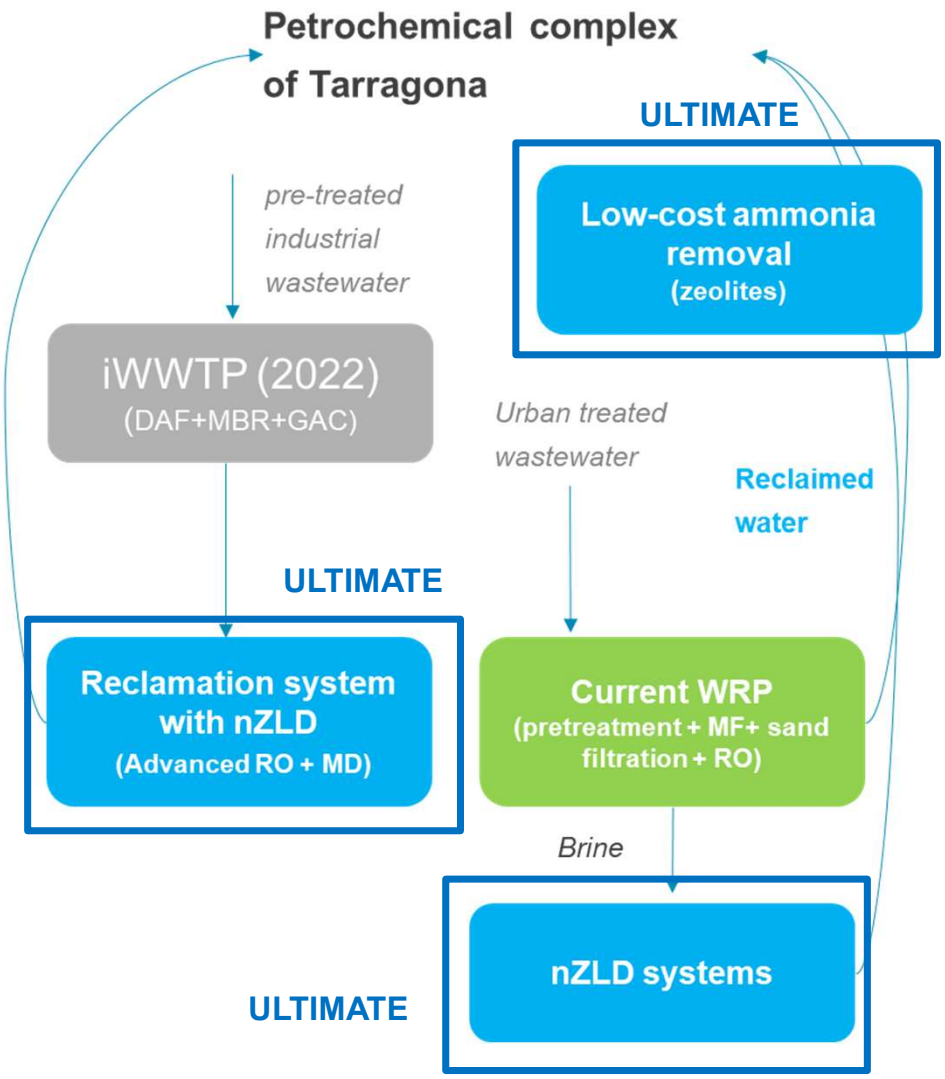
WATER - Task 1.2.1

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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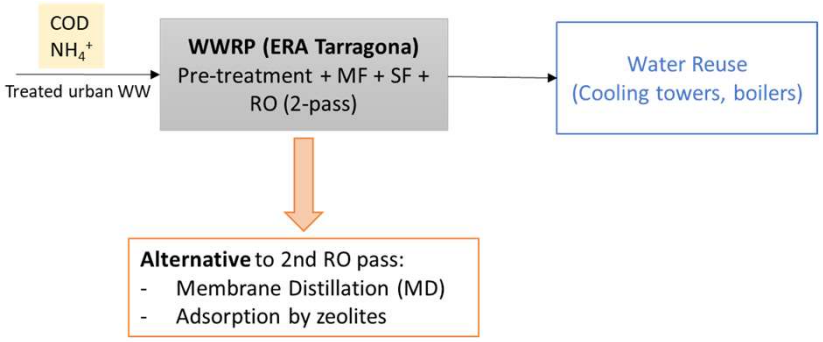
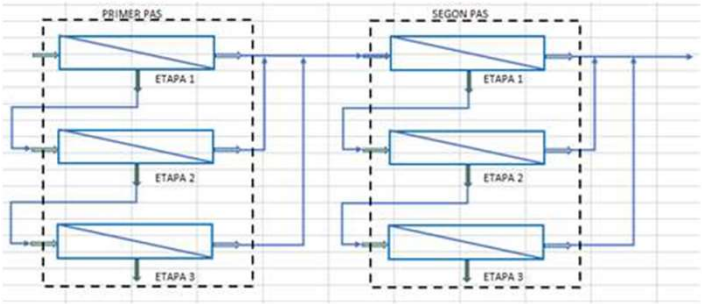
Ammonium removal from wastewater

- 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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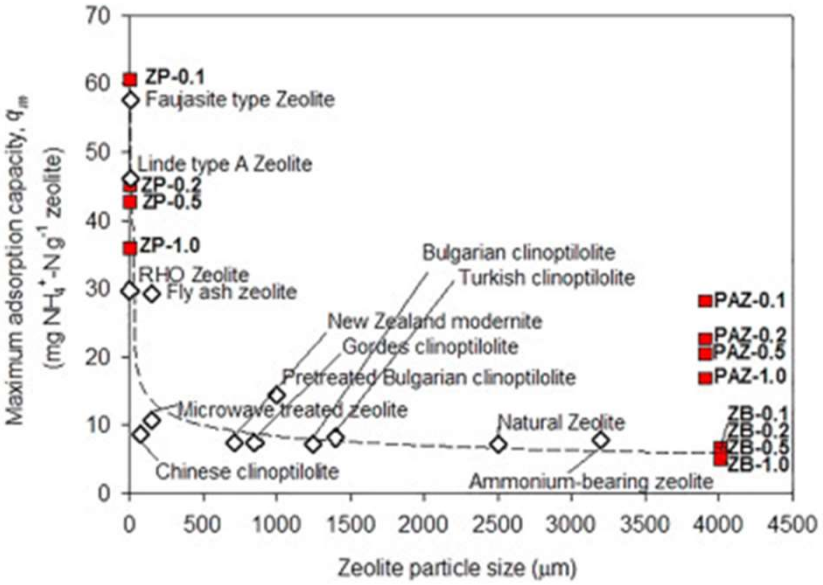
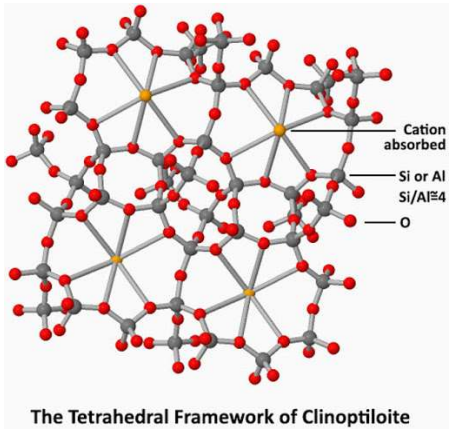
Ammonium removal from water by adsorption with zeolites

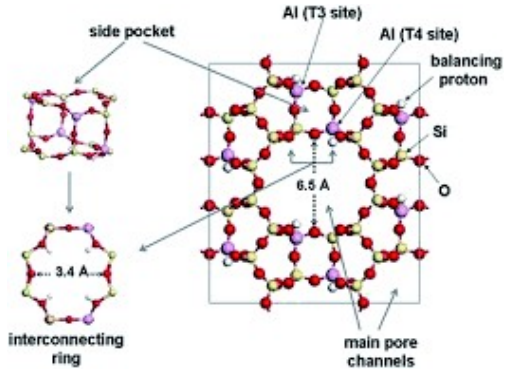
ZEOLITES SELECTION

- 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	4.5–5.0	Orthorhombic	1.83	Na,H,Ca	1.39	0.88	4
(small port)							
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	—	—	5.5

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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)

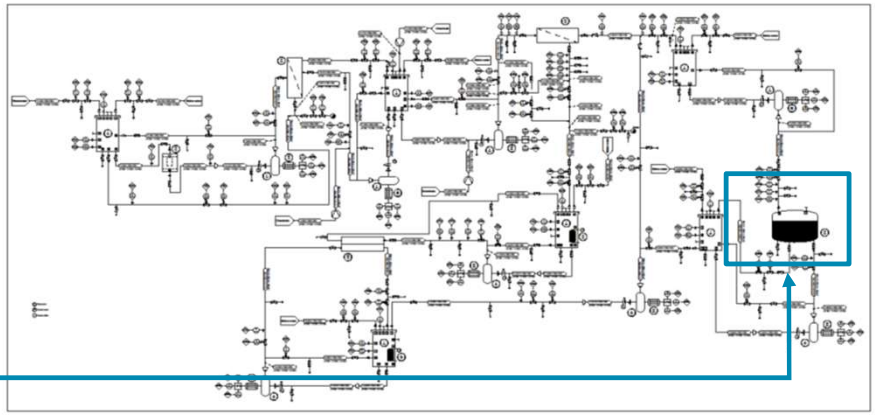
Experimental set-up



- **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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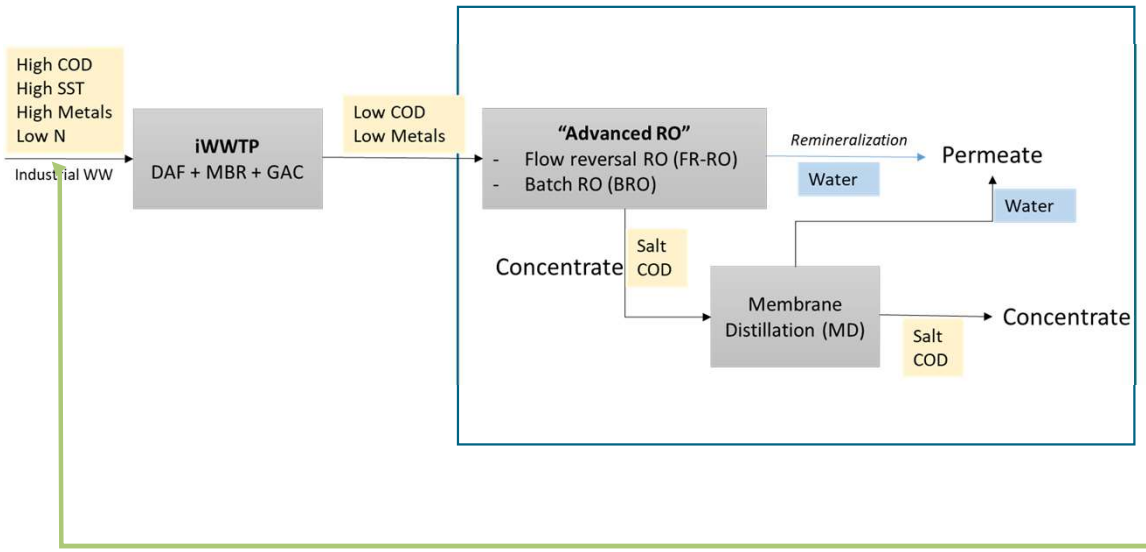
Ammonia removal by adsorption with zeolites

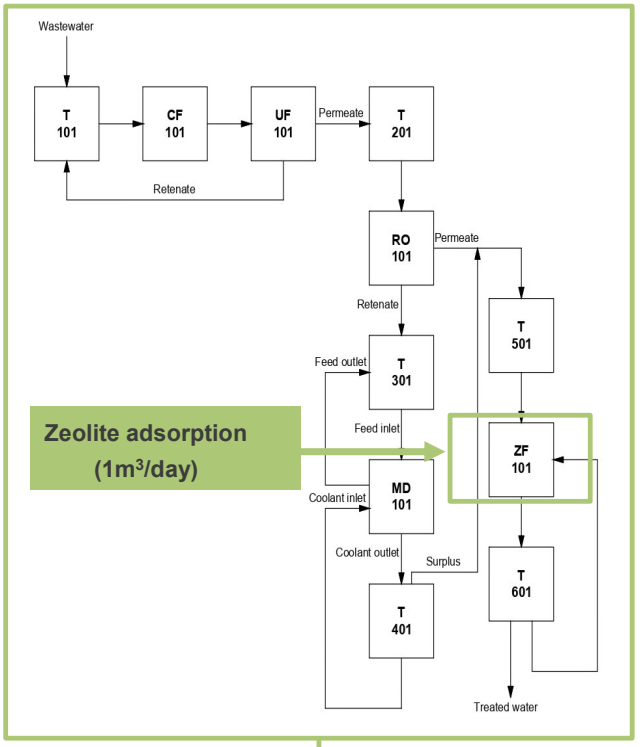
PILOT PLANT SCALE TESTS

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

ULTIMATE CS1 Internal milestones:		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
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

Cranfield University

www.cranfield.ac.uk

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

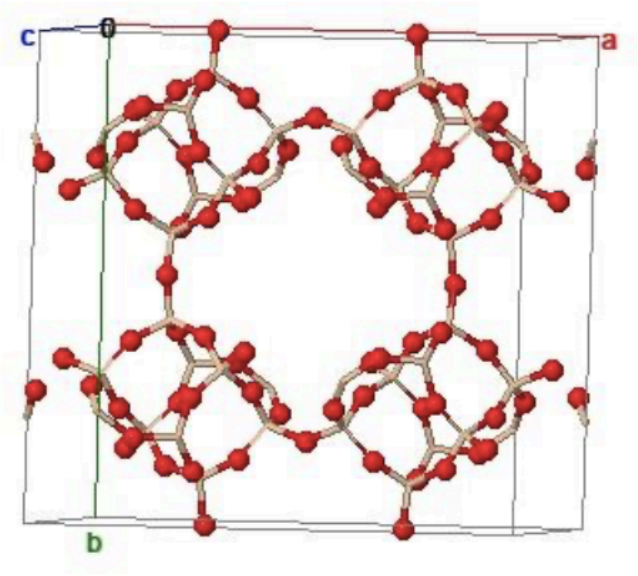


Phosphorus removal: hybrid anion exchange
Adsorption of P to iron nanoparticles. Can be reversed by an increase in pH

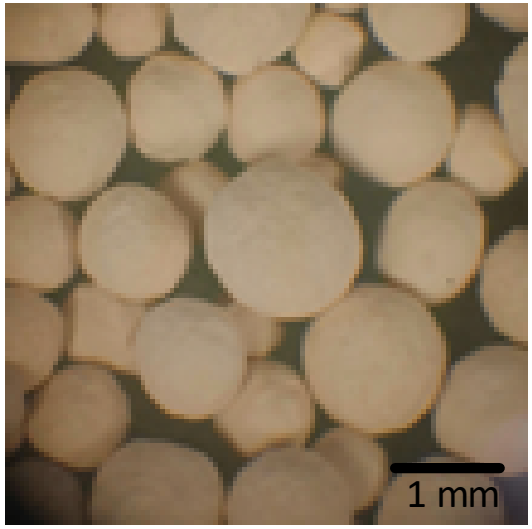
Zeolites

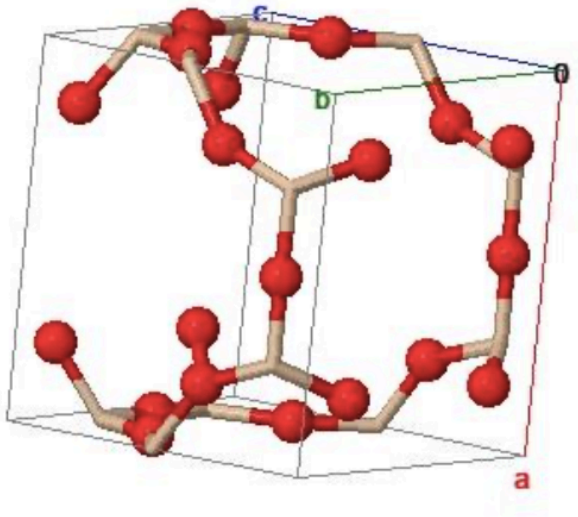
Clinoptilolite





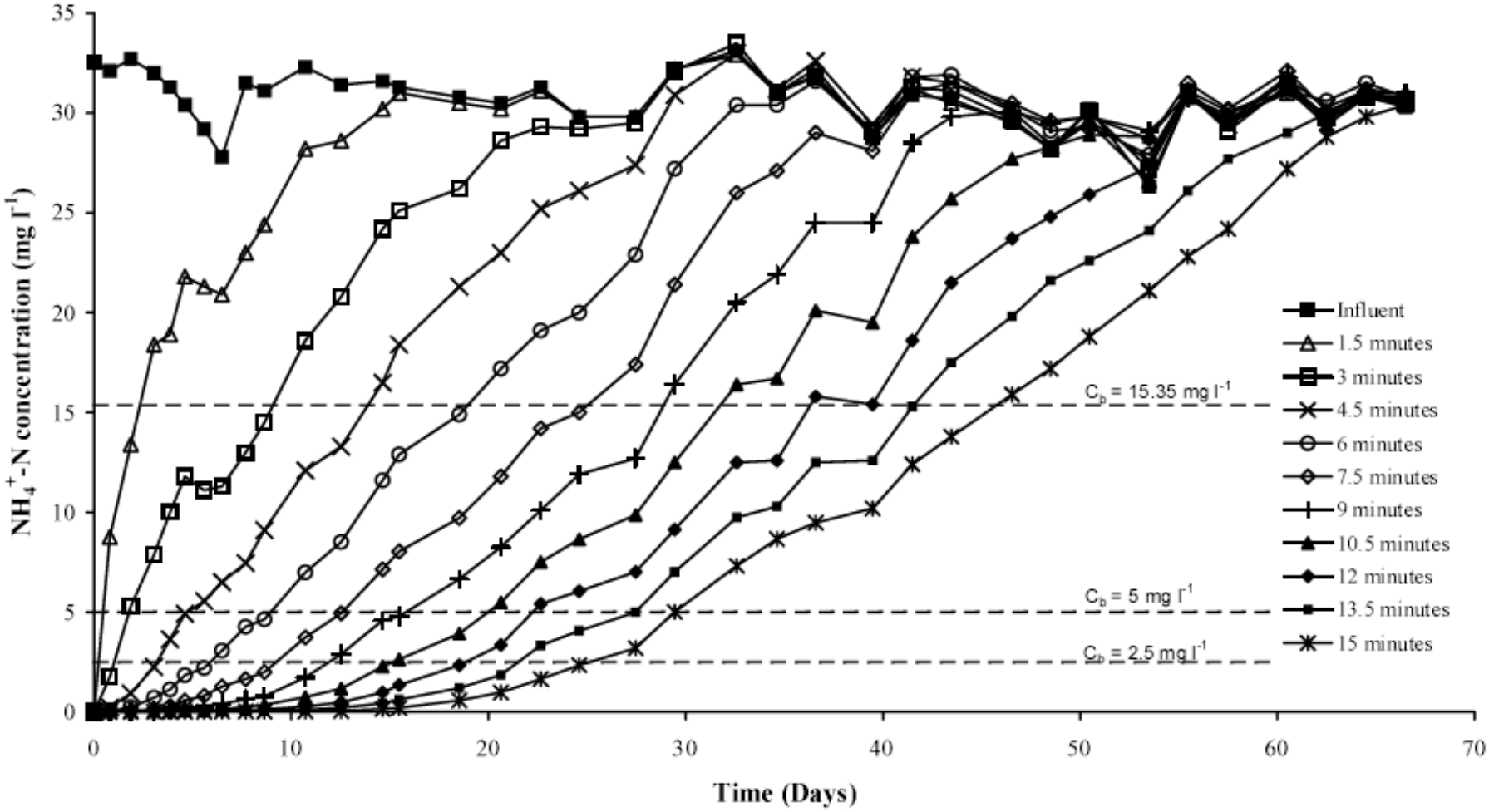
Zeolite-N





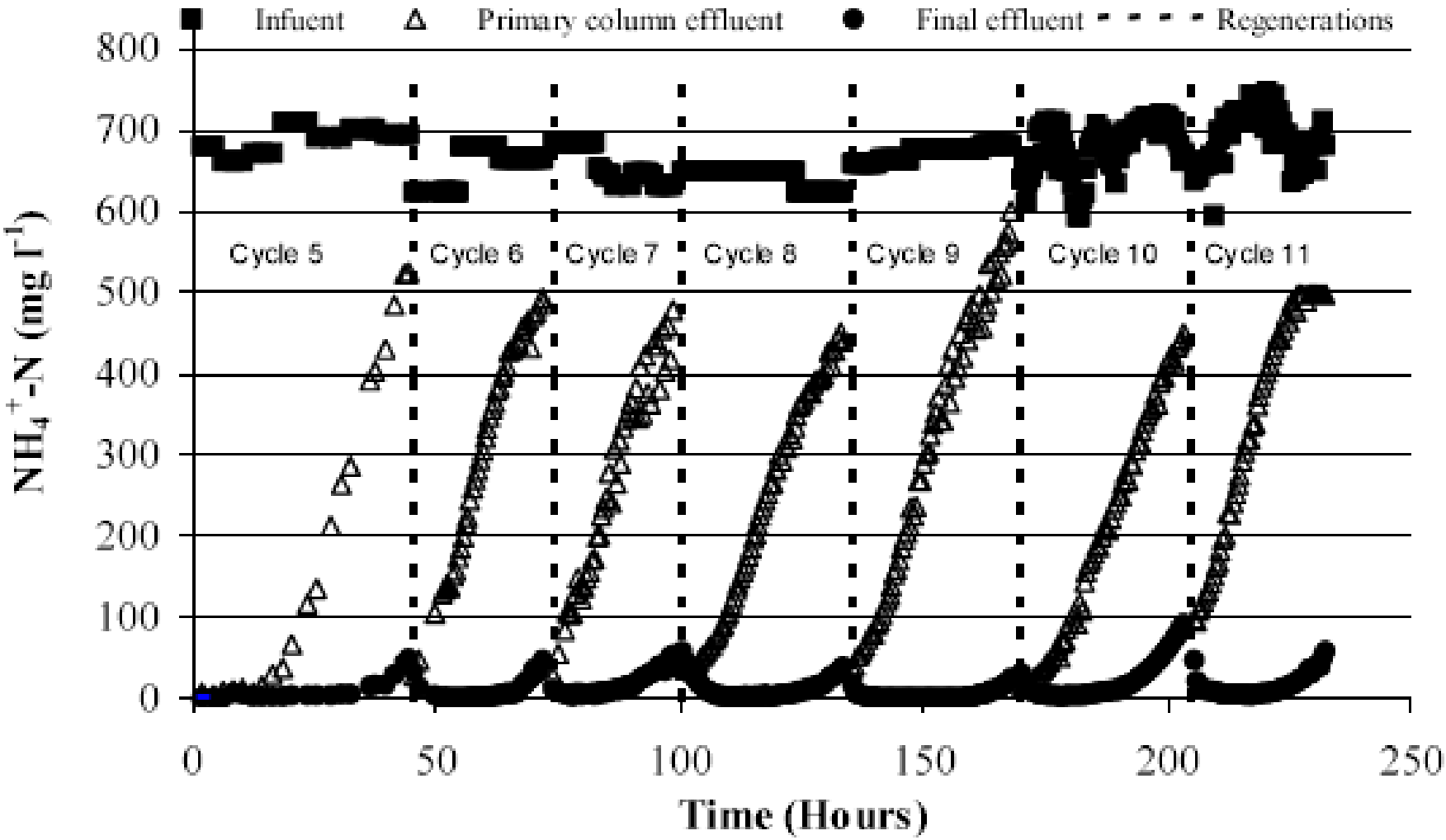
Zeolite-N

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



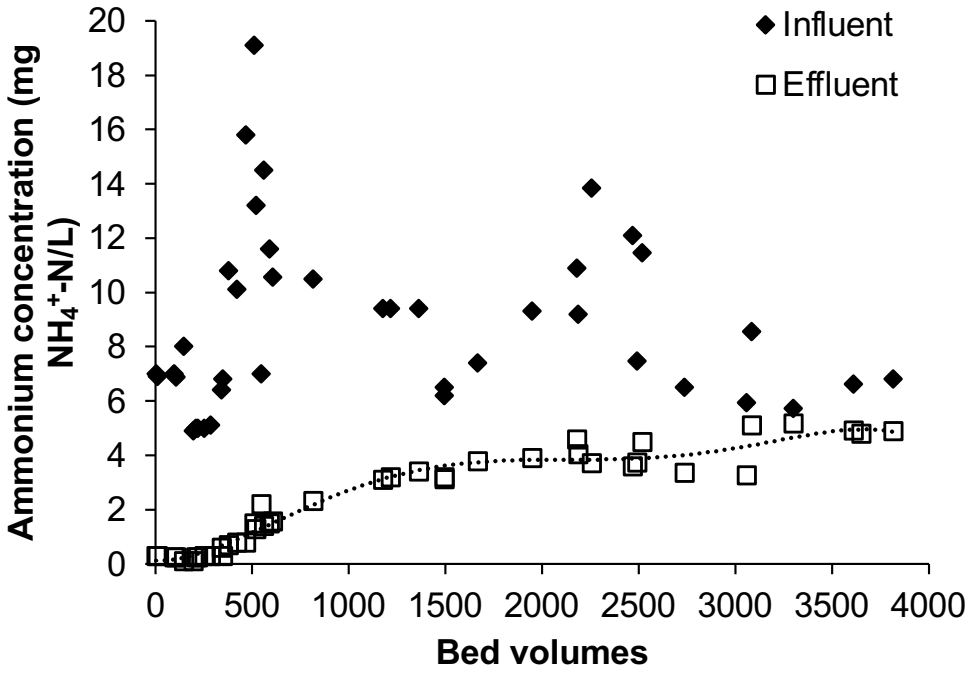
A. Thornton, P. Pearce, S.A. Parsons. Ammonium removal from digested sludge liquors using ion exchange. Water Res., 41 (2007), 433-439

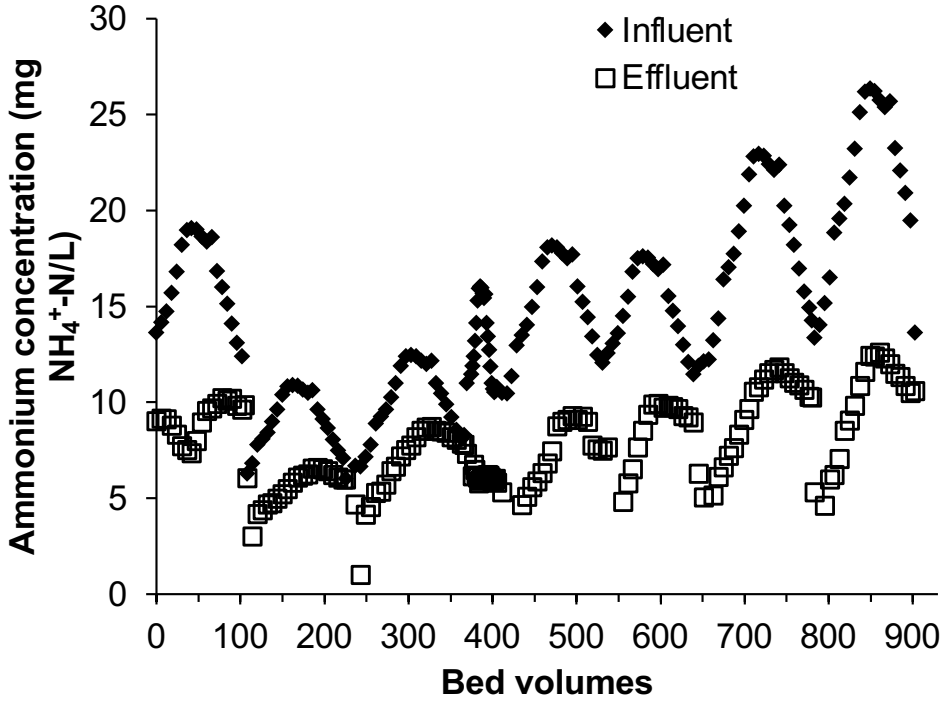
Process developed for sludge liquor treatment is very effective



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

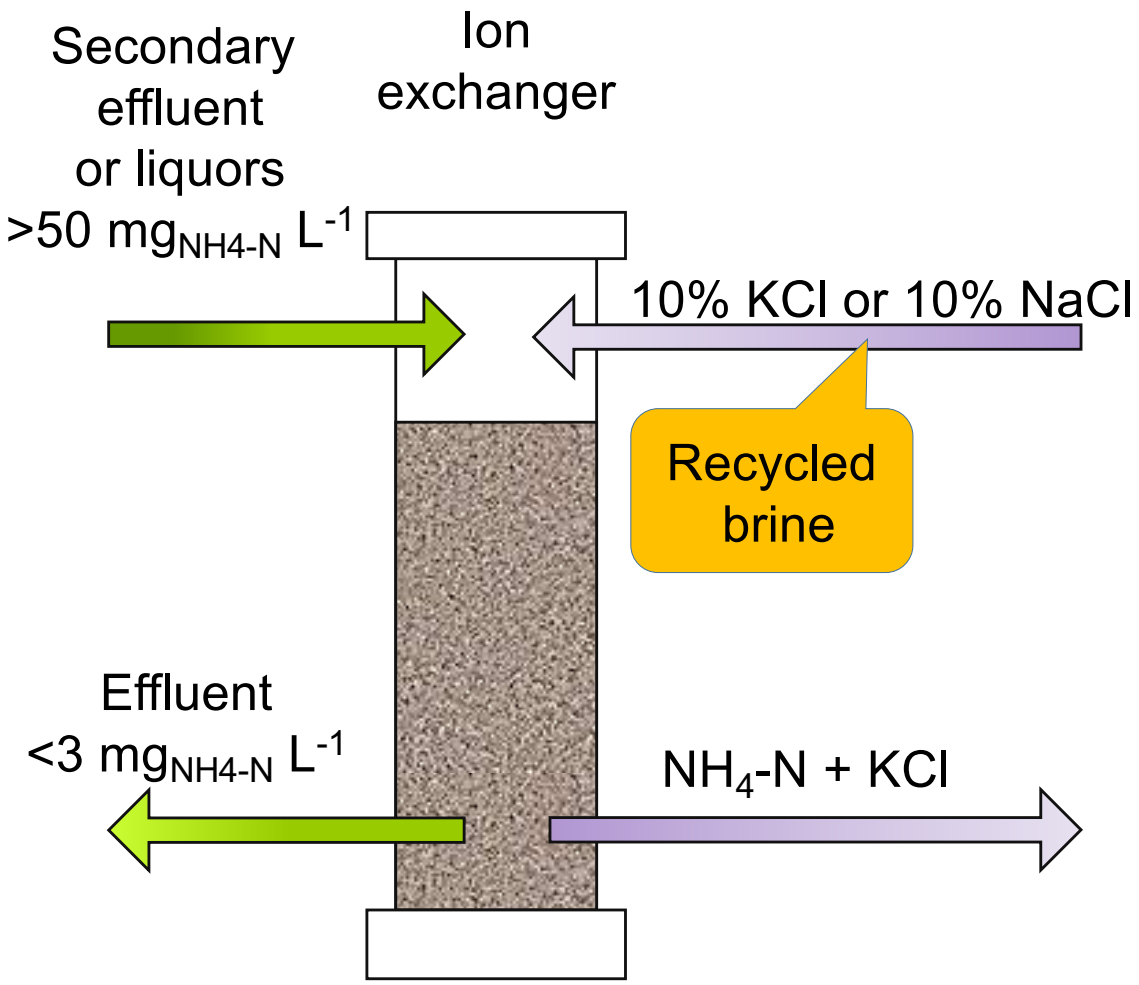
Process developed for tertiary treatment

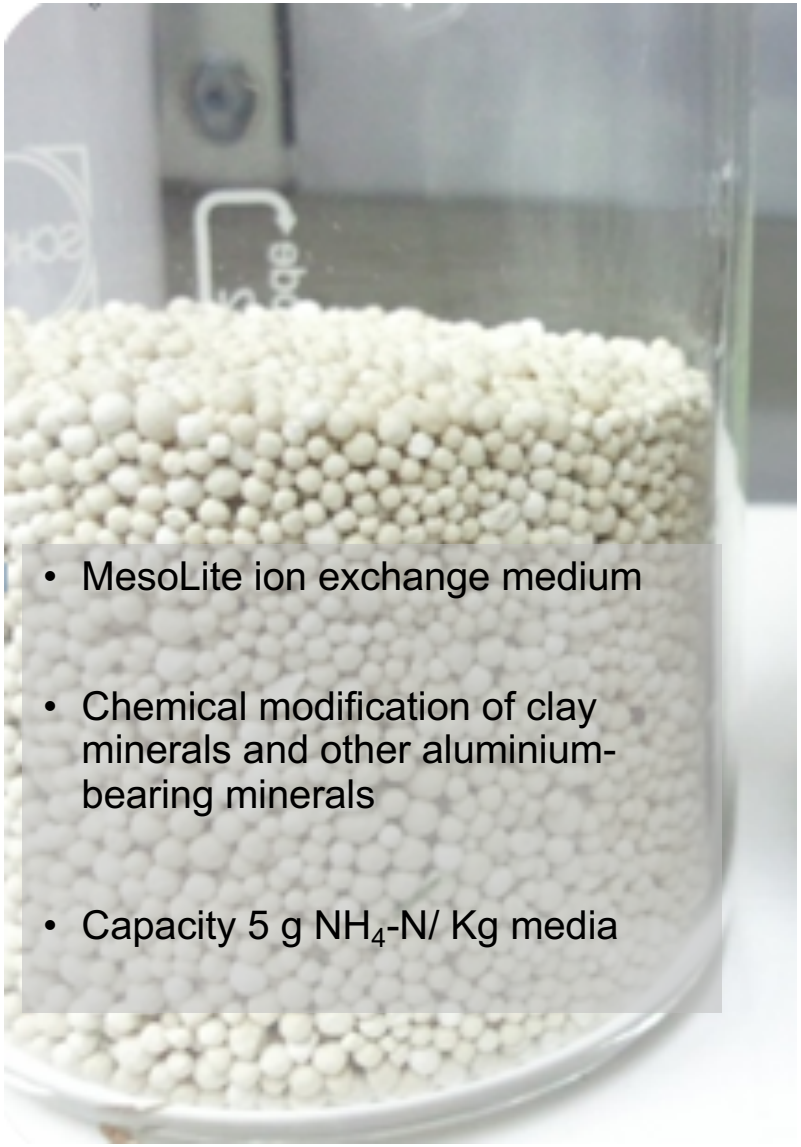




Guida S, Conzelmann L, Remy C, Vale P, Jefferson B, Soares A. 2021. Resilience and life cycle assessment of ion exchange process for ammonium removal from municipal wastewater. Science of the Total Environment. https://doi.org/10.1016/j.scitotenv.2021.146834

But what about the brine?

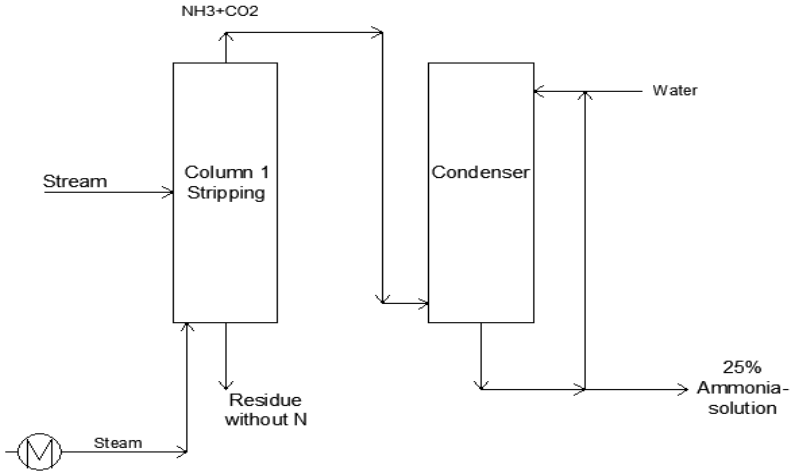




Regenerant and ammonia recovery using commercial products

SMART-Plant
Supported by the Horizon 2020 Framework Programme of the European Union

Ammonia steam stripping process

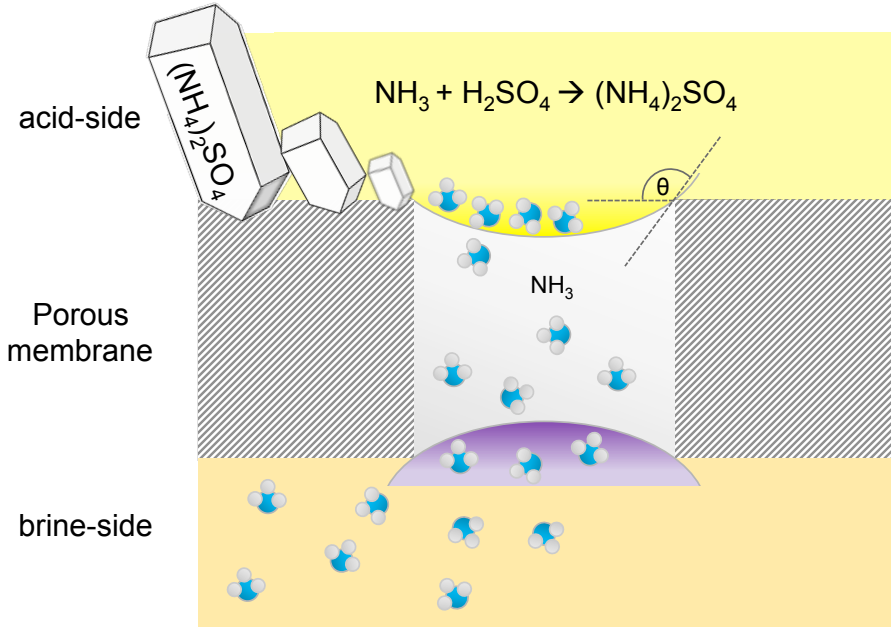


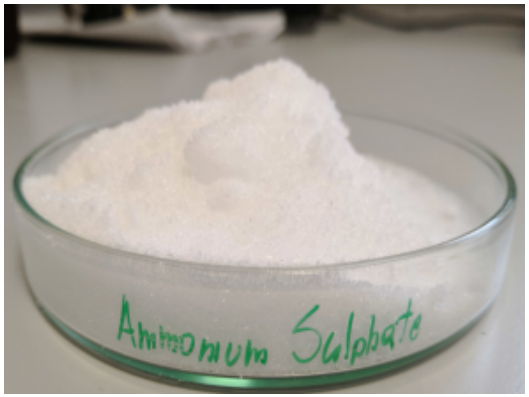


Ammonia water (25%)

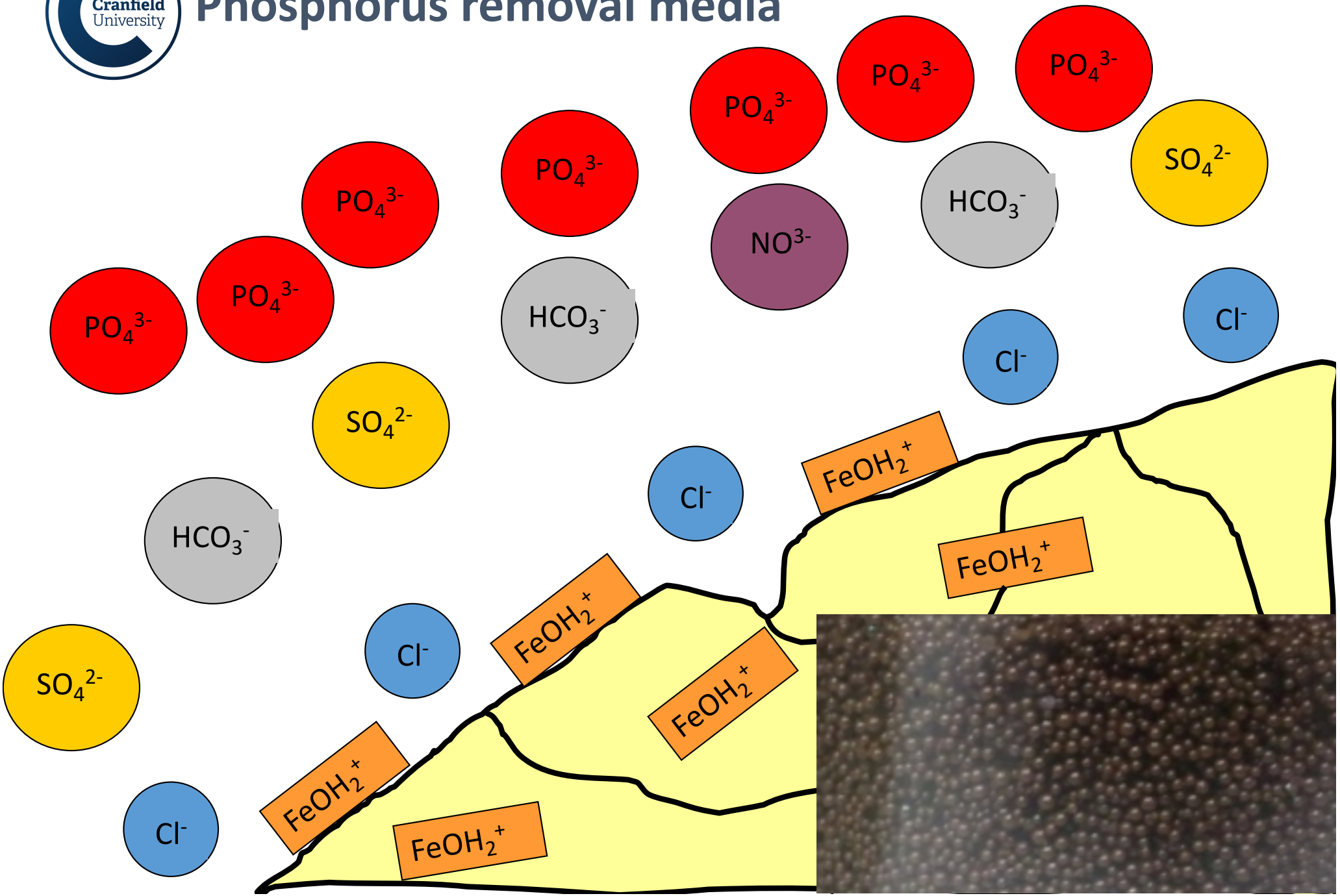
Hollow fibre membrane contactor



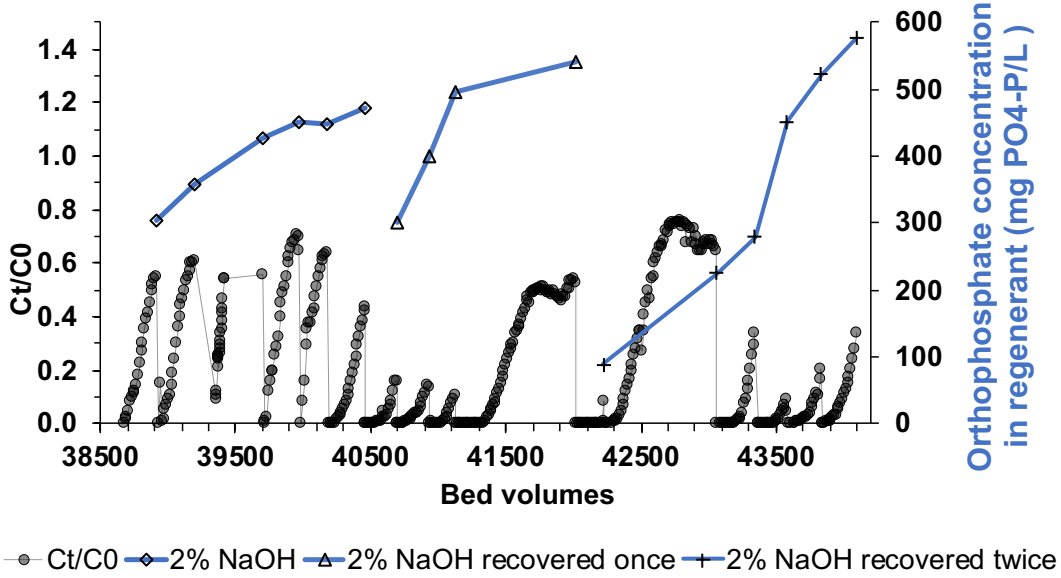




Phosphorus removal media



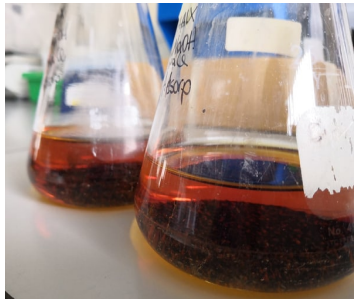
Operation of the phosphorus removal IEX



-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

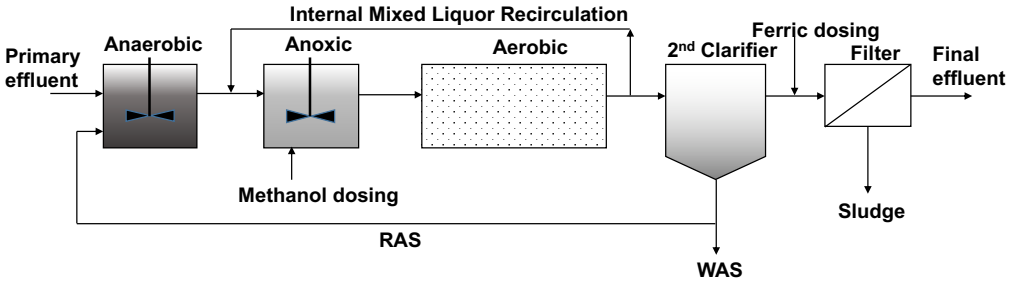
Up to 30% COD removal

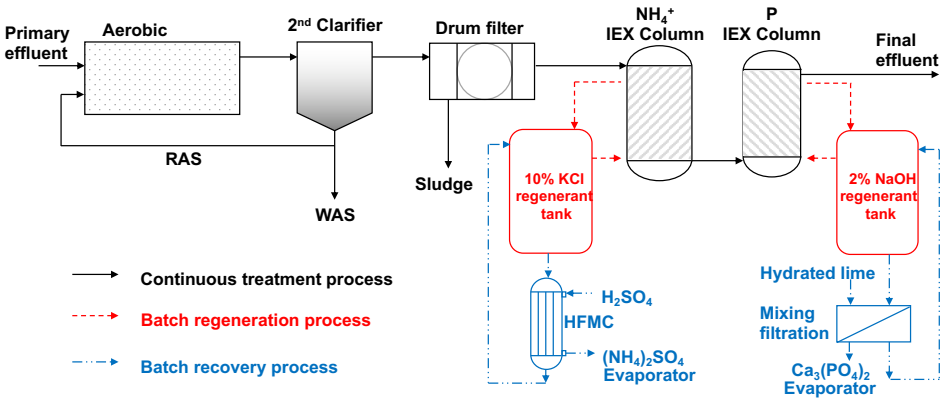
Guida S, Rubertelli G, Jefferson B, Soares A. 2021. Demonstration of ion exchange technology for phosphorus removal and recovery from municipal wastewater. Submitted.

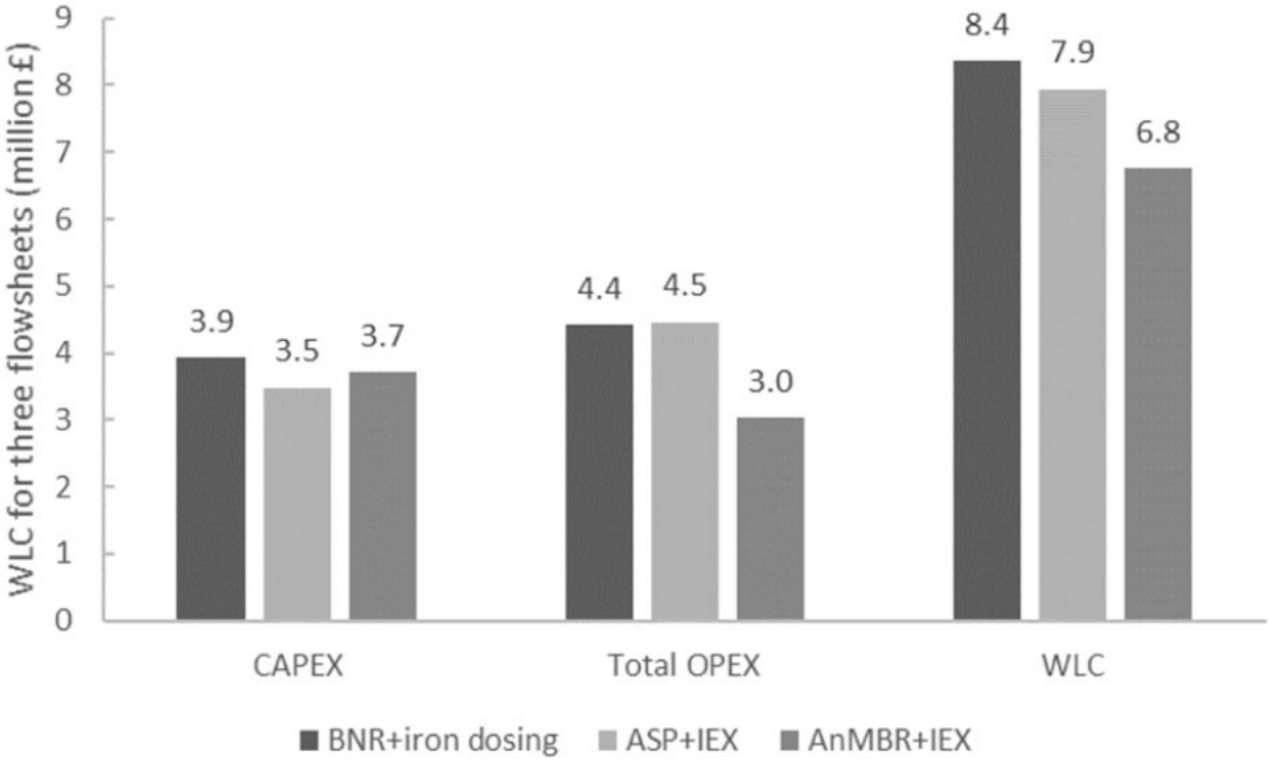
SMART-Plant

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

Water **Materials** **Energy**

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

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).



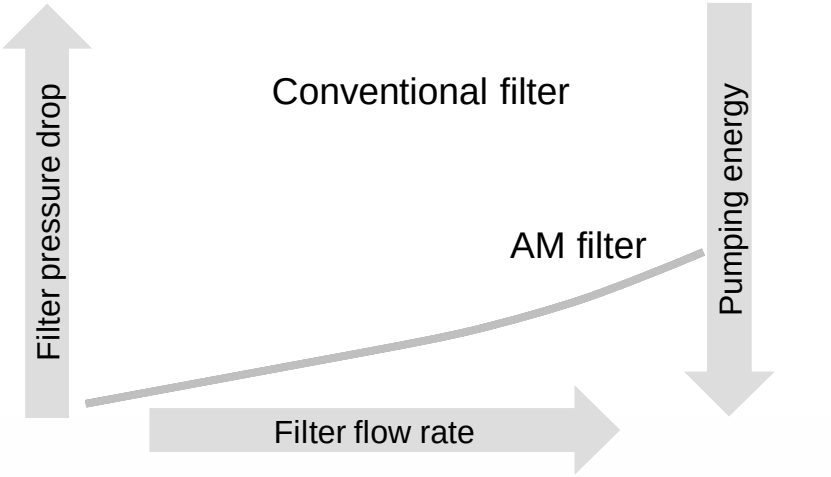
Thank You

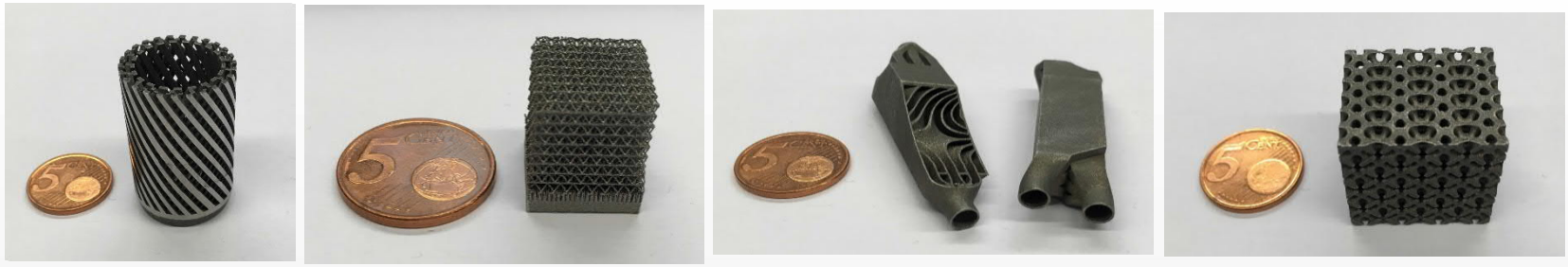
3D Printed Adsorbents for Metal Recovery

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).

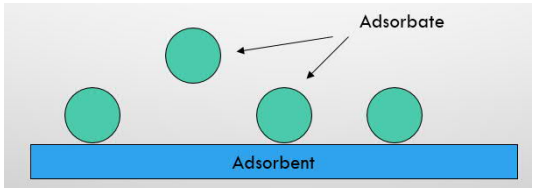




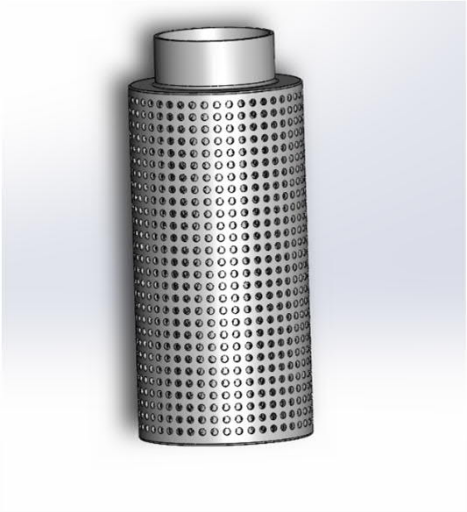
Designs by LUT Laser

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

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

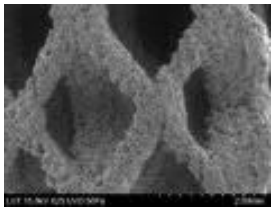
Test solution (pH 3)	After adsorption
Co 2.9 ppm	Co 2.9 ppm
Au 7.3 ppm ⇒	**Au 0.2 ppm**
La 36 ppm	La 36 ppm
Pt 6.7 ppm	Pt 6.5 ppm
Pd 6.0 ppm	Pd 5.7 ppm

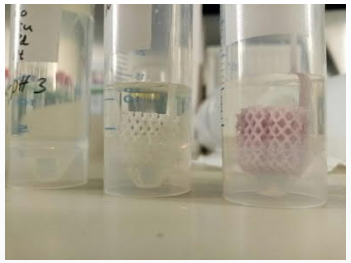
Test solution (pH 5)	After adsorption
Co 4.9 ppm	Co 4.9 ppm
Au 6.6 ppm ⇒	**Au 0.4 ppm**
La 62 ppm	La 62 ppm
Pt 6.0 ppm	Pt 5.9 ppm
Pd 6.4 ppm	Pd 6.0 ppm



Selective laser sintering



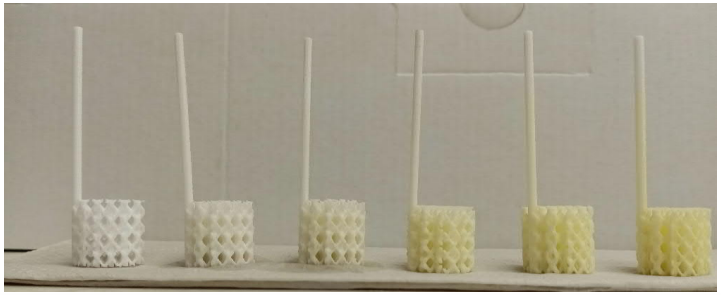


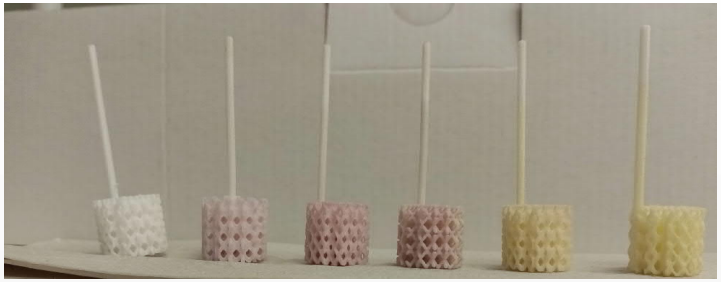


Our premilinary experiments:
Gold recovery by 3D-printed nylon adsorbents

Gold concentration in the initial solution

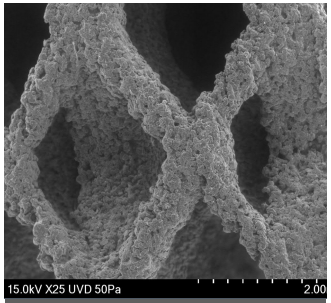
0 mg/l 10 mg/l 50 mg/l 100 mg/l 150 mg/l 200 mg/l



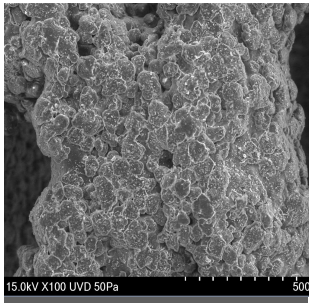


Directly after adsorption The colored ones show adsorbed gold from the solution

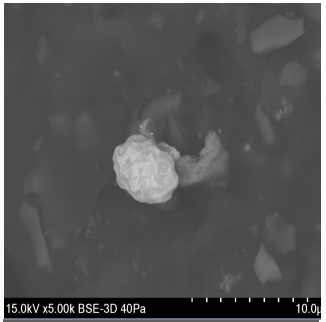
After 24 hours gold nanoparticles formed on the surface change the colour reddish



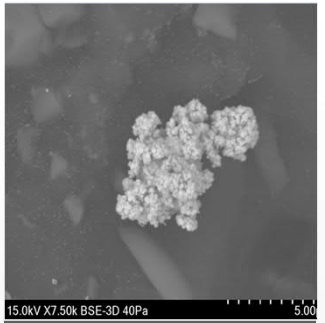
Magnification X 2 mm



Magnification X 500 µm

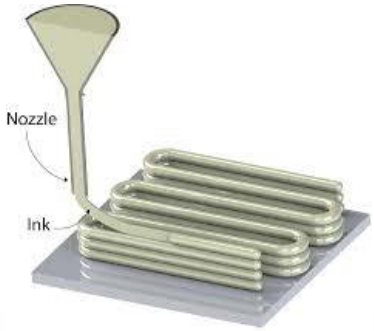


Magnification X 10 µm

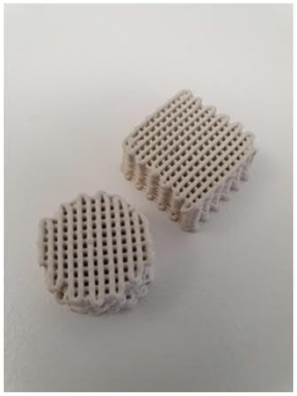


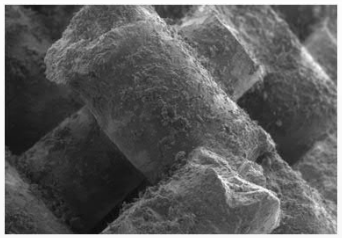
Magnification X 5 µm

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

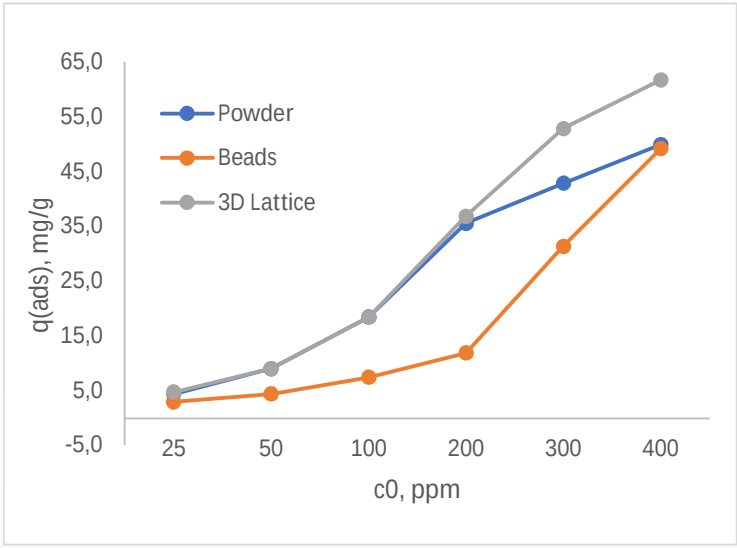


Direct ink-jet writing
(University of Padova)





Adsorption of
Orange II

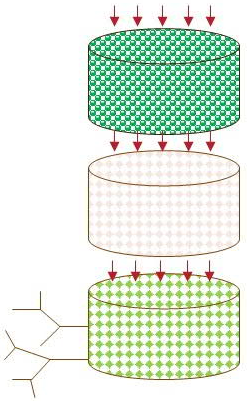


Sea4Value project

LUT task: Production of selective 3D-printed adsorbents

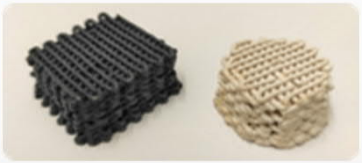
- Adsorption/ion-exchange is effective and selective way to recover trace amounts of metals
- Especially, selective ion-exchange resins are widely applied
- In Sea4Value project:
  - Inks and printing powders will be prepared by mixing matrix materials (polymers) with selective ion-exchange resins
  - 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

3D-printed selective
"adsorption modules"



Special functionalities such as IDA, EDTA, phosphonates



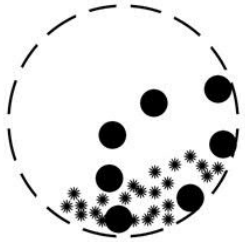


Production of 3D-printed adsorbents

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

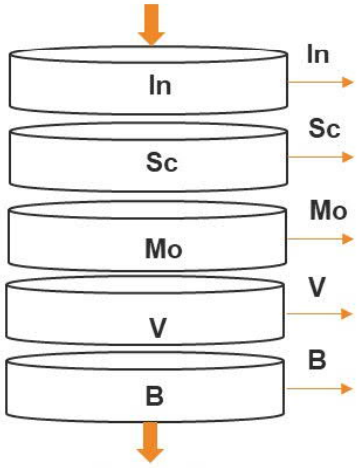
Ball mill

Particle size aprx. 50 micron



Brine solution

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



Mix PA12 powder with resin powder 10 wt%



AM of adsorbents by 3D-printer

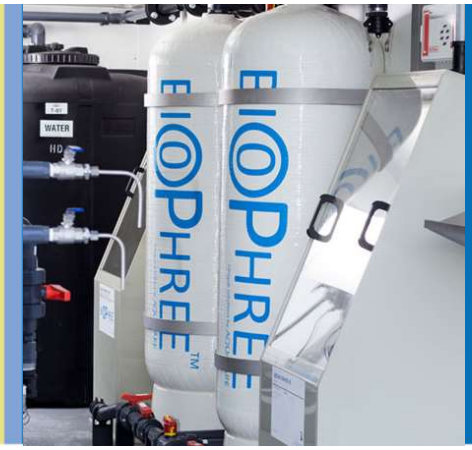




Thank you!

Contact: eveliina.repo@lut.fi

wetsus
european centre of **excellence**
for sustainable **water technology**





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



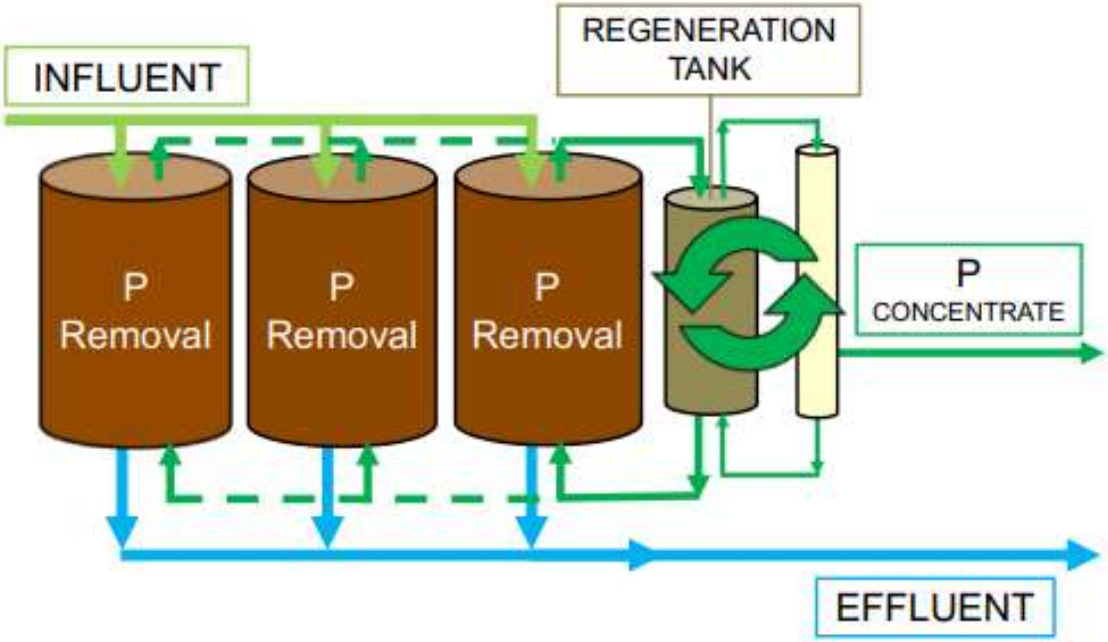
Eutrophication



Zero-Liquid Discharge

wetsus

BioPhree concept





wetsus

Iron oxide based adsorbents



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



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

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

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

wetsus

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 m³ 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

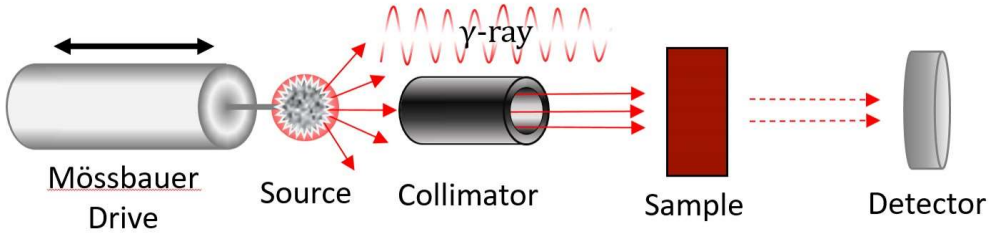
WWTP La Llagosta, Spain (2022-2023)

- 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

Our greatest tool- Mössbauer spectroscopy



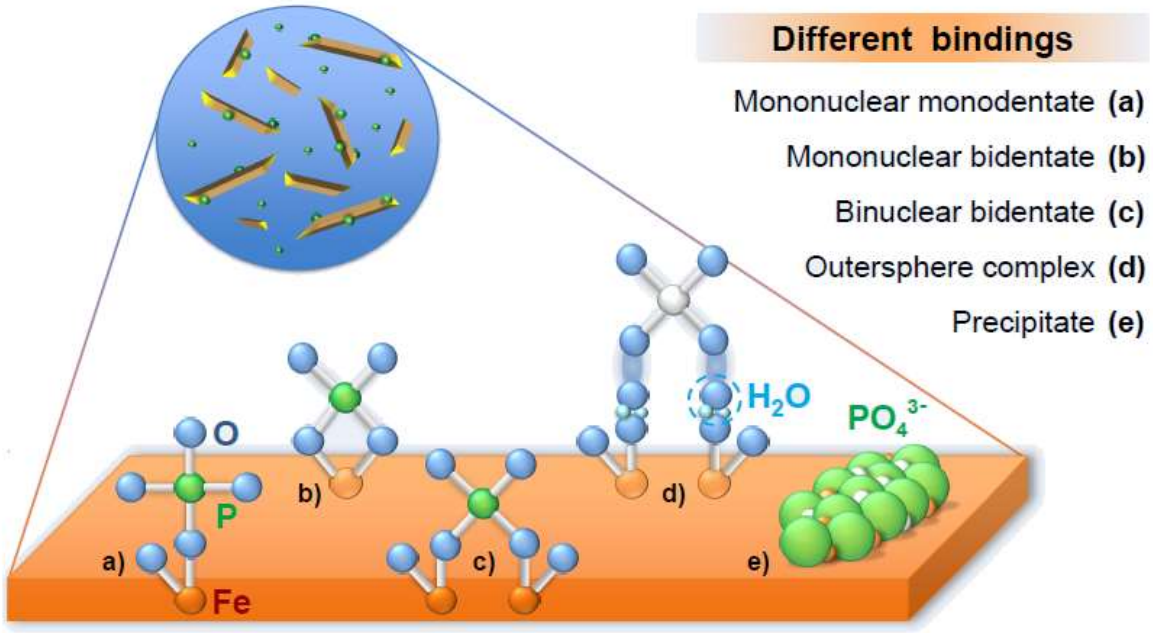
Fresh IEX			Used IEX		
21%	Fe^{3+}	Goethite	31%	Fe^{3+}	Goethite
7%	Fe^{3+}	Hematite	8%	Fe^{3+}	Hematite
72%	Fe^{3+}	Ferrihydrite	61%	Fe^{3+}	Ferrihydrite



wetsus

Nano-particles approach

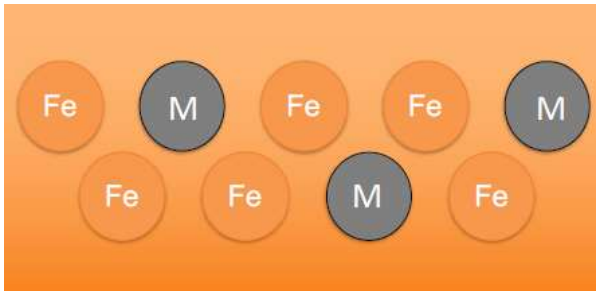
- Pure interaction between iron oxide & P
- Effect of competing ions
- Good signal for Mössbauer study

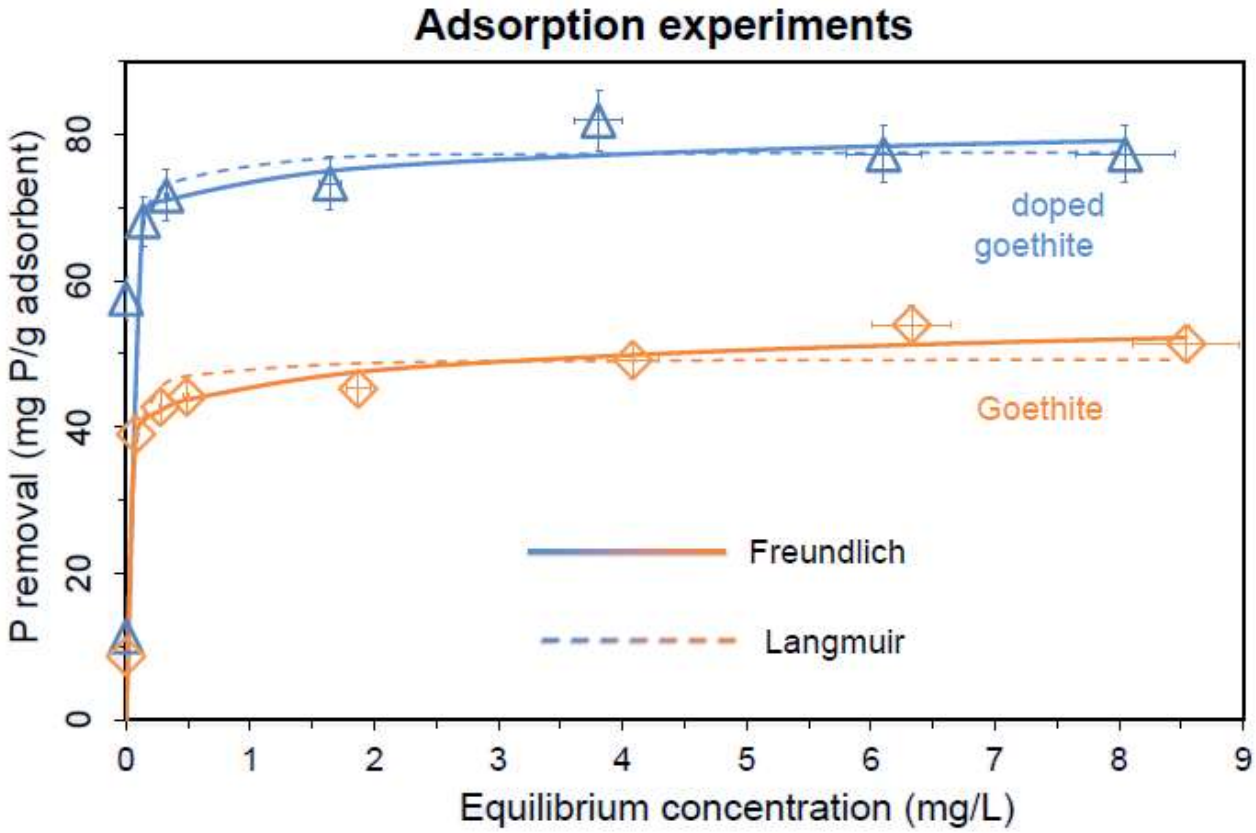


PhD study Carlo Belloni

wetsus

Doping of iron oxides





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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

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





Thank you for your attention

More information:

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

- wokke.wijdeveld@wetsus.nl



wetsus

nextGen
Cirular Water Solutions

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

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:

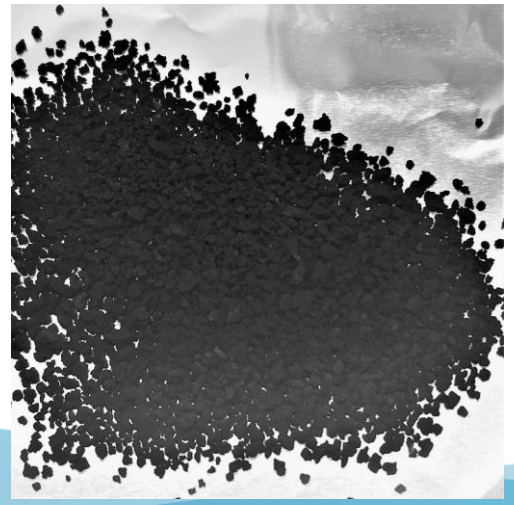
1. Laboratory and pilot experiments to investigate the effect of pyrolysis and activation on GAC performances
2. Definition of the conditions for pyrolysis and activation of 2 renewable resource for GAC production
3. Production of renewables GAC
4. Operation of GAC filter (Pilot plant at AVA Altenrhein)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

Production of renewable GACs

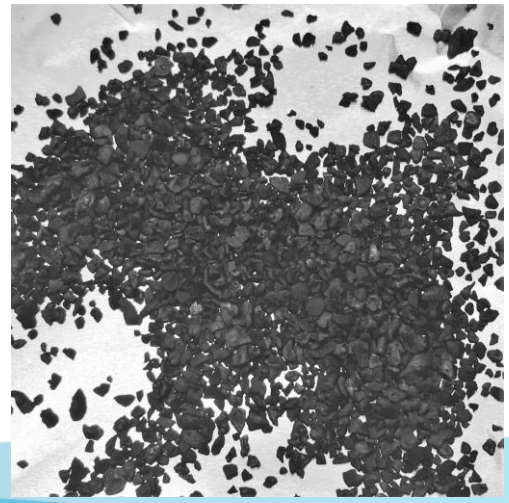
Phase	Objective
Pilot trials (Pyreka, Agroscope)	To generate samples under different conditions: • 2 renewable resources (CP, SS) • Temperature of pyrolisis and activation (700, 800, 900°C) • Activation gas (CO_2, H_2O) • Residence time (10, 20, 30') **21 samples in total**
Characterization of samples	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.

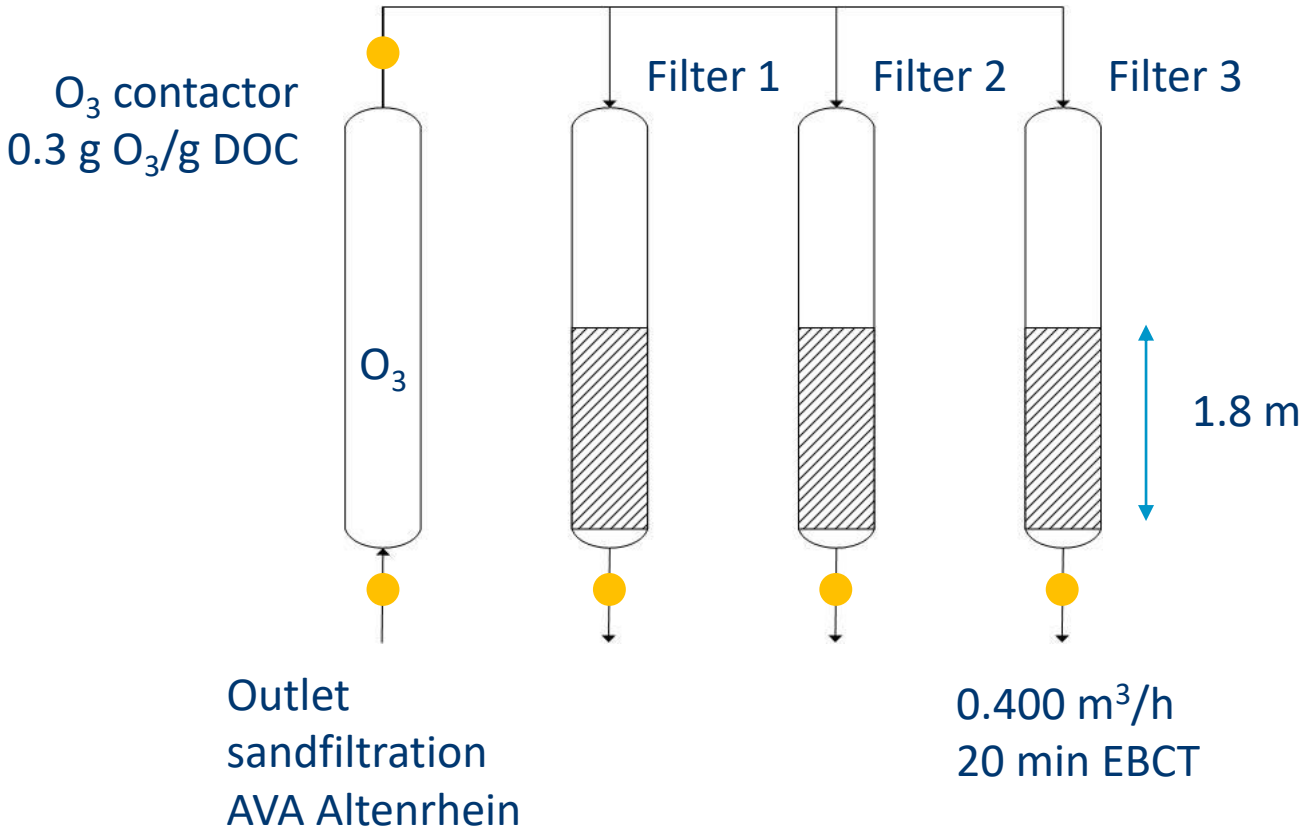


SS_GAC



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

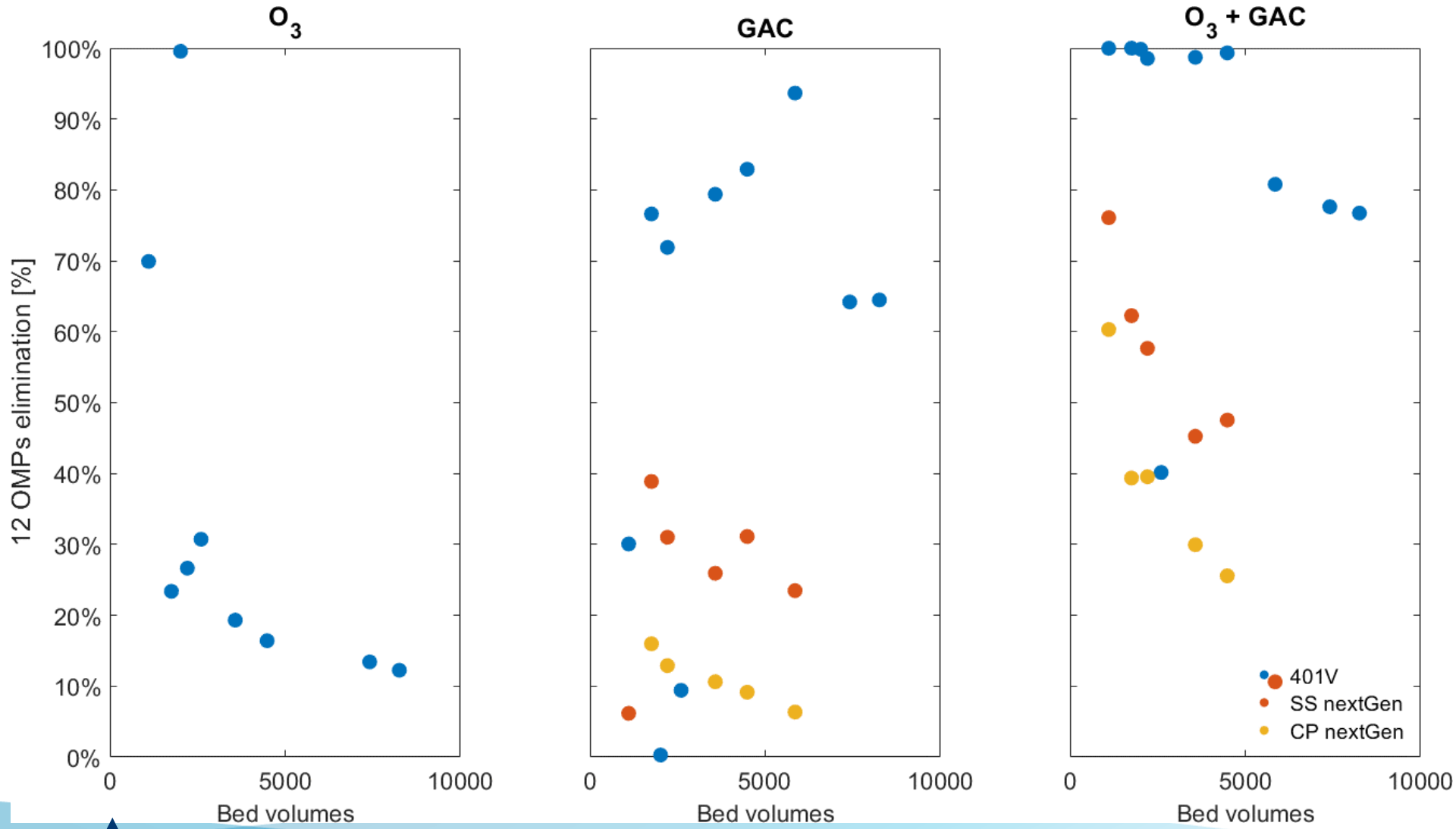
Geometry of the filters		
Diameter of the column	m	0.3
Height of GAK_the fixed bed contactor	m	1.8
Volume of the fixed bed contactor	m^3	0.127
mass of SS_GAC	kg	67
mass of CP_GAC	kg	33
mass of 401V	kg	62

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



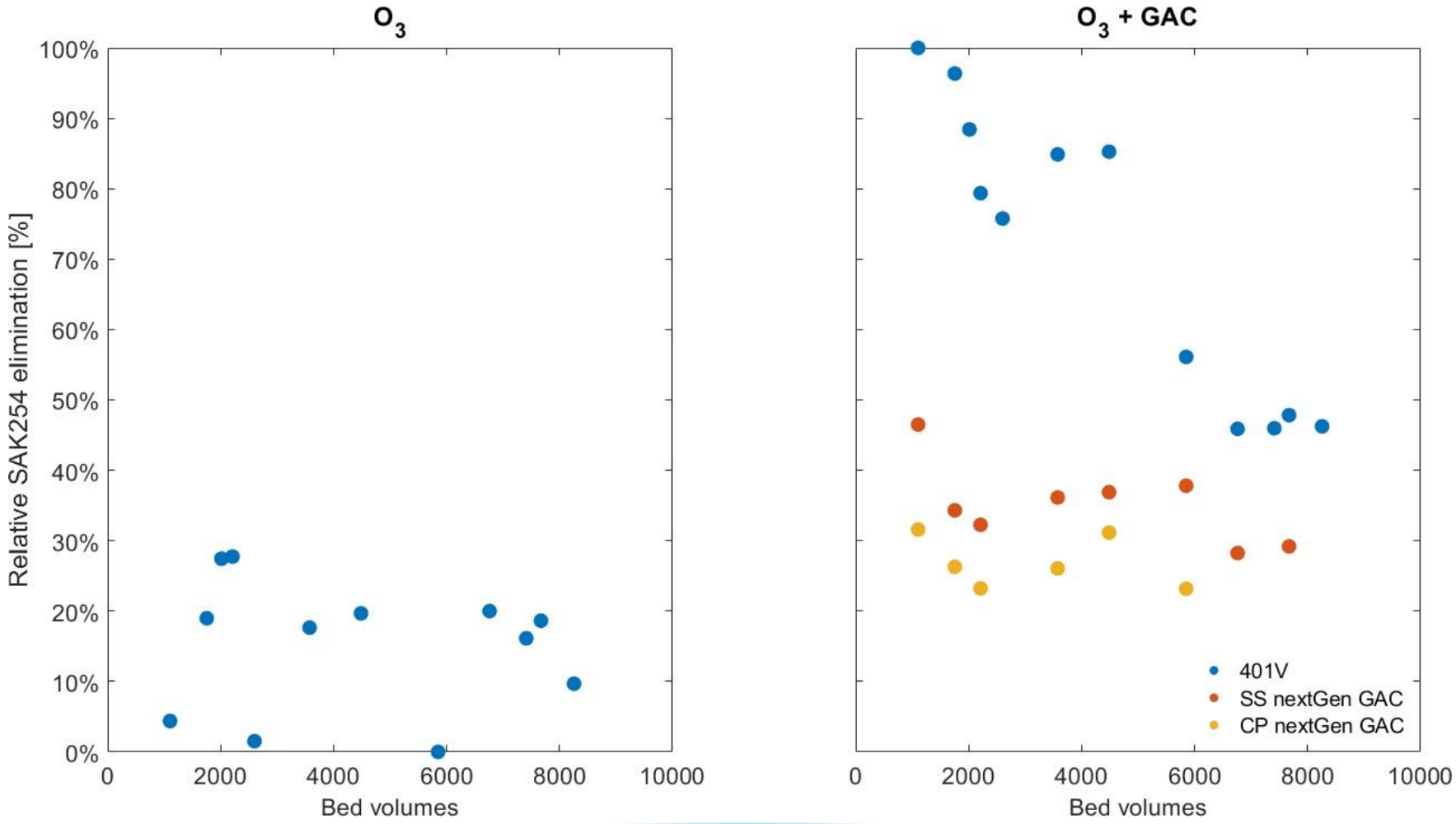
- Automated backwashing system
- Automated sampling at the outlet

Pilot study - 12 OMPs elimination



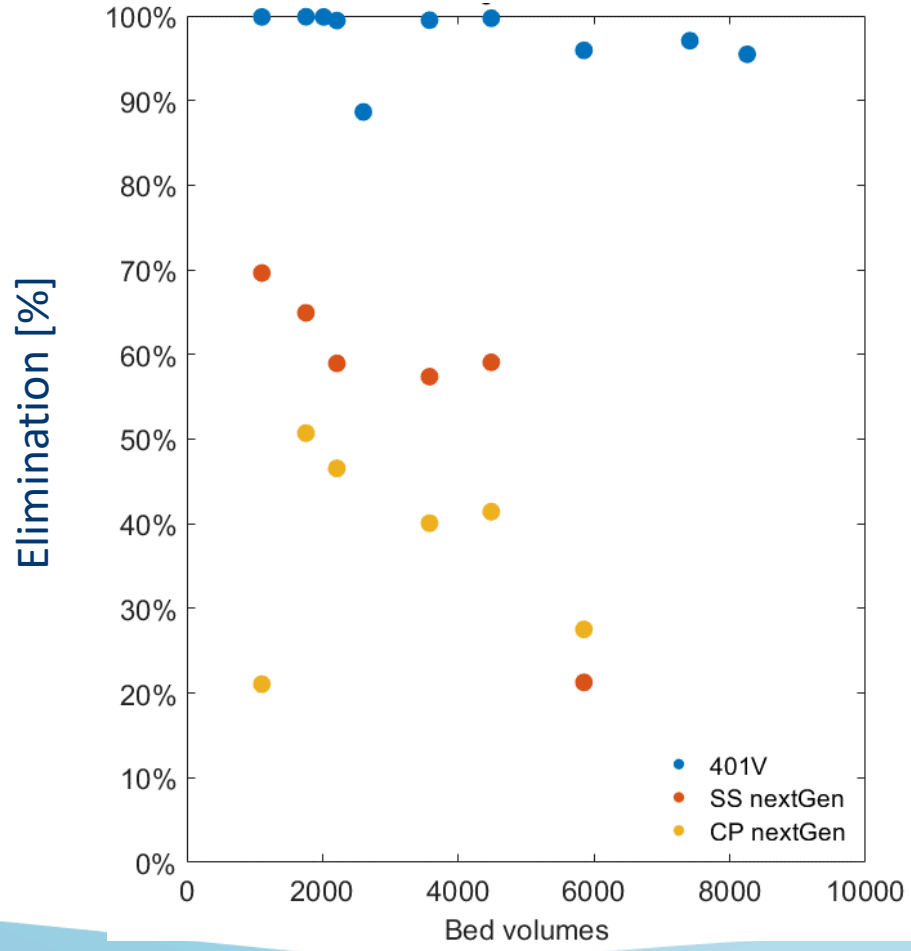
Nov 2020

Pilot study - Relative sak254 elimination

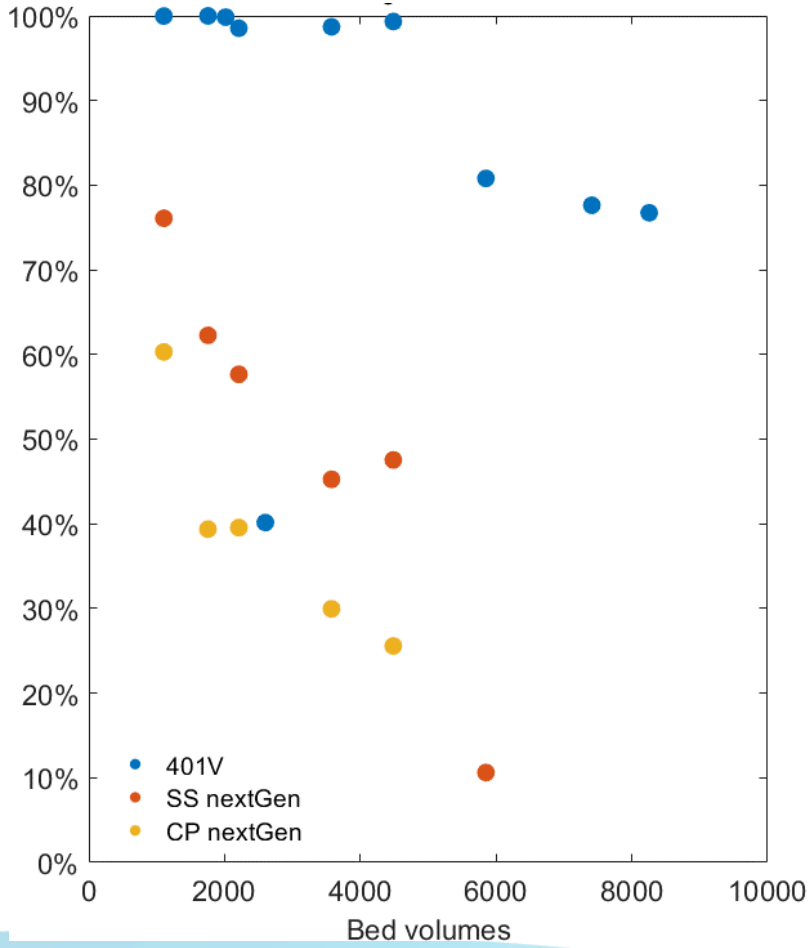


Pilot study - the «worst case» OMPs elimination

12 OMPs

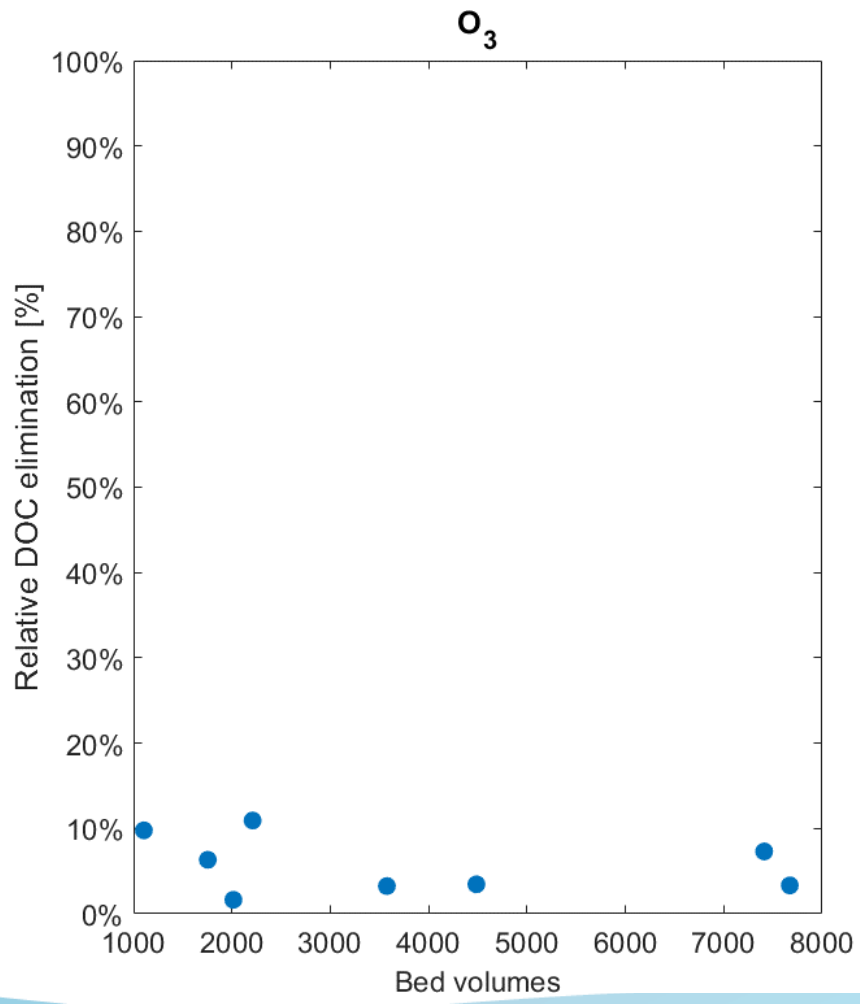


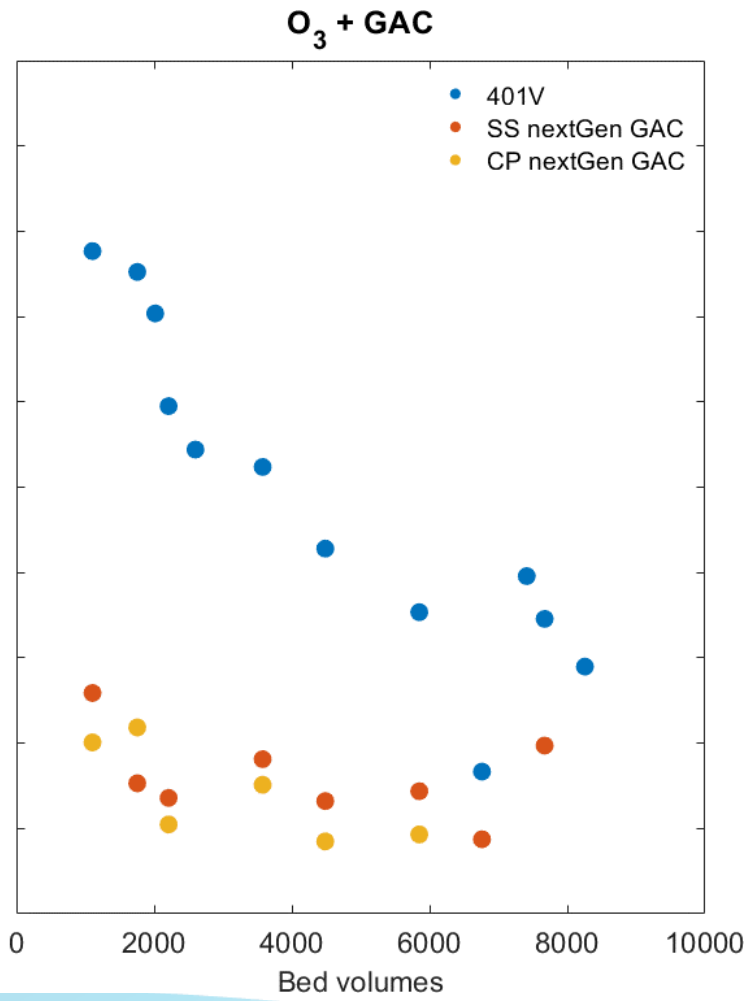
worst case OMPs



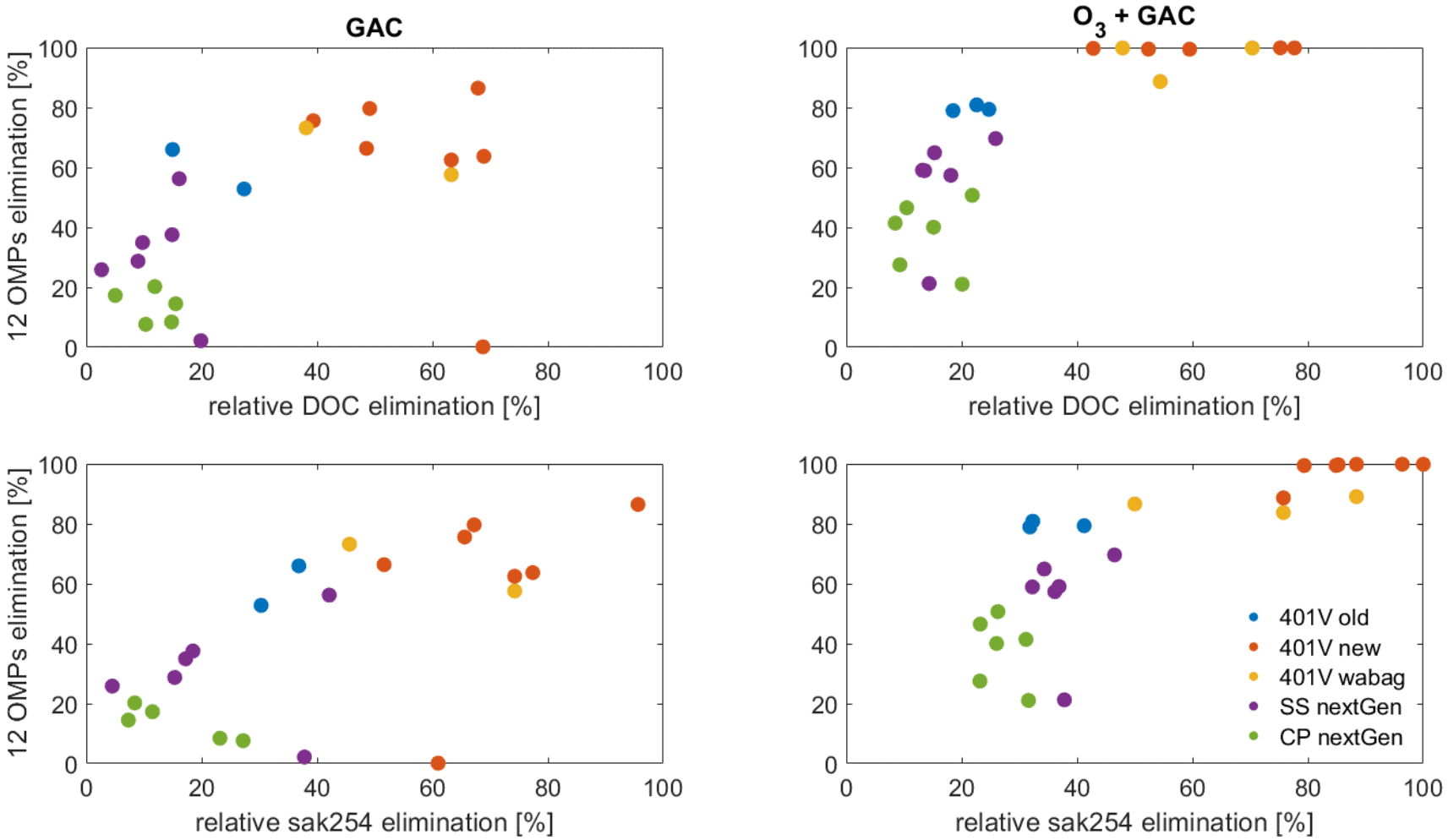
1. Venlafaxin
2. Candesartan
3. Irbesartan

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!

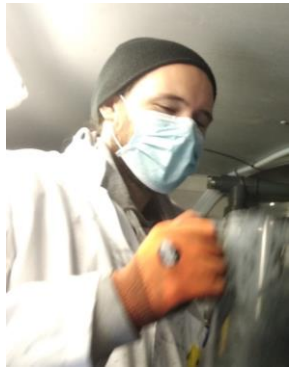
Fachhochschule Nordwestschweiz



M. Thomann



A. Nättorp



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T. Bisang



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ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

Online seminar on innovative biogas technologies

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

October, 30th 2020

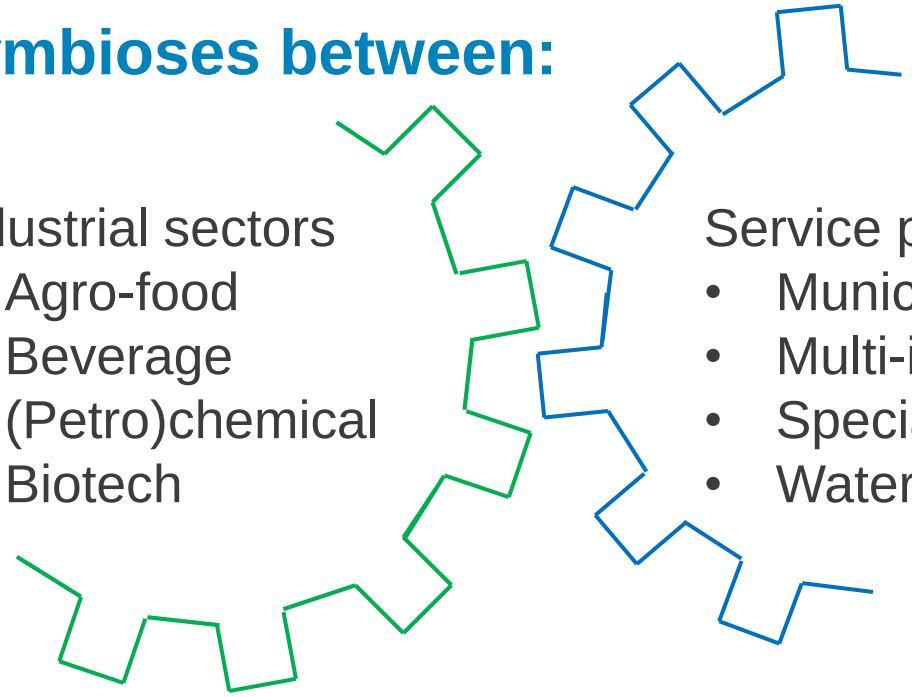


Ultimate (June 2020 – May 2024):

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

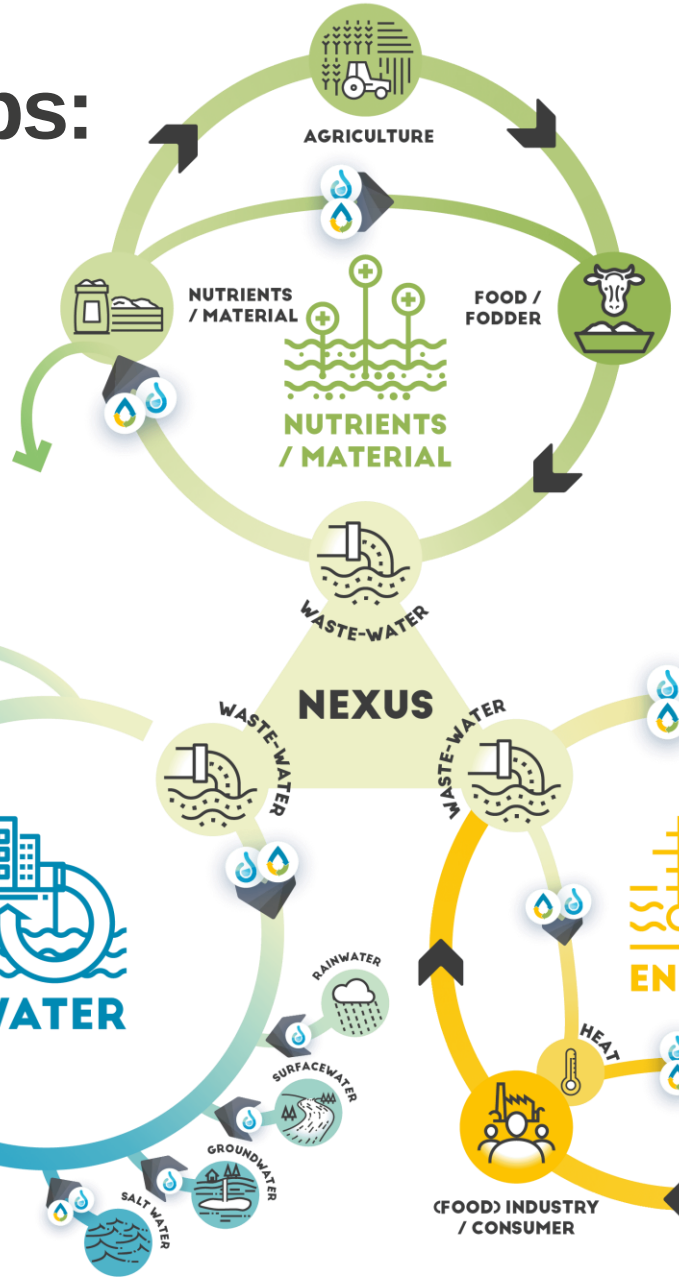
27 Partners

37 Technologies



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







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

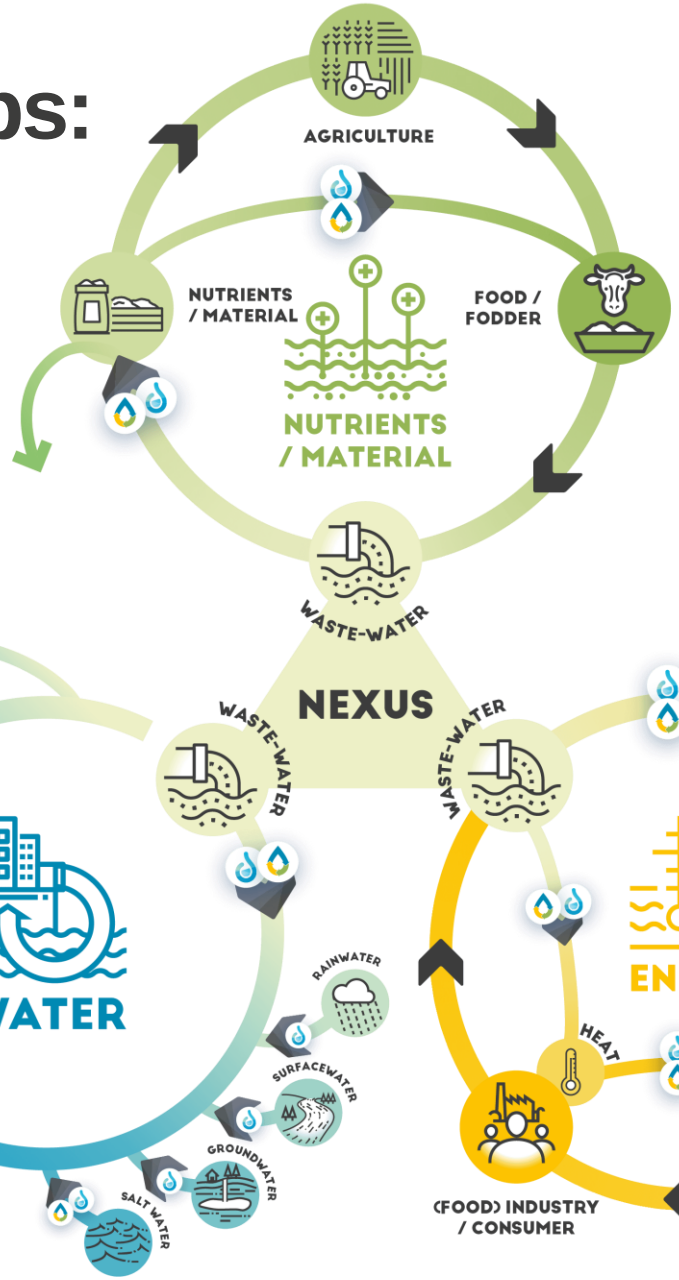


A. Kleyböcker

KOMPETENZZENTRUM WasserBerlin

- Biogas technologies
- Heat recovery
- Digitalization

3 Cross-cutting Technology Groups: 9 Topics







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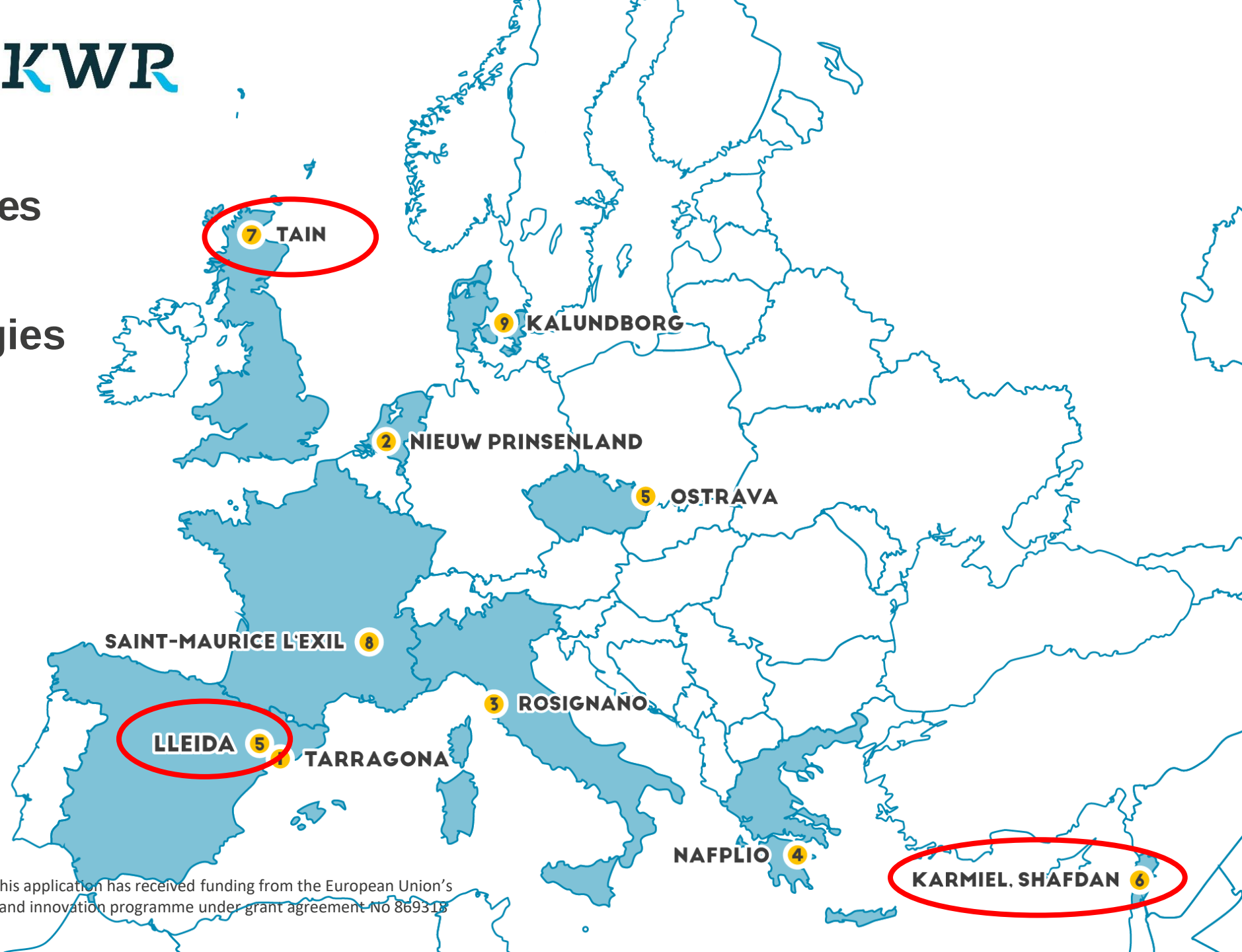

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Online seminar on innovative biogas technologies

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

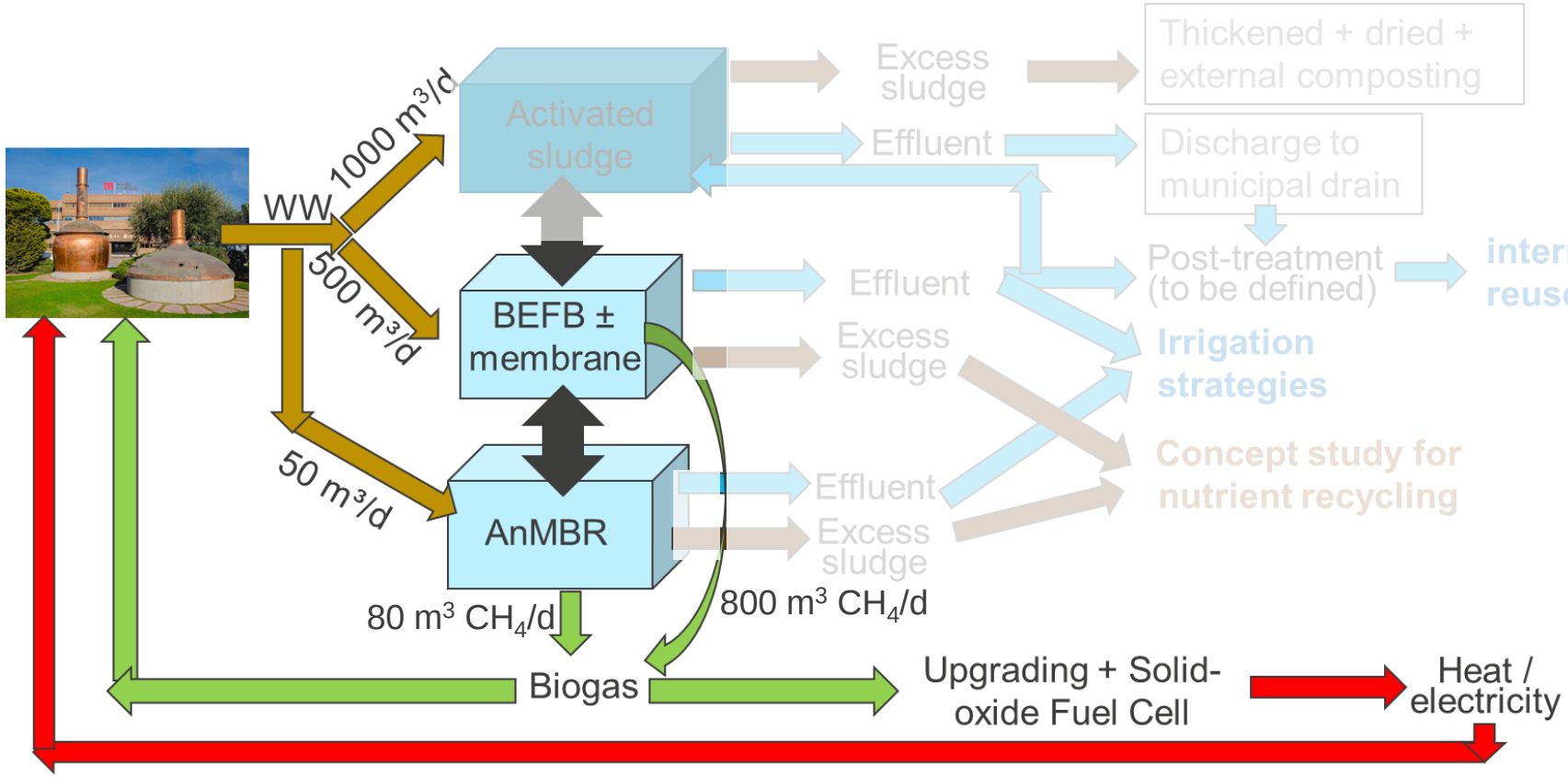
ENERGY - Task 1.3.2

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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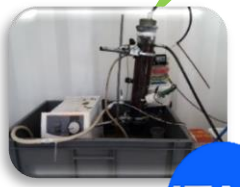
BEFB = BioElectrochemical Fluidized Bed

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

Lab-scale BEFB



V= 1 L

ITACA

Pre-pilot BEFB (BEFB *vs* HRAB)

ANSWER



V= 5.4 L

BEFB Prototype



V= 450 L

BEFB Demo

ADVISOR



V= 1 m³

BEFB Pre-industrial

ULTIMATE



V= 50-150 m³ (Q= 10-20 m³/h)

2013-2014 | 2018 | 2019 | 2020 | 2021

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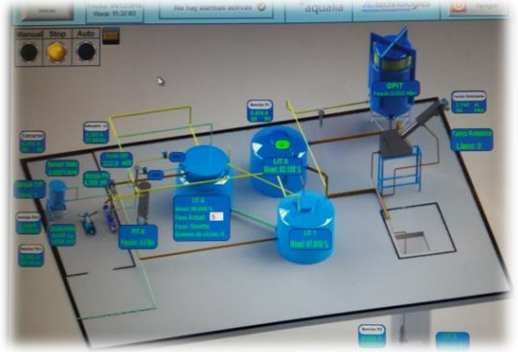
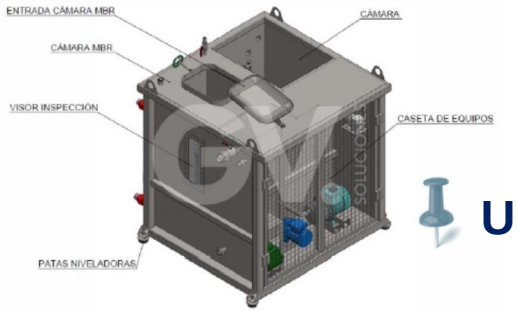
aqualia

AnMBR = Anaerobic Membrane Bioreactor











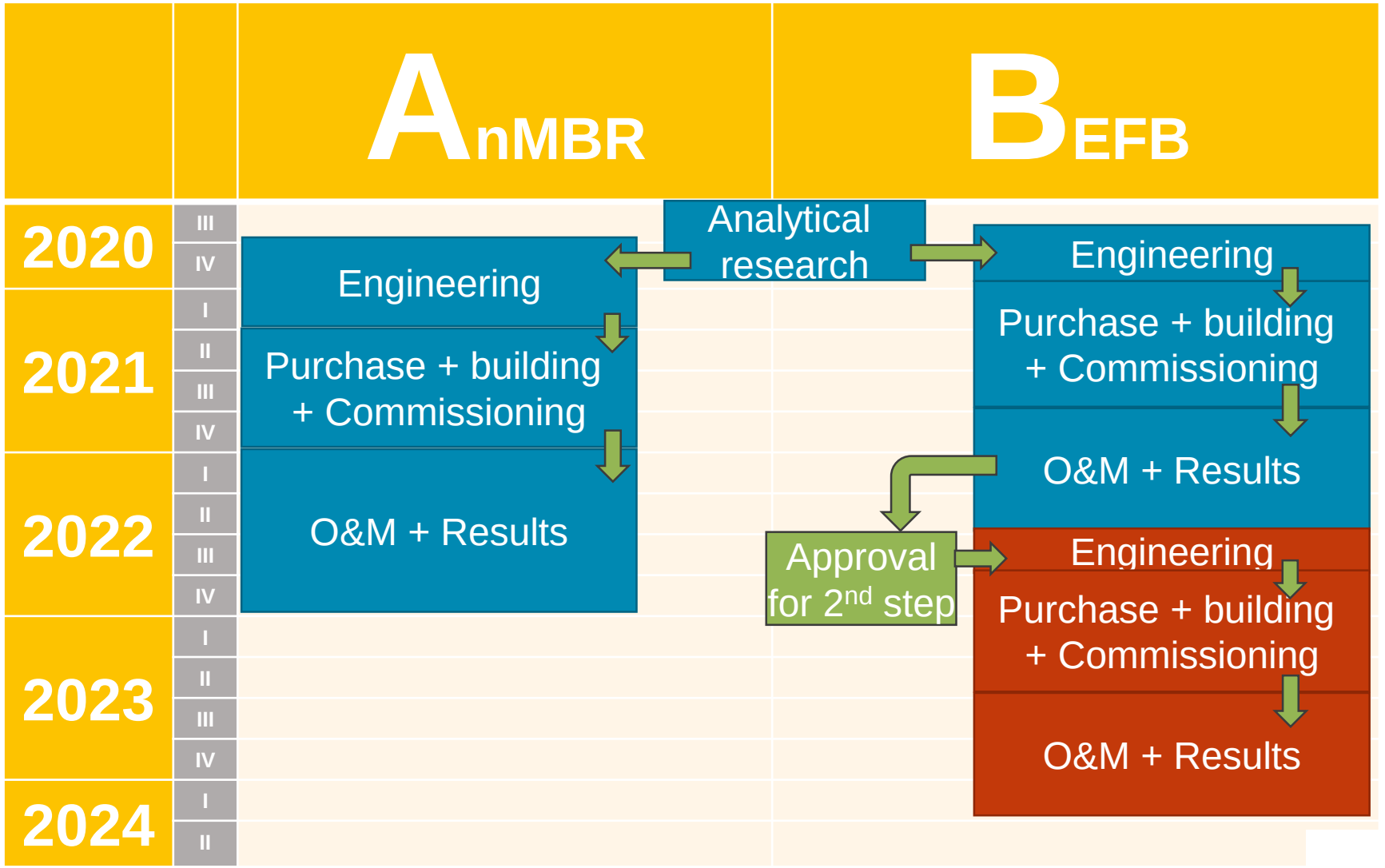


Urban **Black water** **Industry** **OFMSW**

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

Schedule



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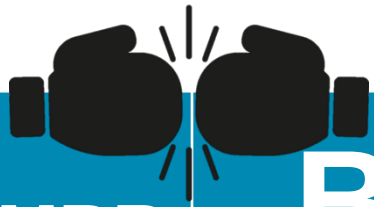
AnMBR vs. BEFB



	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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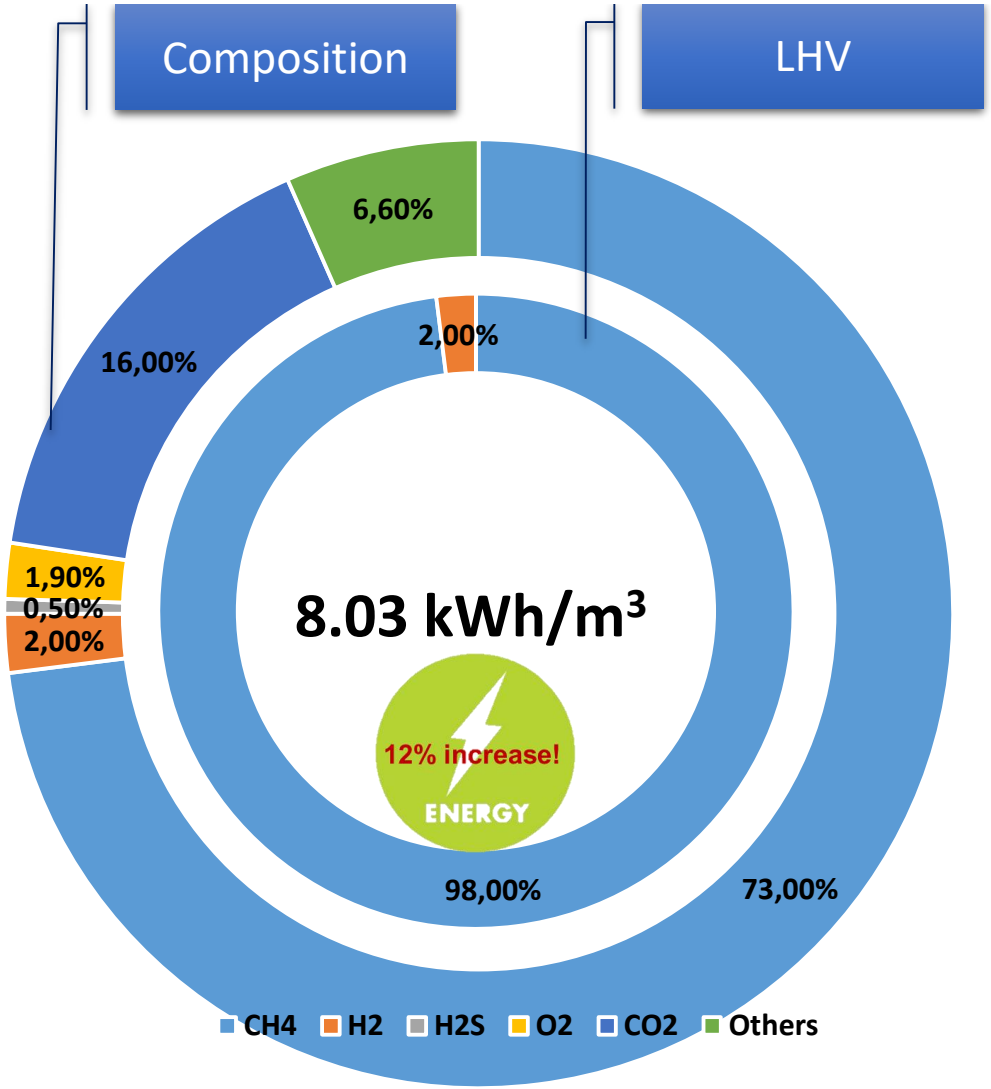
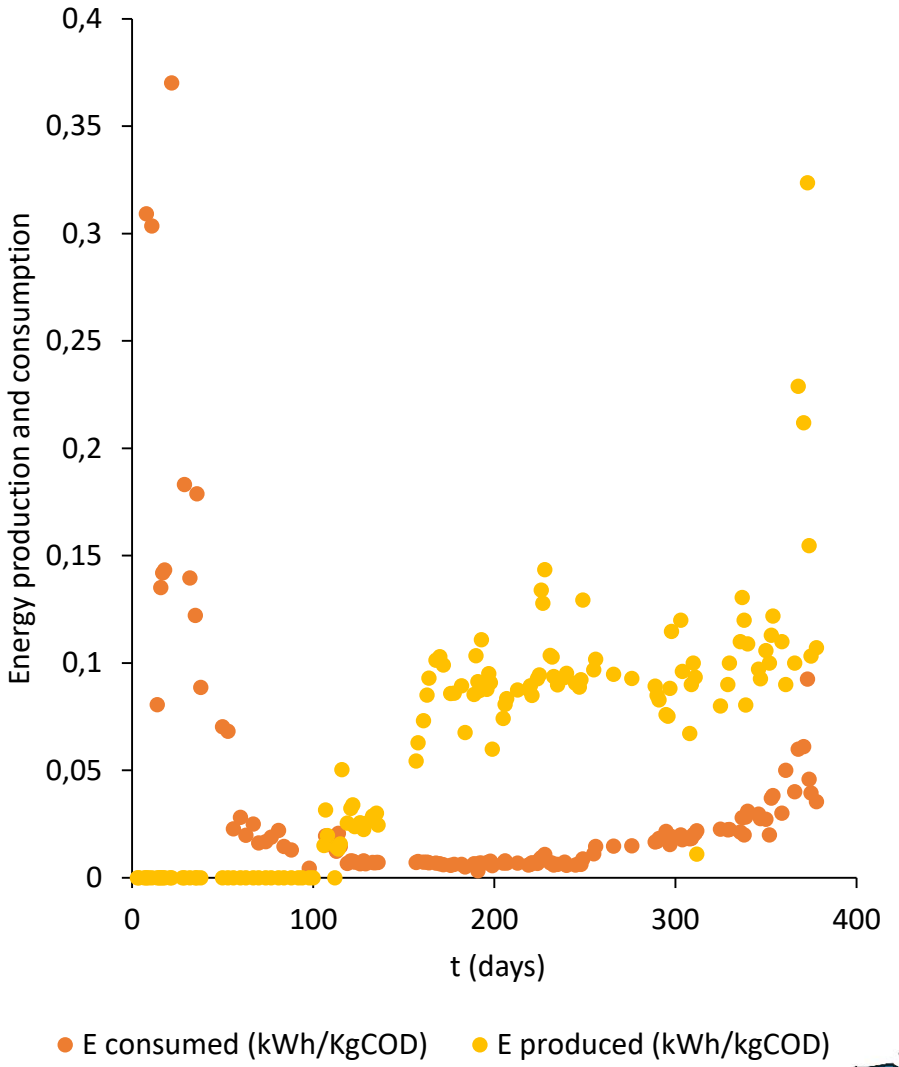
BEFB biogas quality – self-sufficient process





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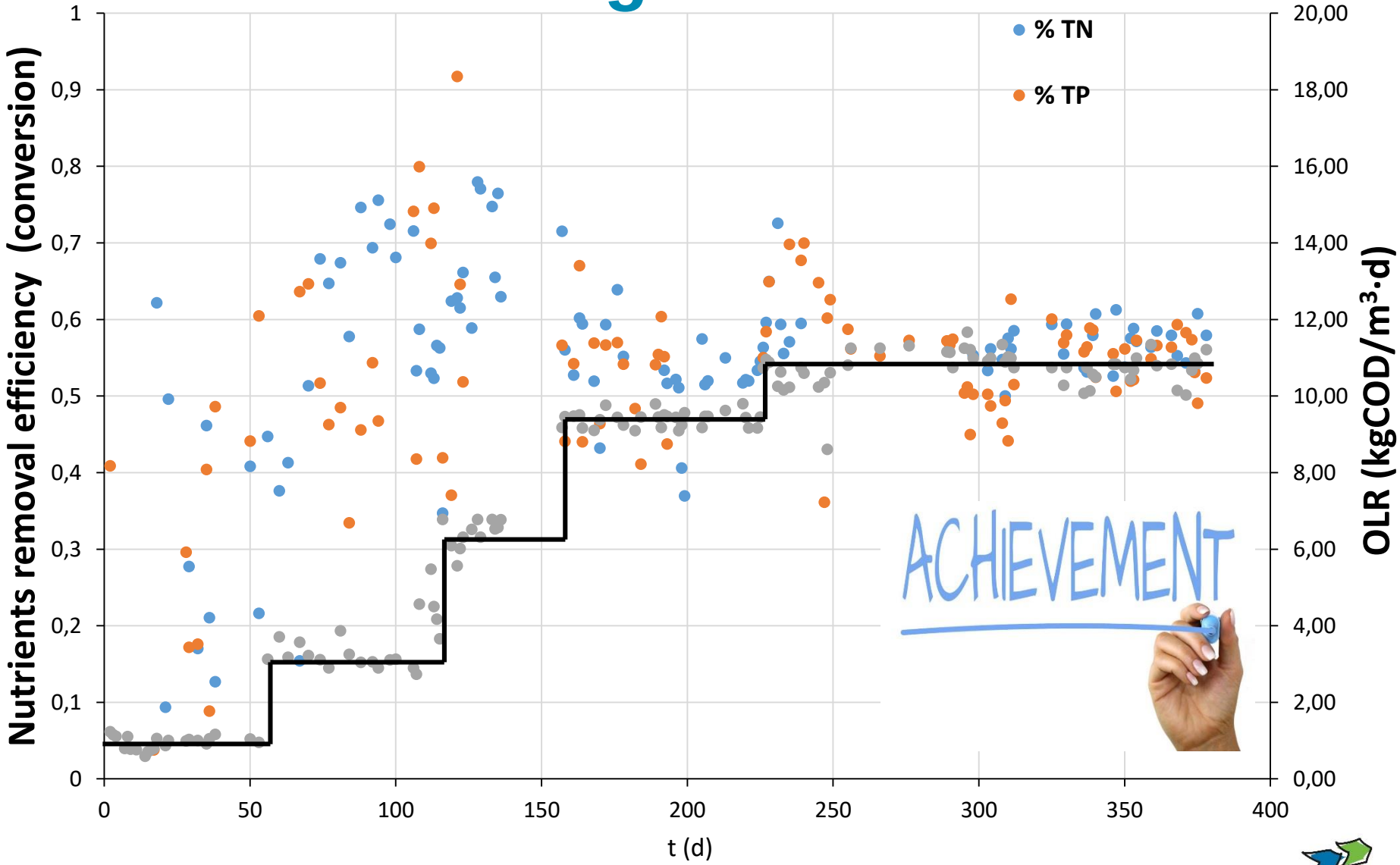
Nutrient removal through an anaerobic treatment



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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



Biogas production in CS5 Lleida: AnMBR versus BEFB, 30.10.2020

ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

CS7 – Tain (Glenmorangie distillery)

Cranfield University

Aquabio

Meeting: October, 30th 2020



CS7

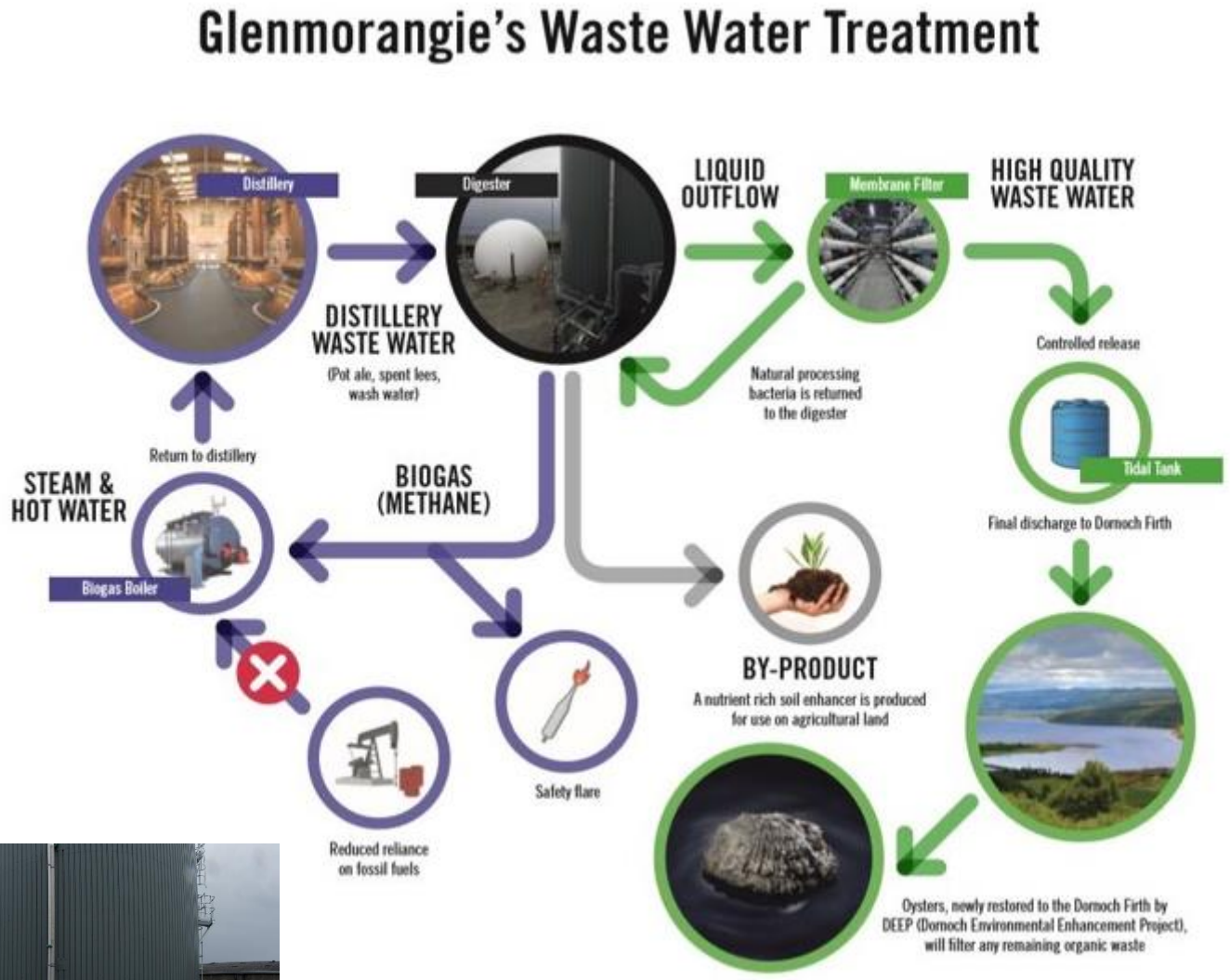

7 TAIN
9 KALUNDBORG
2 NIEUW PRINSENLAND
5 OSTRAVA
SAINT-MAURICE L'EXIL 8
3 ROSIGNANO
LLEIDA 5
1 TARRAGONA
NAFPLIO 4
KARMIEL, SHAFDAN 6


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





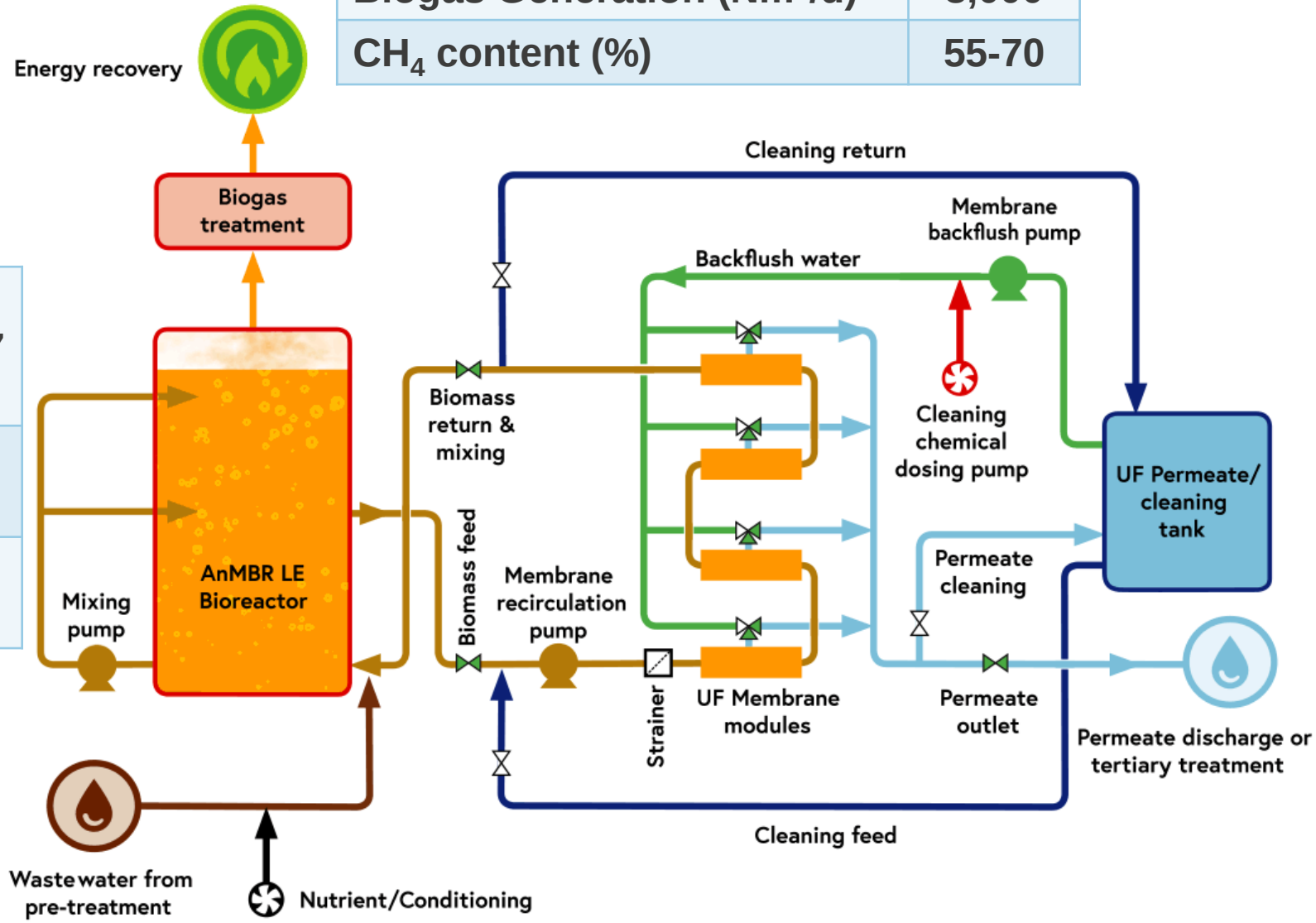
- Dornoch Environmental Enhancement Project: restore Native European oysters and enhance biodiversity in the Dornoch Firth

AnMBR LE™

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%



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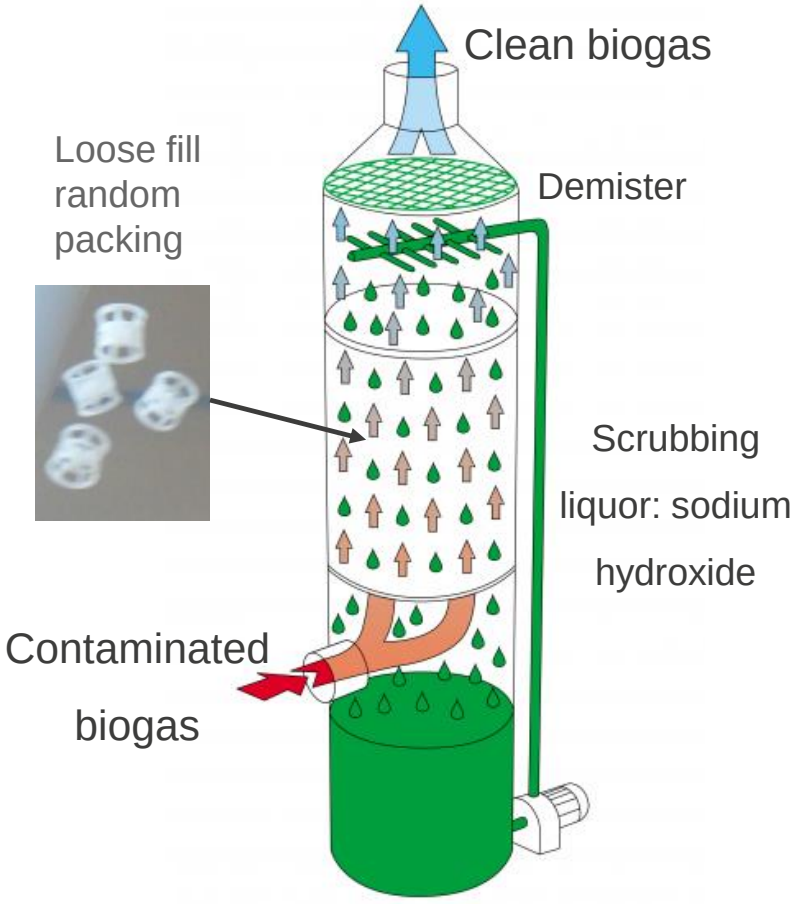
Biogas scrubber and boiler

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**

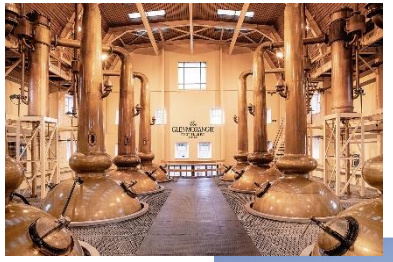
The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

Current system

Reduces the dependence in fossil fuel

of the distillery by 15%





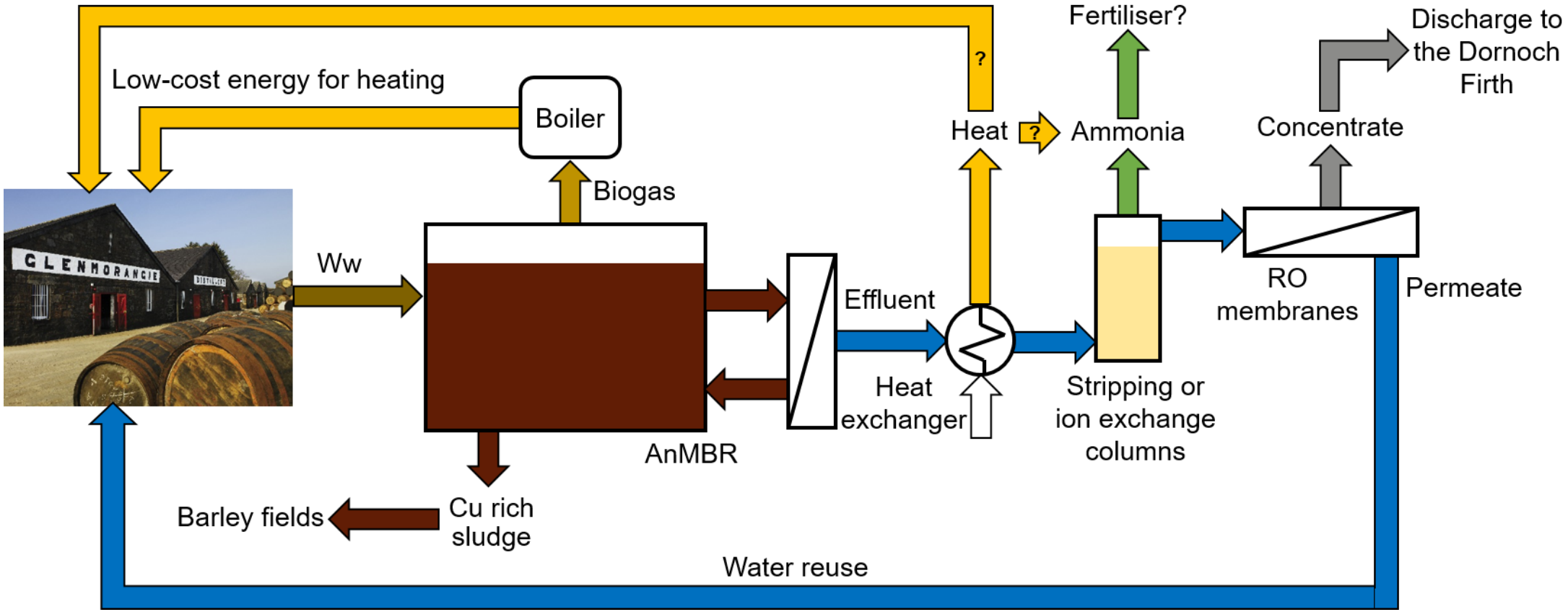






The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

As part of Ultimate…



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!

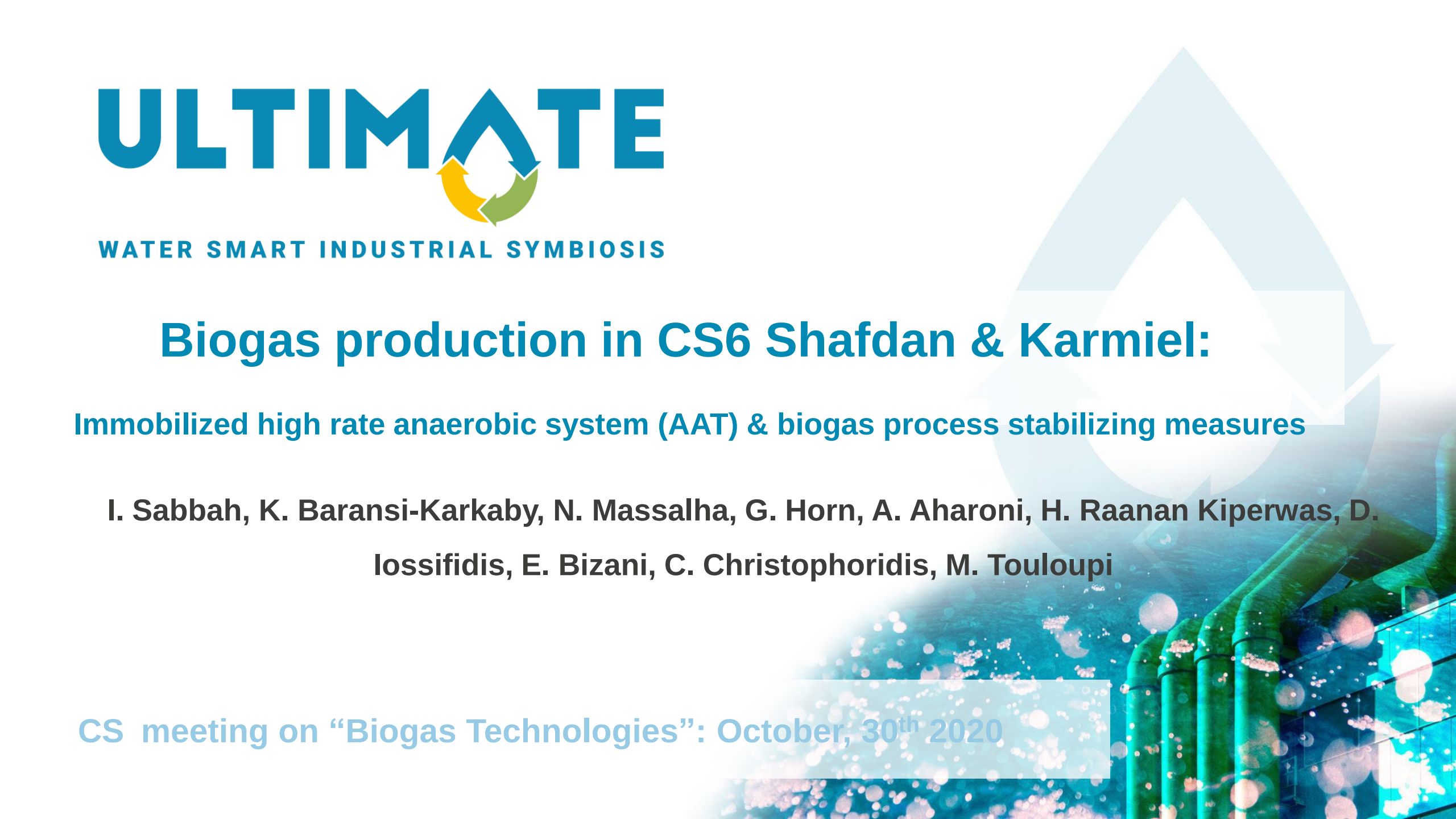
ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

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:



Current situation

Karmiel

30 K m³/d → Karmiel WWTP

Municipal / Agro-industrial WW and (demo scale AAT)

- Pre-treatment
- Primary clarifier
- Activated sludge
- Sand filtration

Shafdan

400 K m³/d → Shafdan WWTP

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

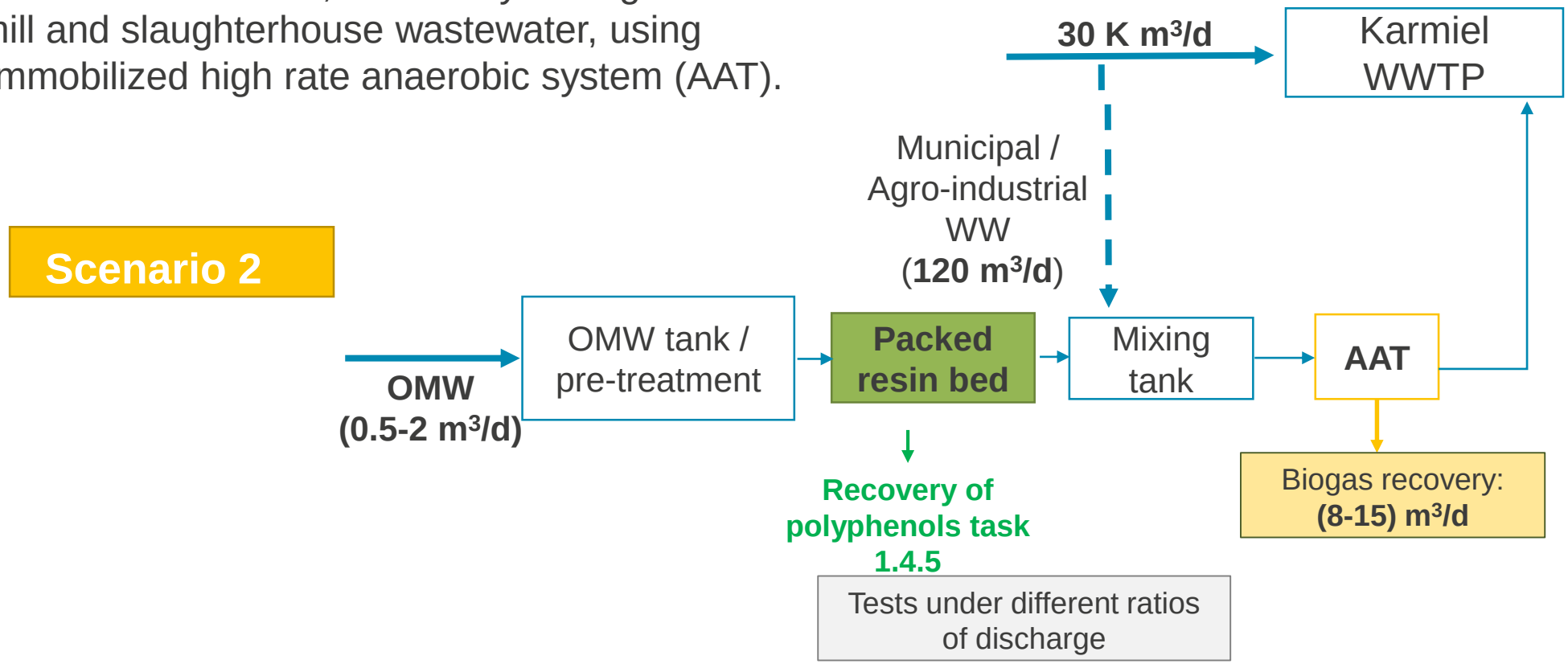
Biogas production from anaerobic pre-treatment of municipal and/or industrial wastewater in **Karmiel**

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).



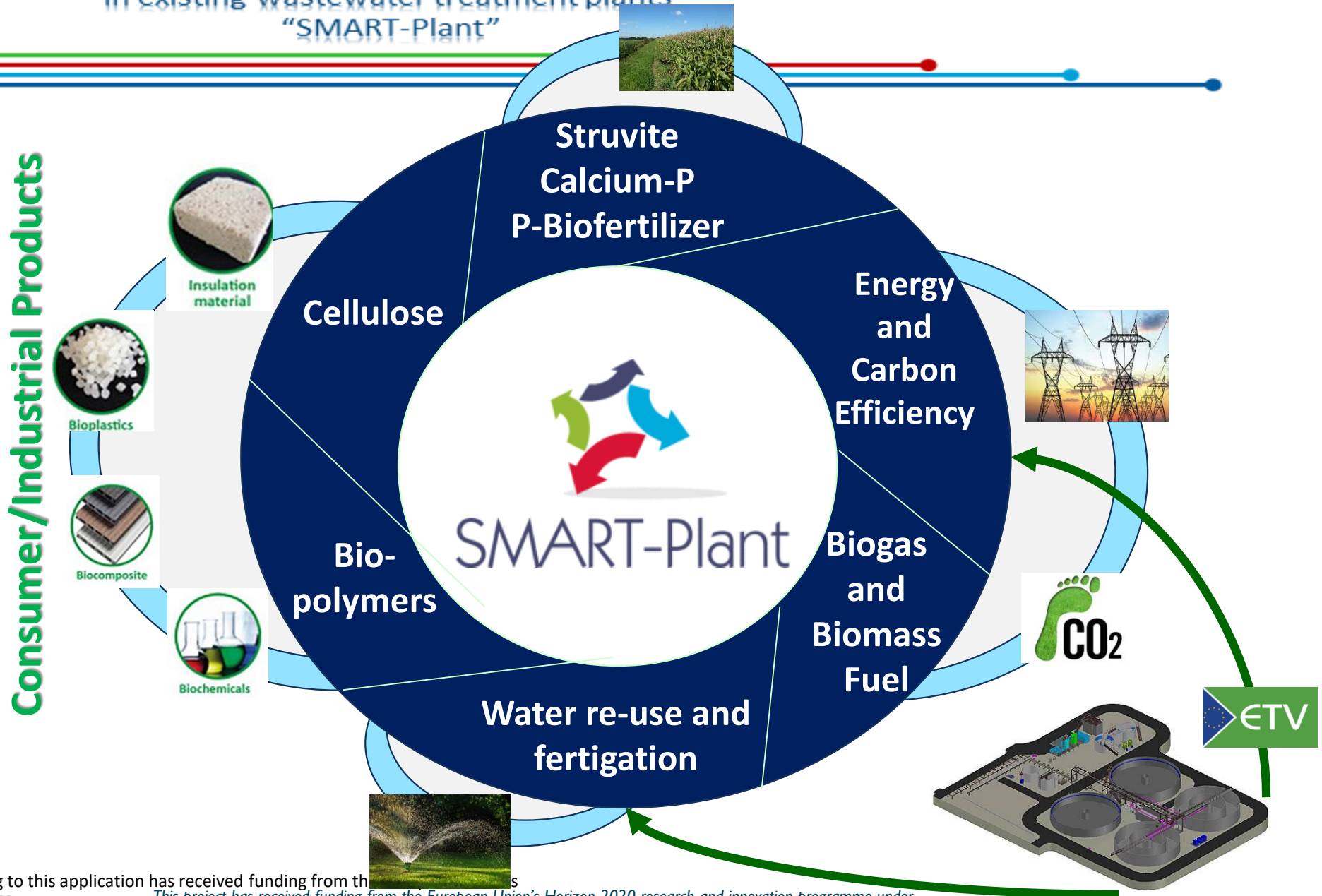


The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

Methane Yield: 0.12-0.15 m³ CH_4/kg oDM

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

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 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

4

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









Aim

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

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

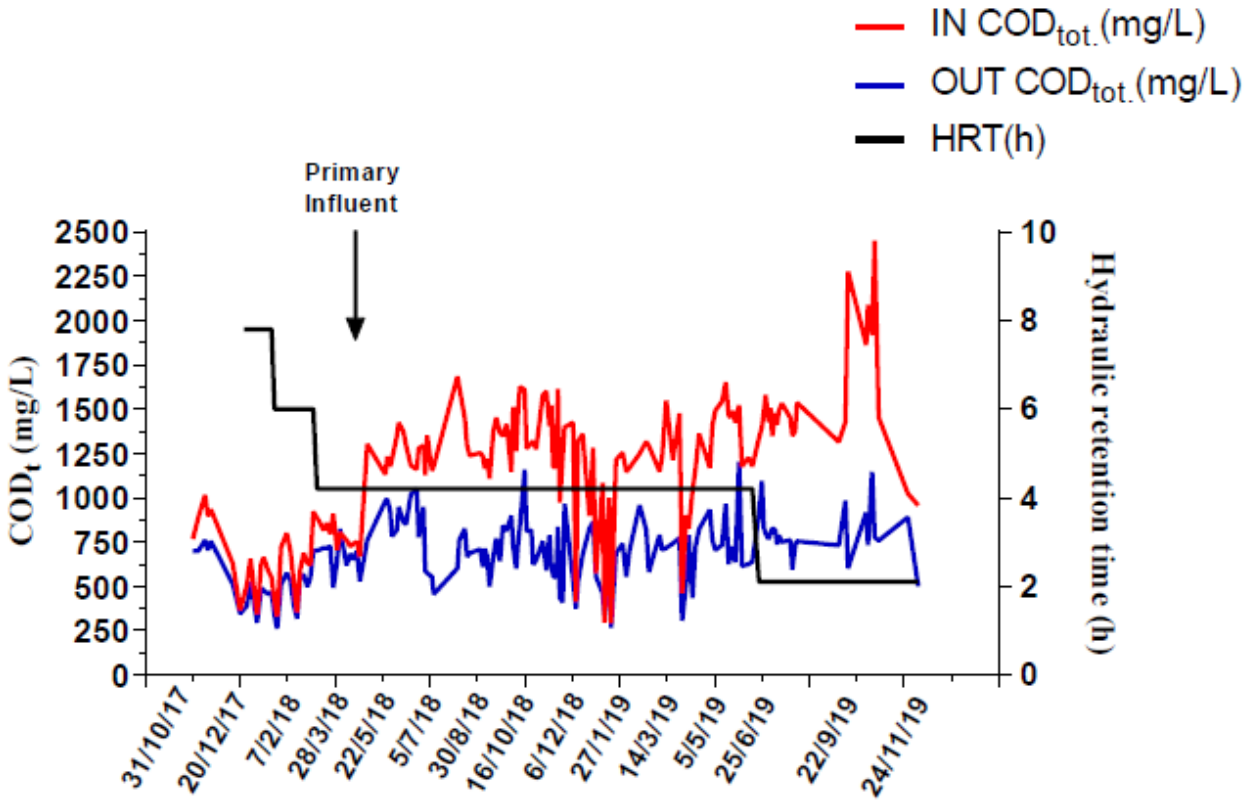
European Commission | Horizon 2020 European Union funding for Research & Innovation

Operation

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

Recovery Efficiency

- 5-10 m³ biogas/day
- 72% CH4%

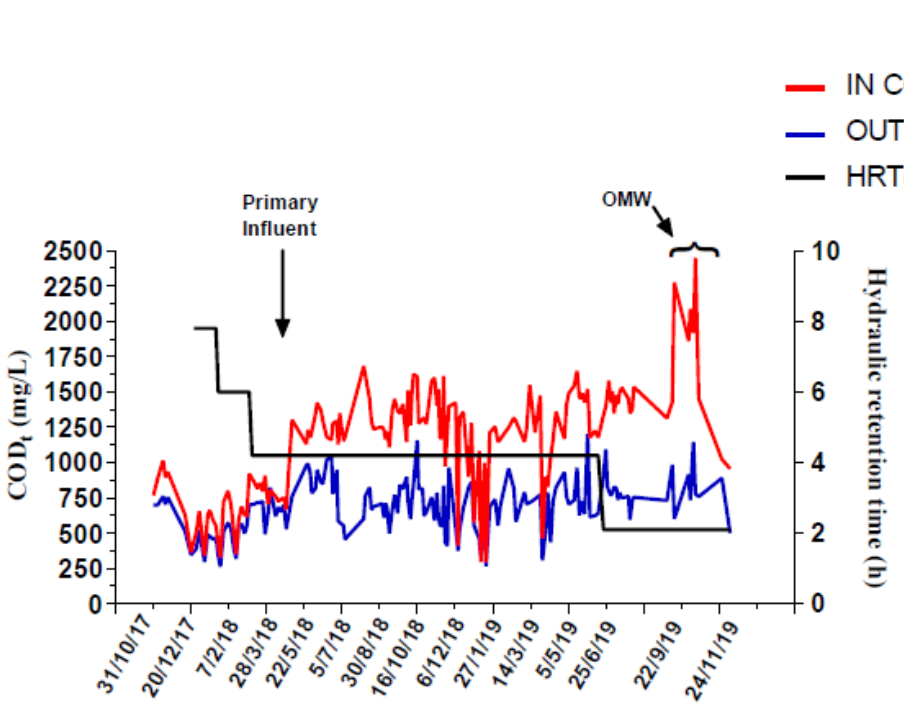


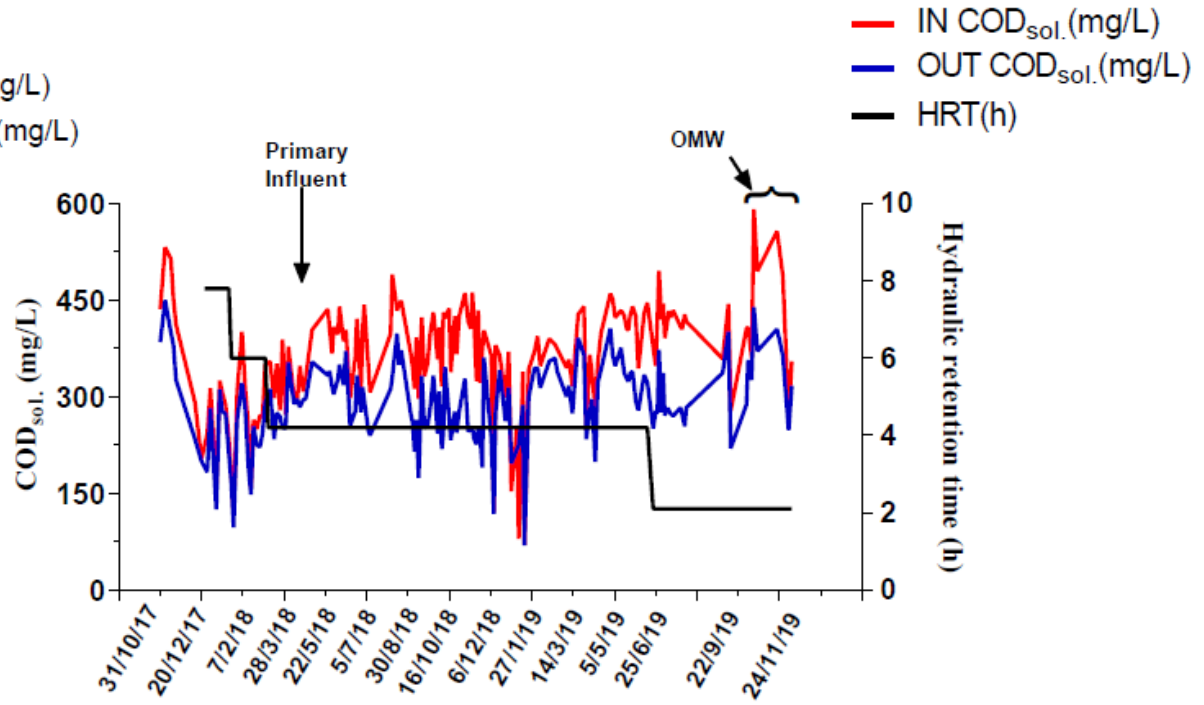
The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318.

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

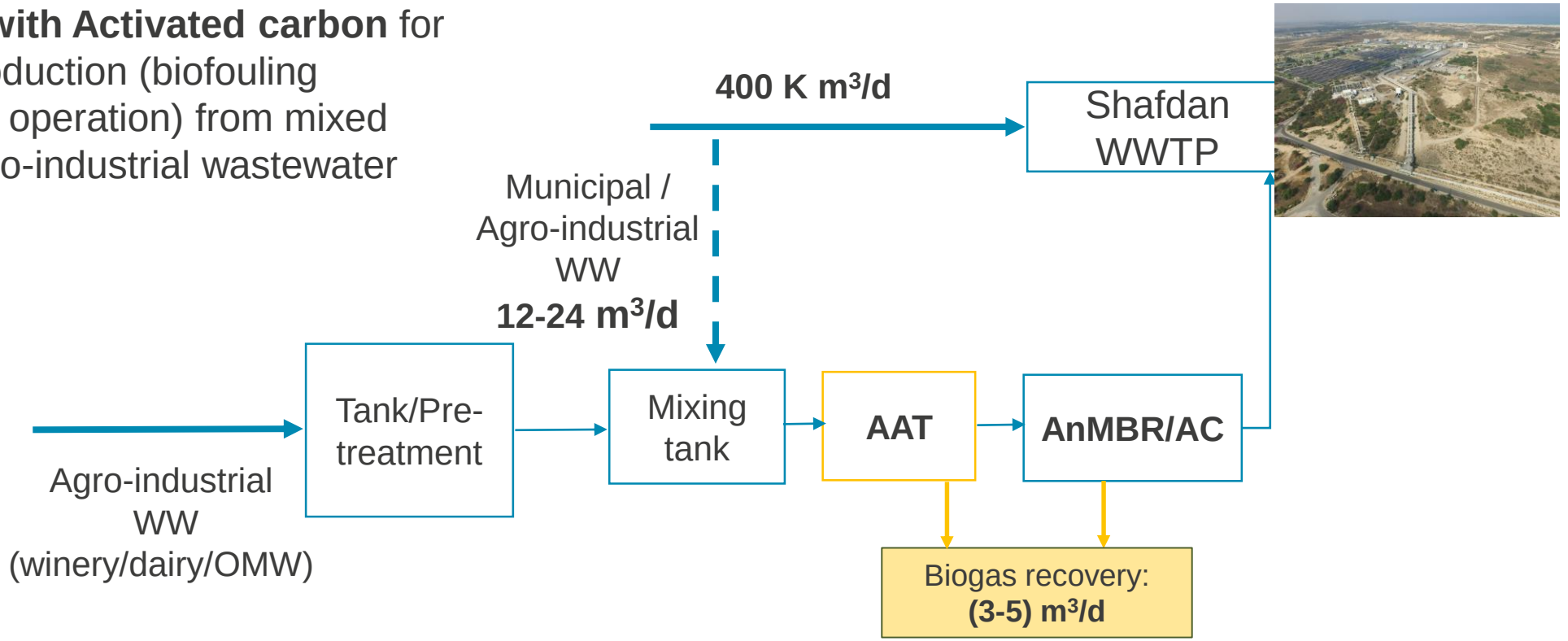
ENERGY - Task 1.3.4

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

Partners: MEKOROT Israel National Water Co., AgRobics, The Galilee Society, Greener than Green TECHNOLOGIES

OBJECTIVE:

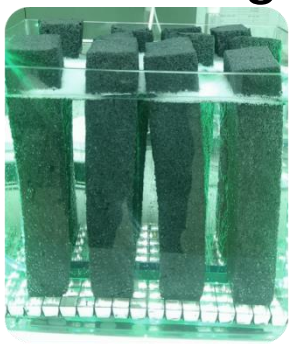
Testing the **efficiency of AnMBR based on AAT combined with Activated carbon** for higher biogas production (biofouling reduction/optimal operation) from mixed domestic and agro-industrial wastewater



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

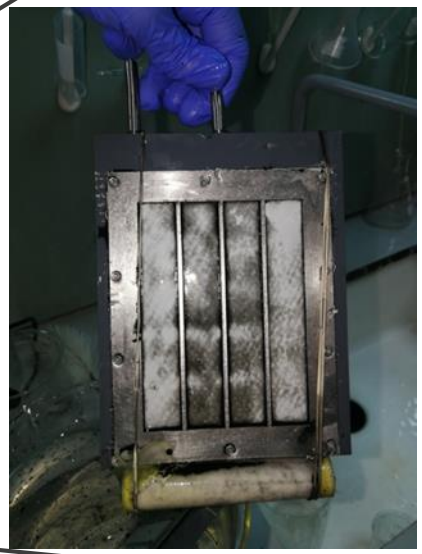
Innovation: The use of immobilized biomass in PAC fixed foam instead of granular biomass offers a promising approach for fouling reduction which is unexplored yet within AnMBR technologies.



IBF

The project leading to this application has received fur
Horizon 2020 research and innovation programme under grant agreement No 869518





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:

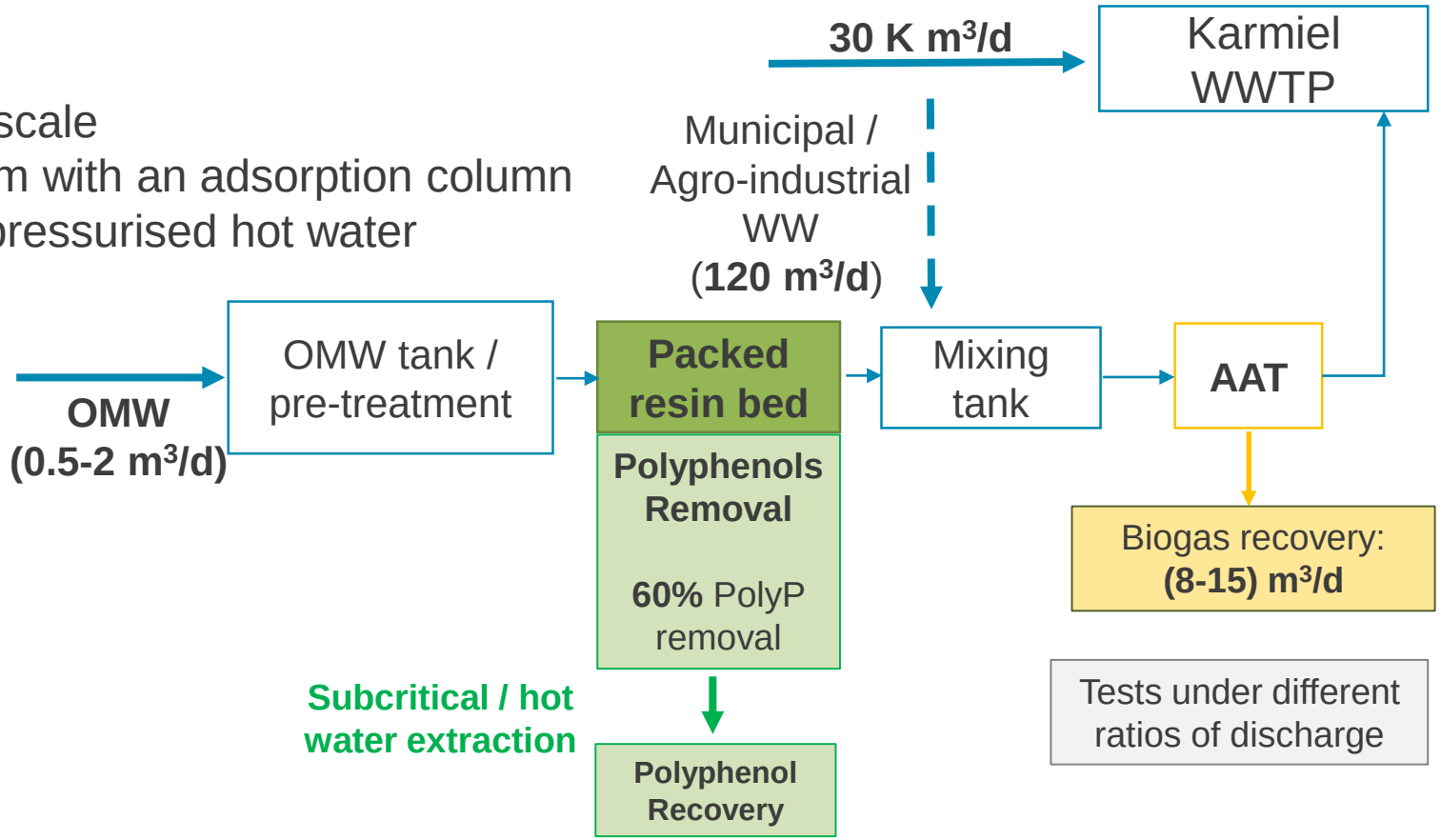
OBJECTIVES:

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





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

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, 30th 2020

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

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

Evaluation and simulation at a pilot-scale system

Isam Sabbah

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

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

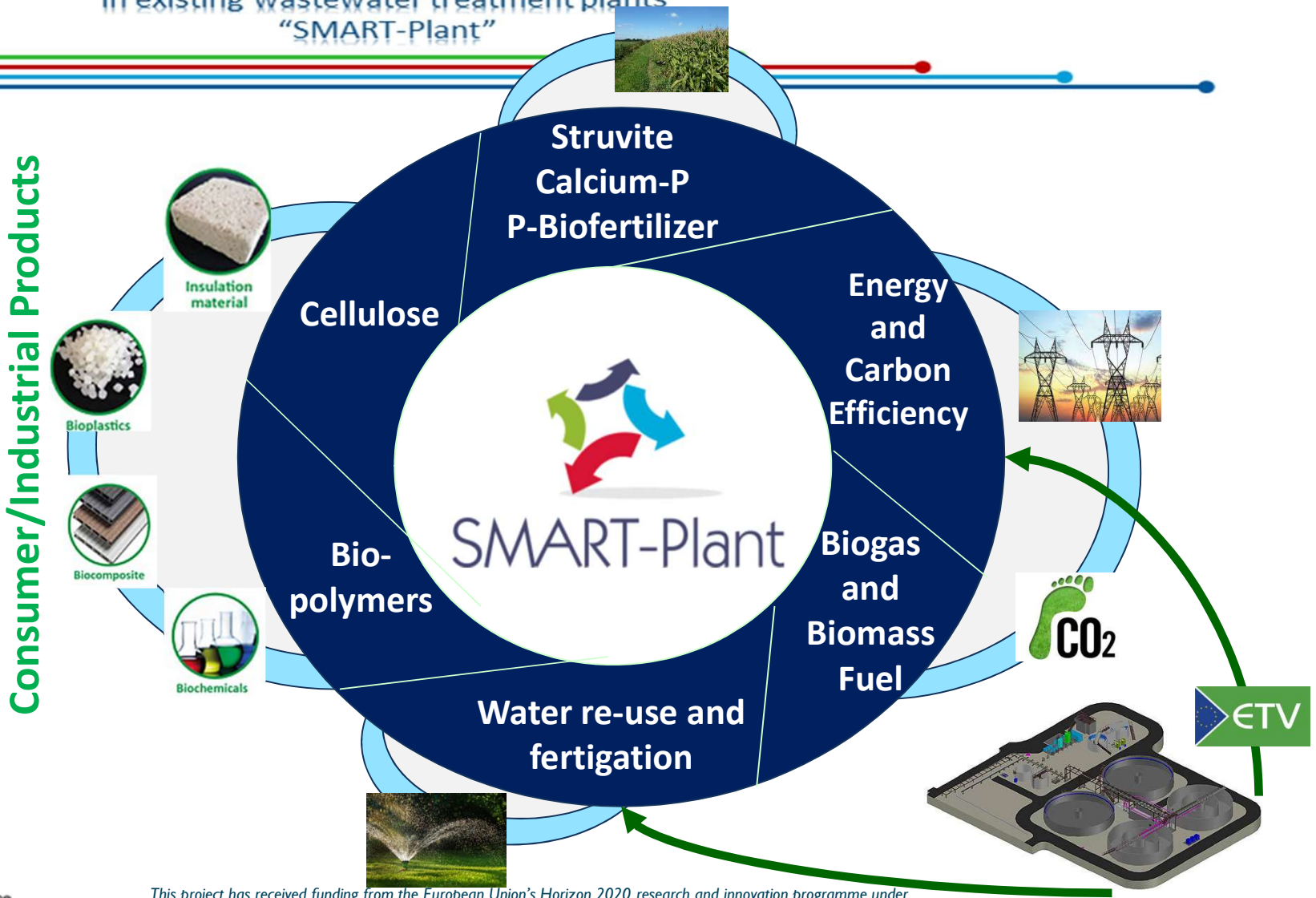
Introduction

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



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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

SMART-Plant

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)



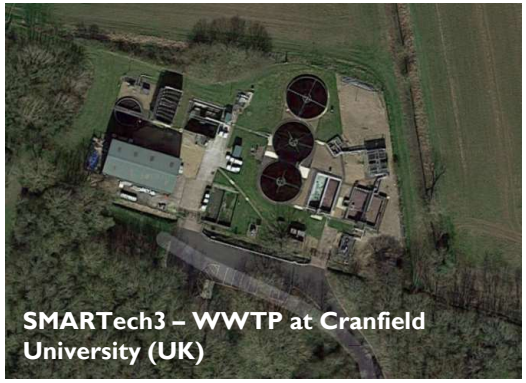
SMARTech1 - Geestmerambacht WWTP (NL)



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 ETV	Cranfield (UK)	Mainstream **tertiary hybrid ion exchange**	**Nutrients**
Sidestream	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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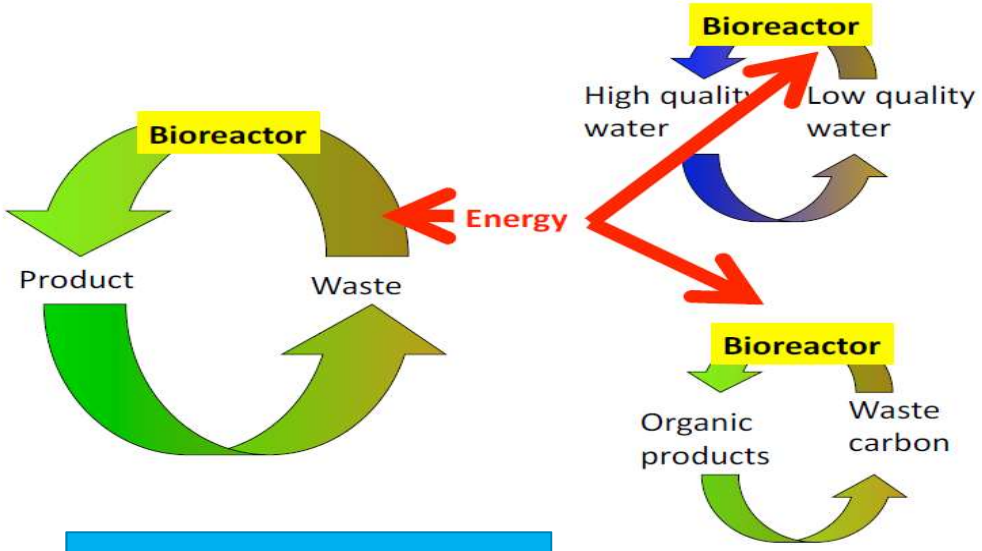
Circular Economy:

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)

Co-f... of the European Union

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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SMART

Anaerobic Waste Treatment Fundamentals

Public Work 1964

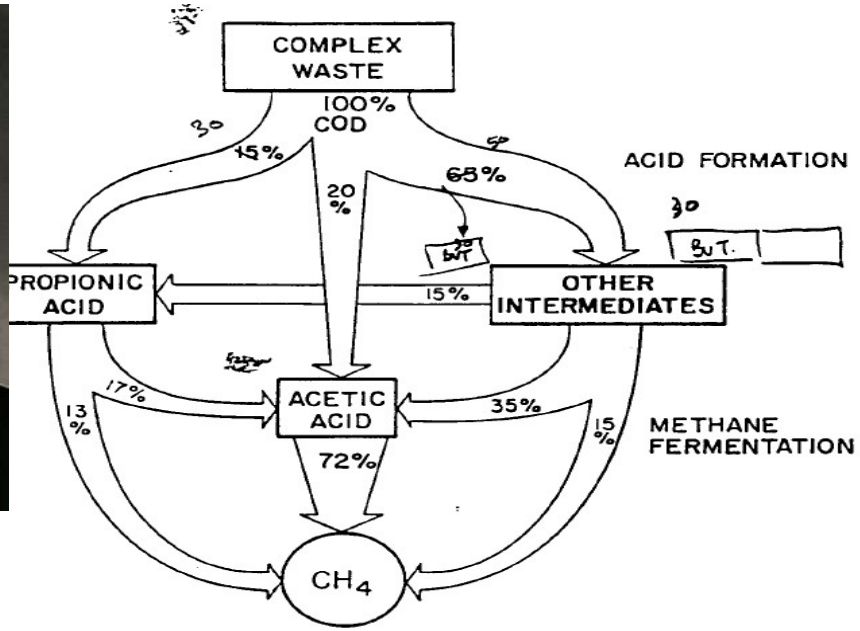
PART ONE | Chemistry and Microbiology

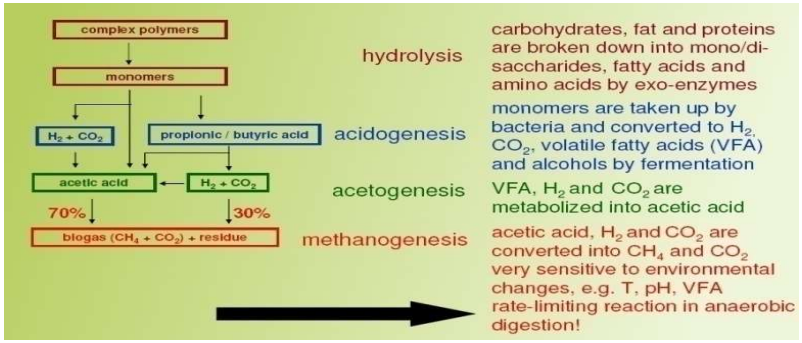
PERRY L. McCARTY
Associate Professor of Sanitary Engineering
Stanford University

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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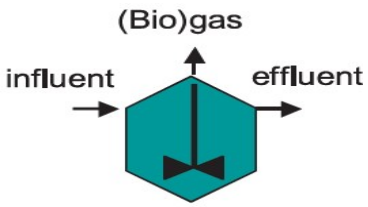
High-rate anaerobic systems

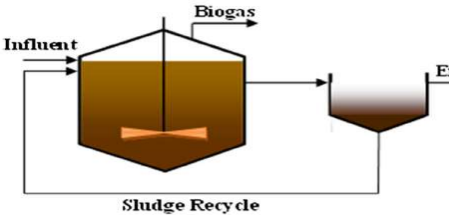
1955 (Schroepfer et al., 1955)

CSTR



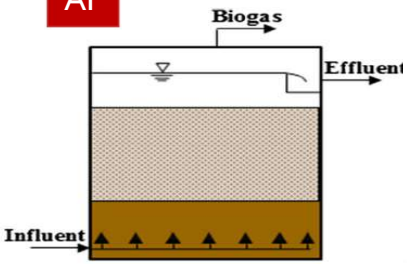
Relative capacity: 1

ACP



1960s Young & McCarty 1966)

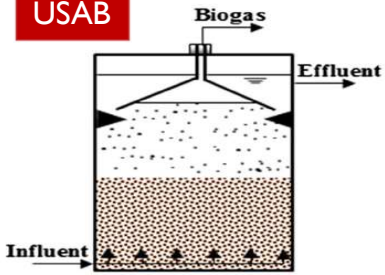
AF



Relative capacity: 5

1970s & Lettinga

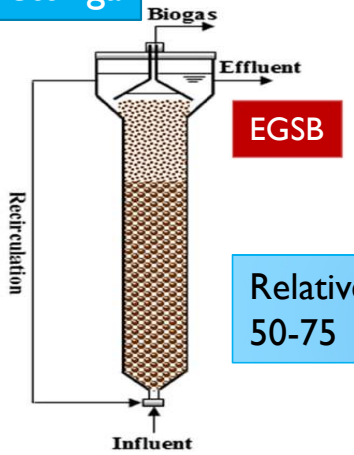
USAB



Relative capacity: 25

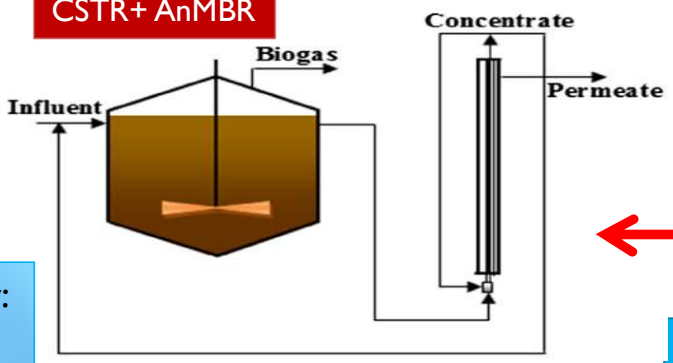
1980s Lettinga

EGSB



Relative capacity: 50-75

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





SMARTech2a – Karmiel WWTP (IL)

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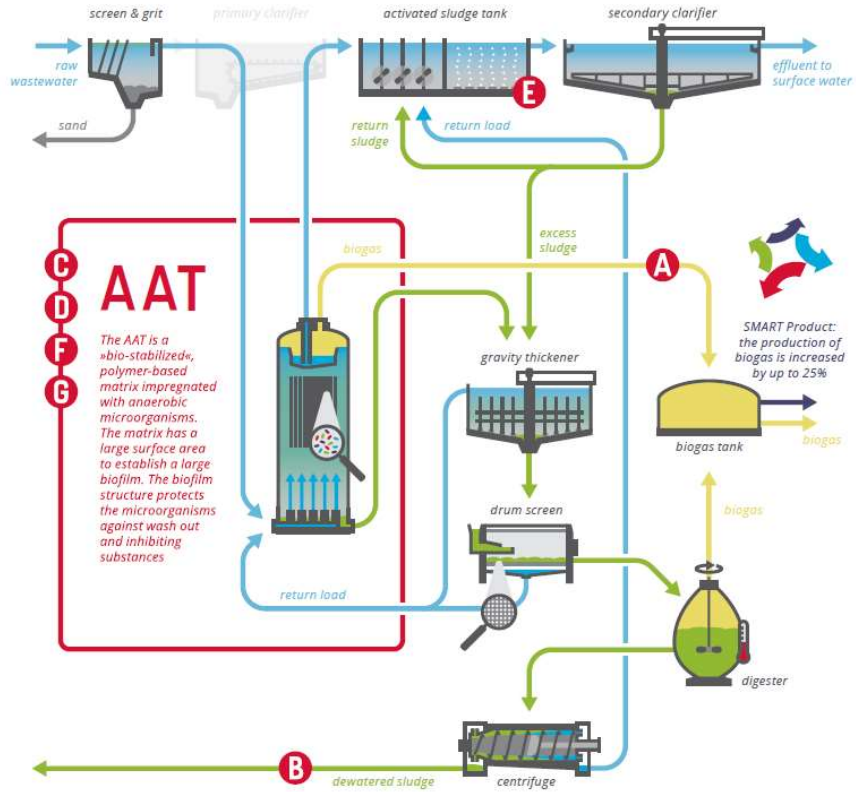
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 690323

SMART-Plant Approach



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SMARTech 2a – *Mainstream polyurethane-based anaerobic biofilter with biogas recovery*

WWTP – Karmiel, Israel









ETV

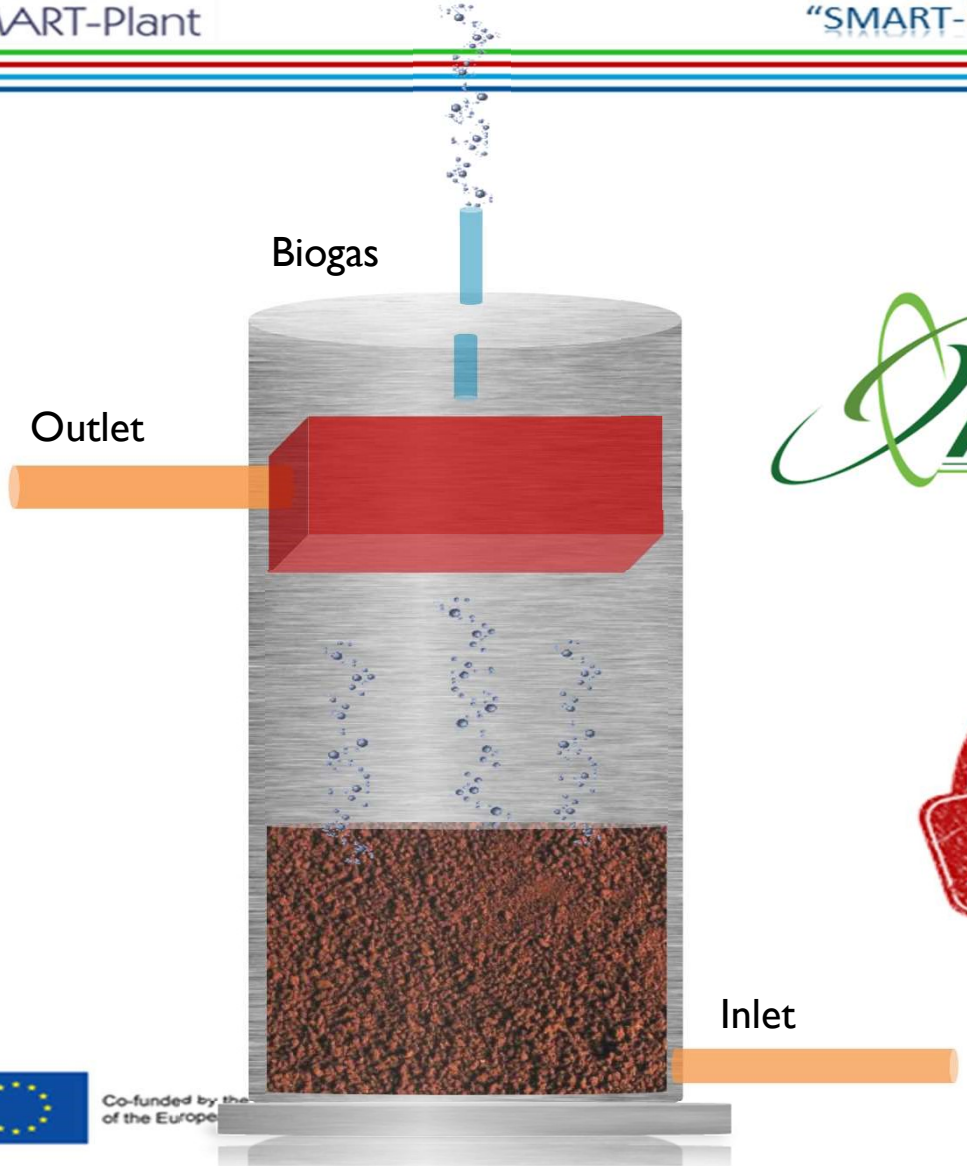
Aim

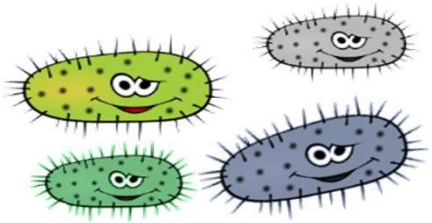
Reduced **loads of COD and TSS** on the biological treatment system → Energy-efficient water reuse; **Biogas** production.

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

SMART-Plant

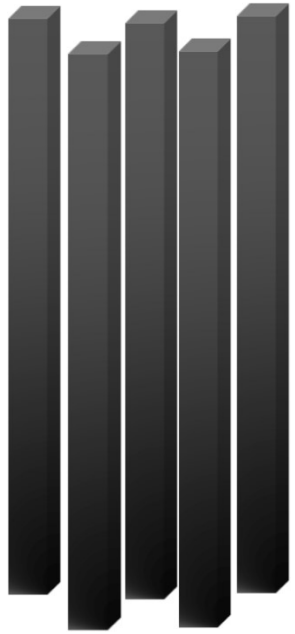
Scale-up of low-carbon footprint material recovery techniques
in existing wastewater treatment plants
"SMART-Plant"





AgRobics





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of the Europe

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

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.*

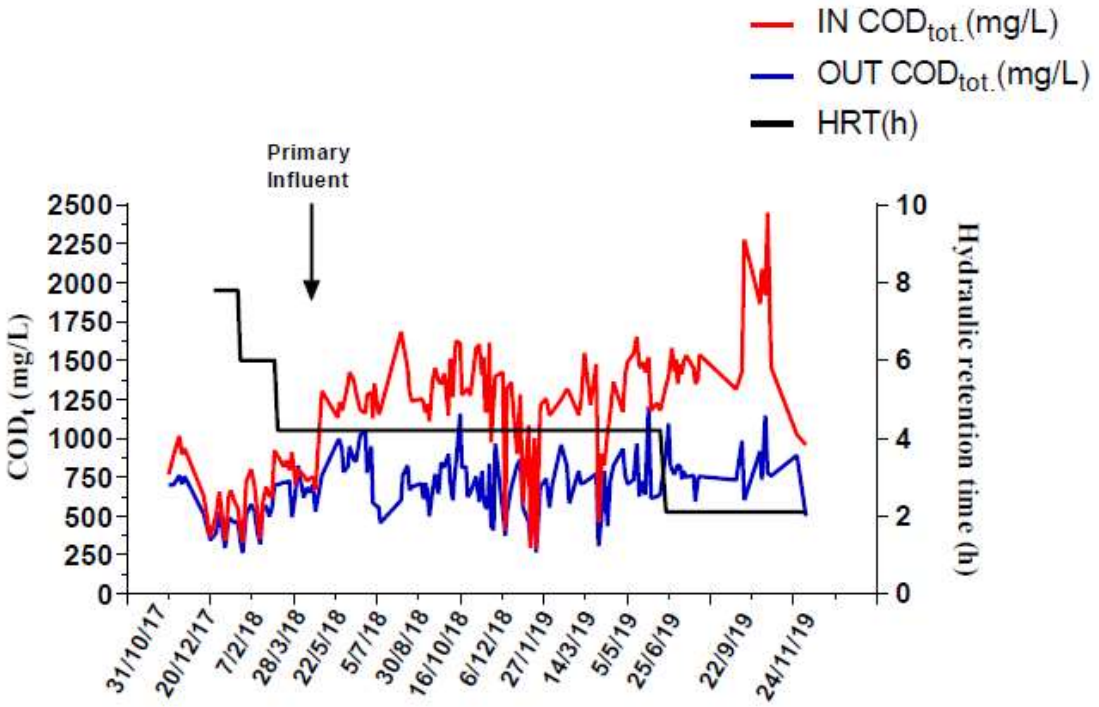
European Commission | Horizon 2020 European Union funding for Research & Innovation

Operation

- 240 m^3/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

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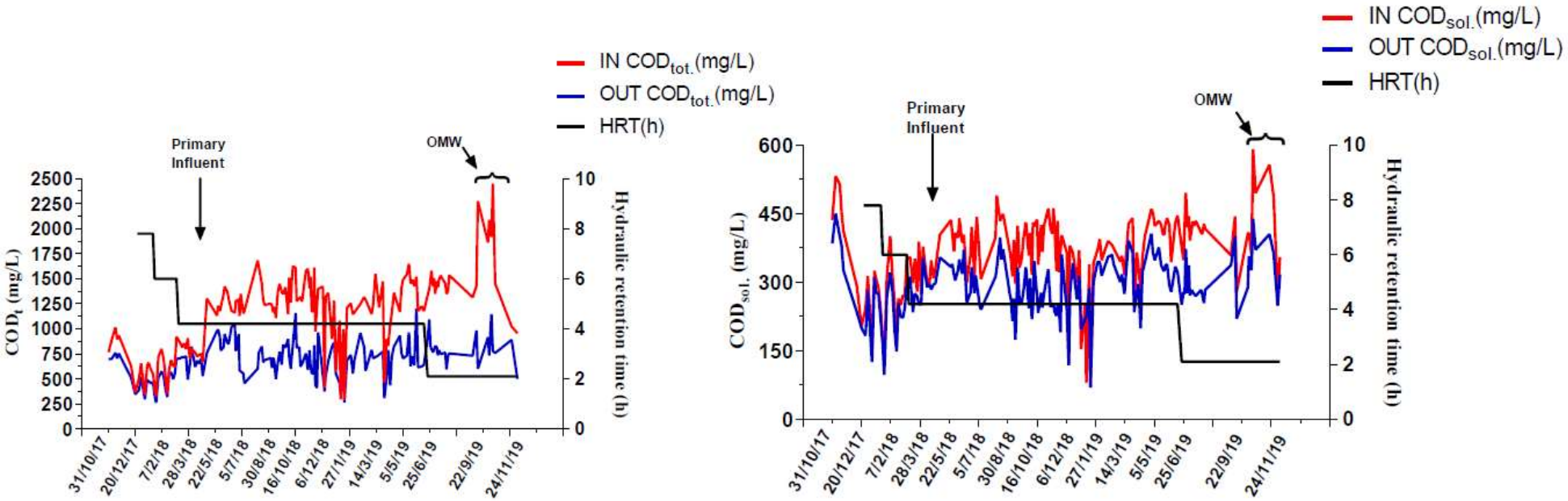
Shaving the peaks



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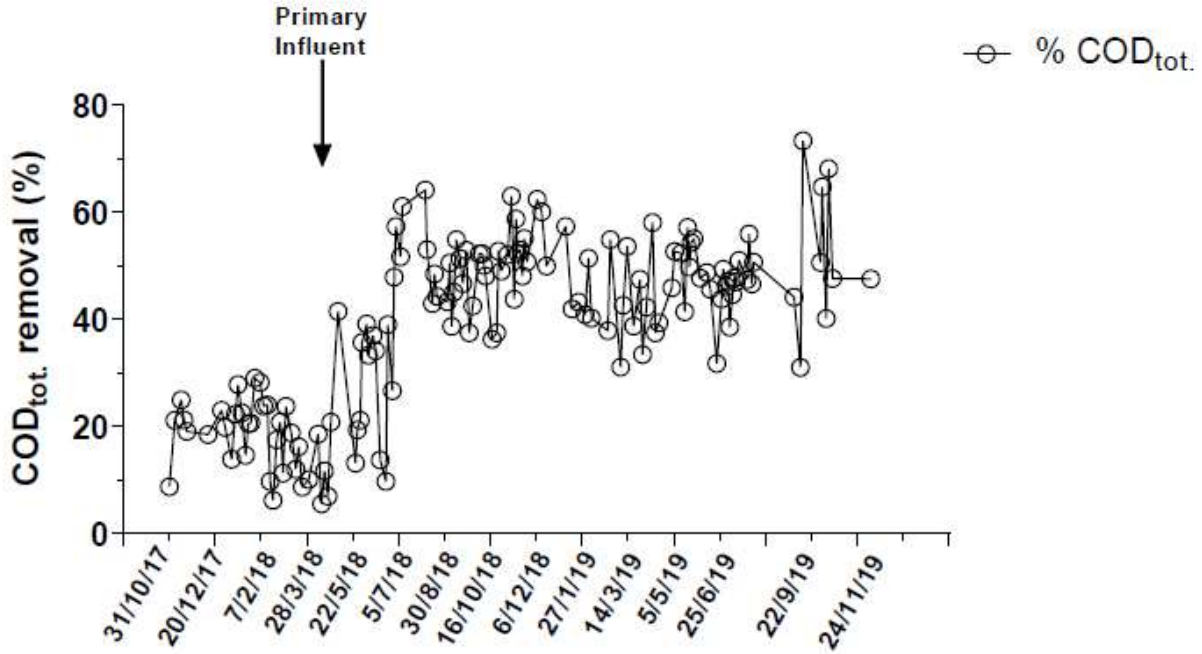

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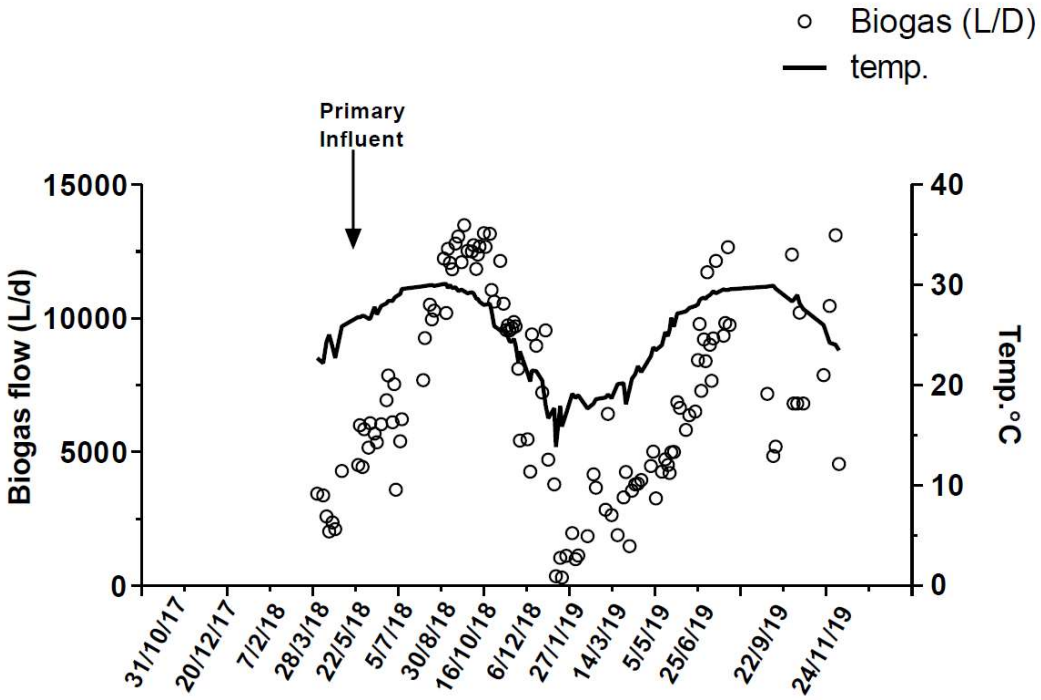

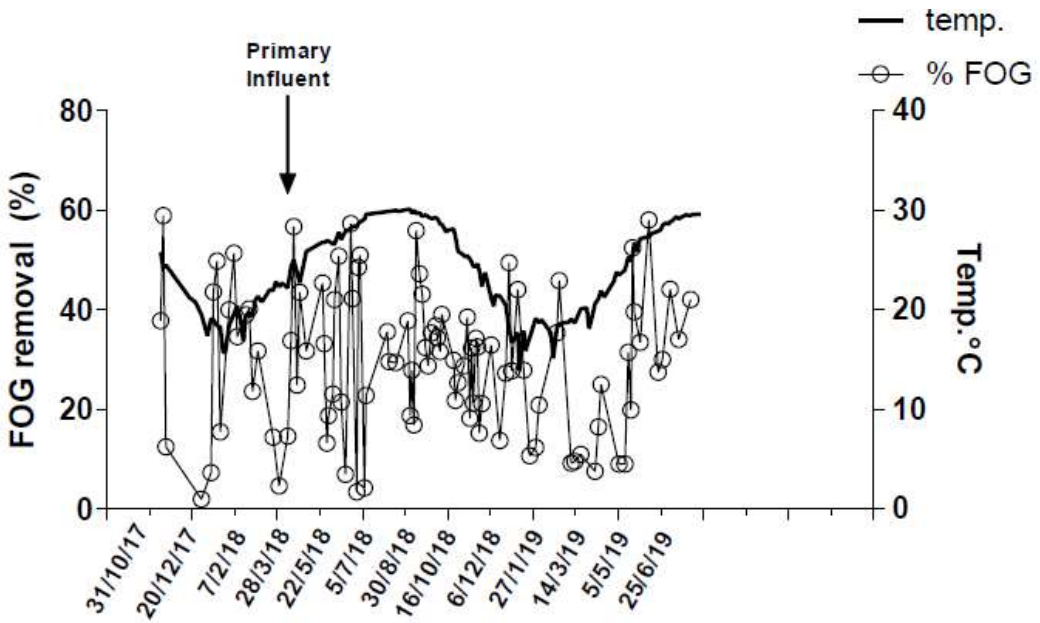

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Material and Methods – *Mainstream polyurethane-based anaerobic biofilter with biogas recovery* WWTP – Karmiel, Israel

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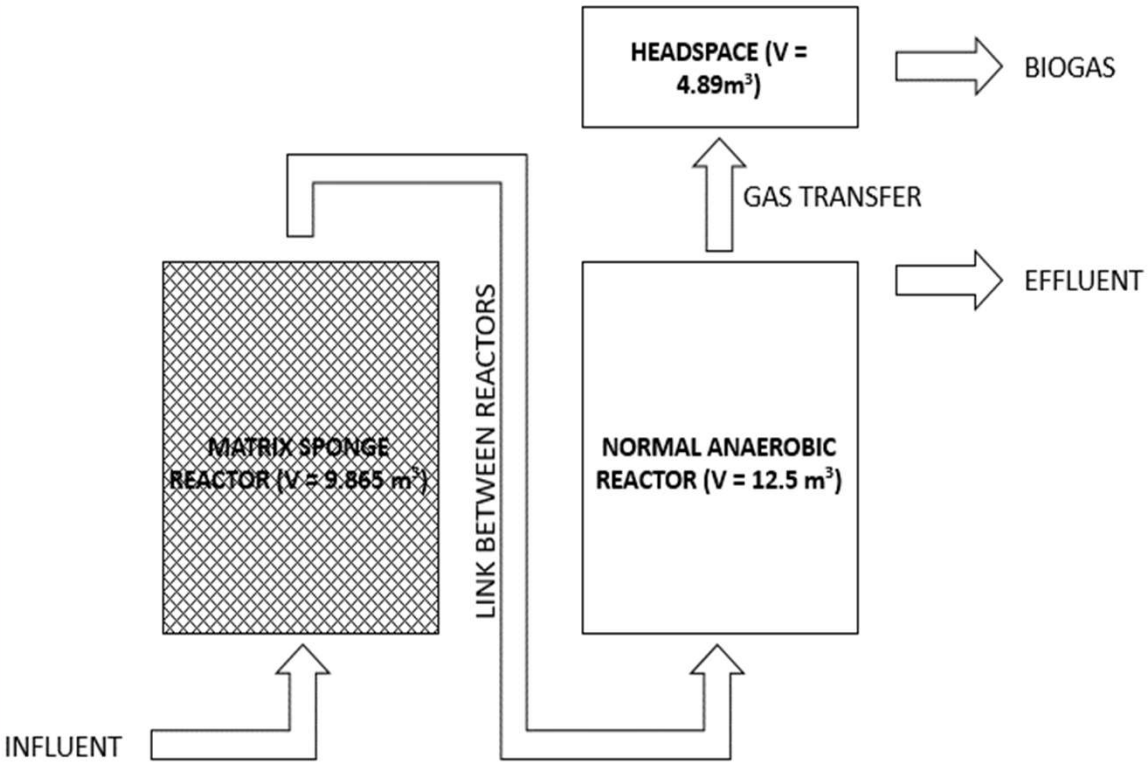
Modelling approach – *Mainstream polyurethane-based anaerobic biofilter with biogas recovery* WWTP – Karmiel, Israel



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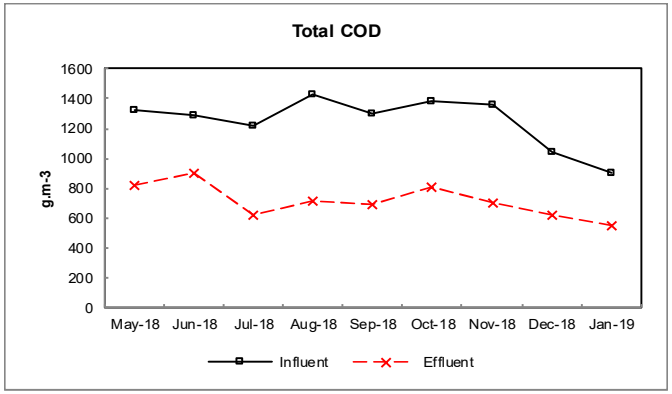
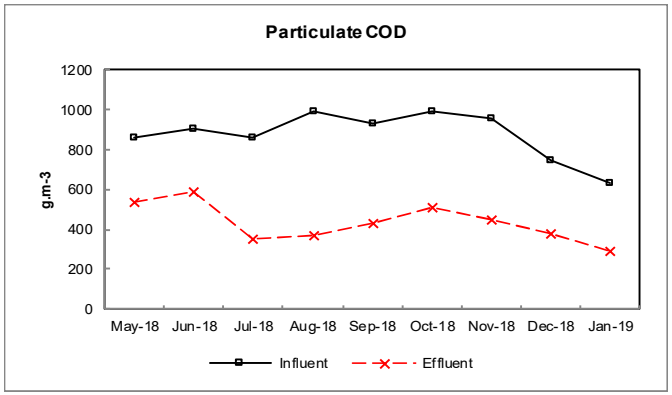
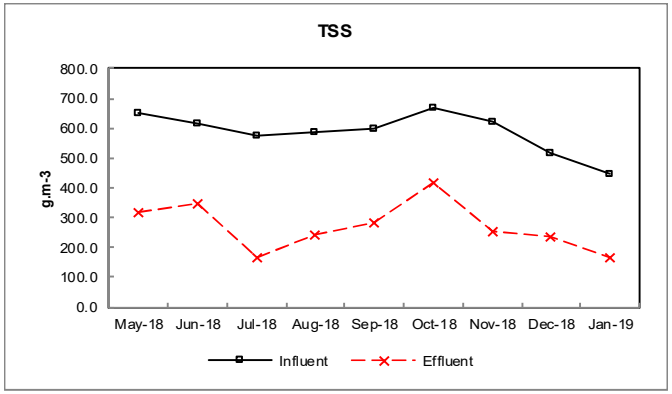
2nd Scenario (steady-state operation without PC) – *Mainstream polyurethane-based anaerobic biofilter with biogas recovery* WWTP – Karmiel, Israel

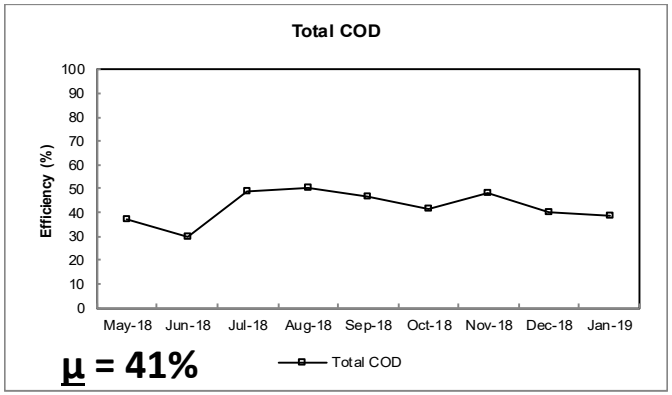
Concentration



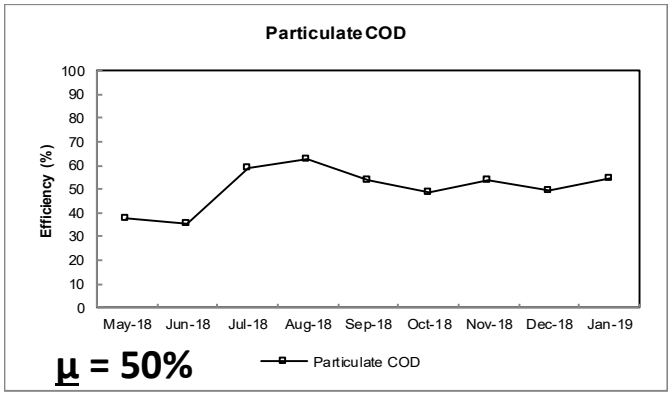




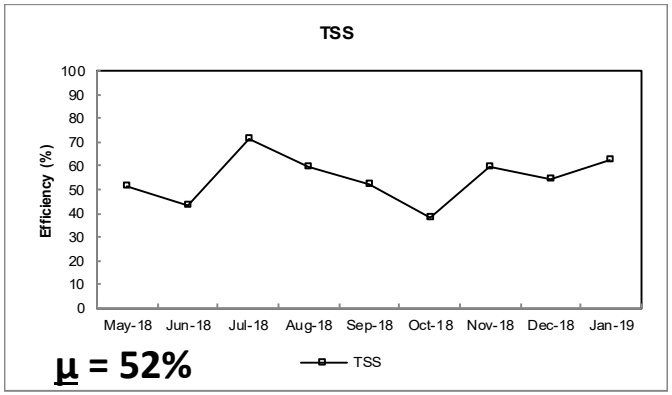
Removal efficieny



μ = 41%



μ = 50%



μ = 52%

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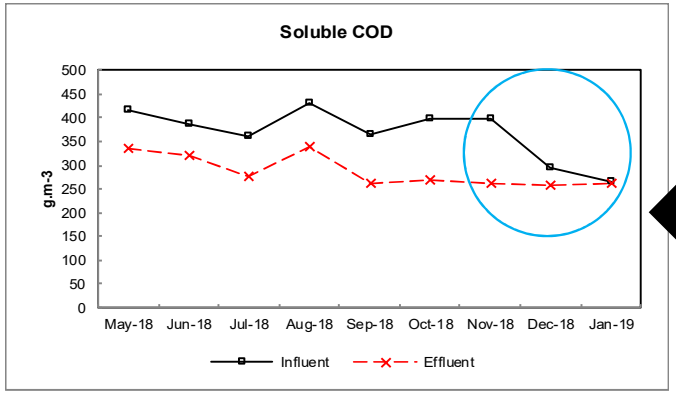
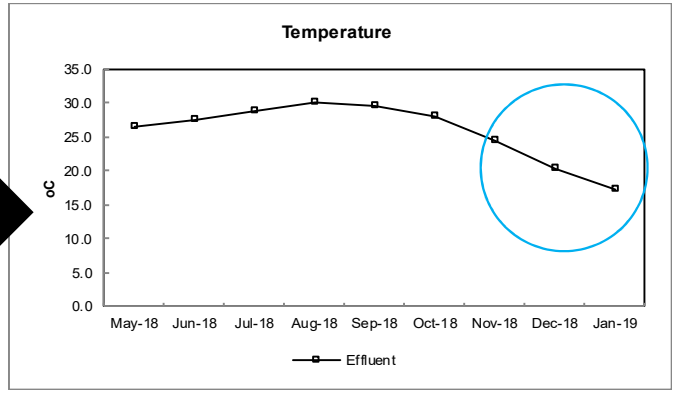
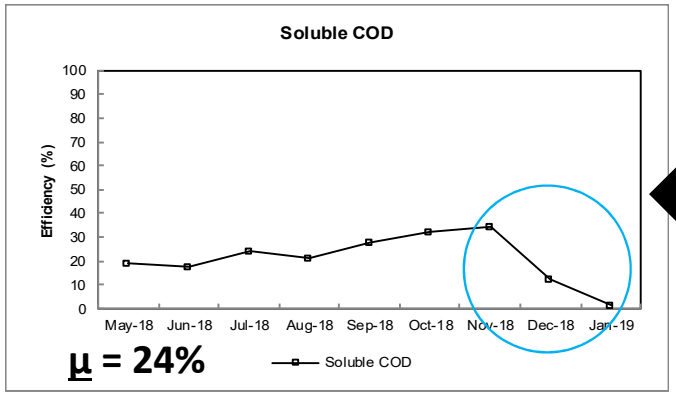
2nd Scenario (steady-state operation without PC) – *Mainstream polyurethane-based anaerobic biofilter with biogas recovery* WWTP – Karmiel, Israel

Concentration

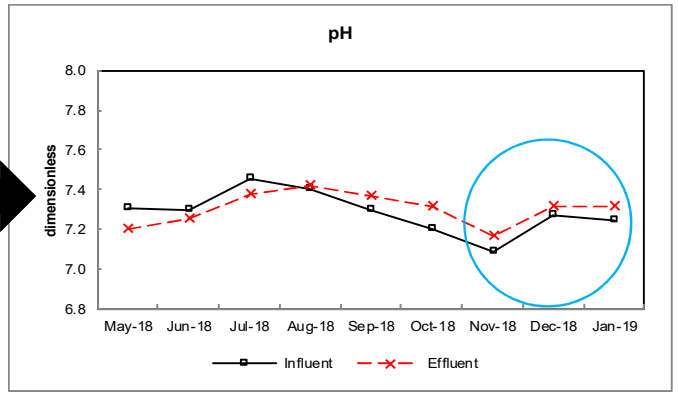




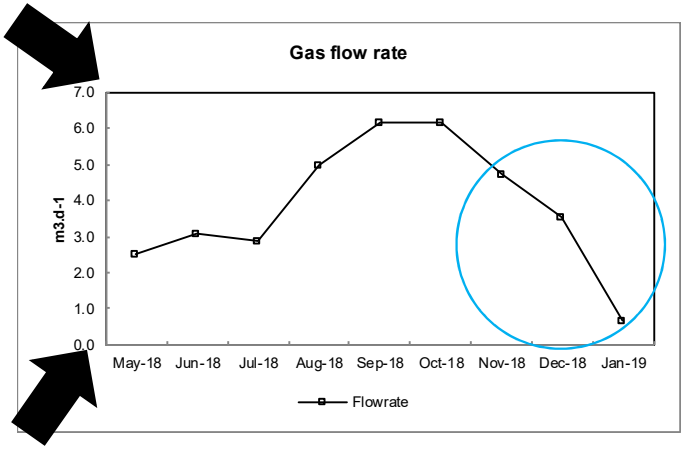
Removal efficieny



μ = 24%



High production during hot months



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

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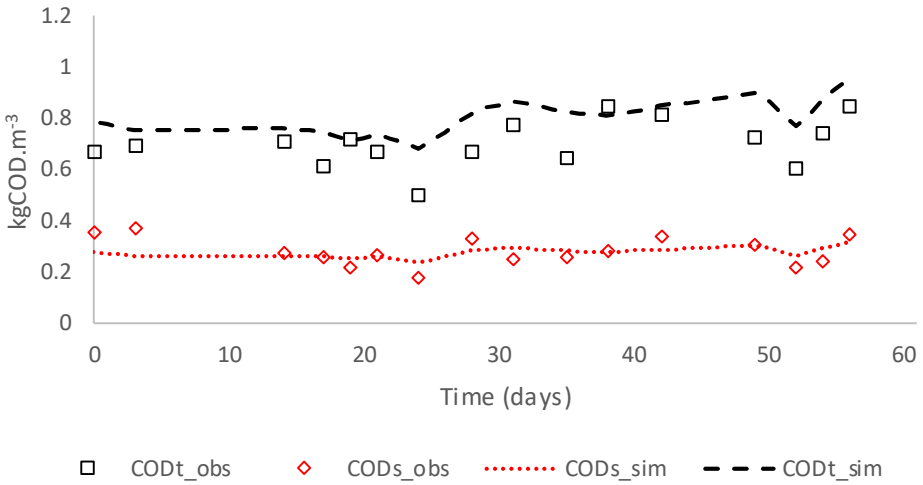
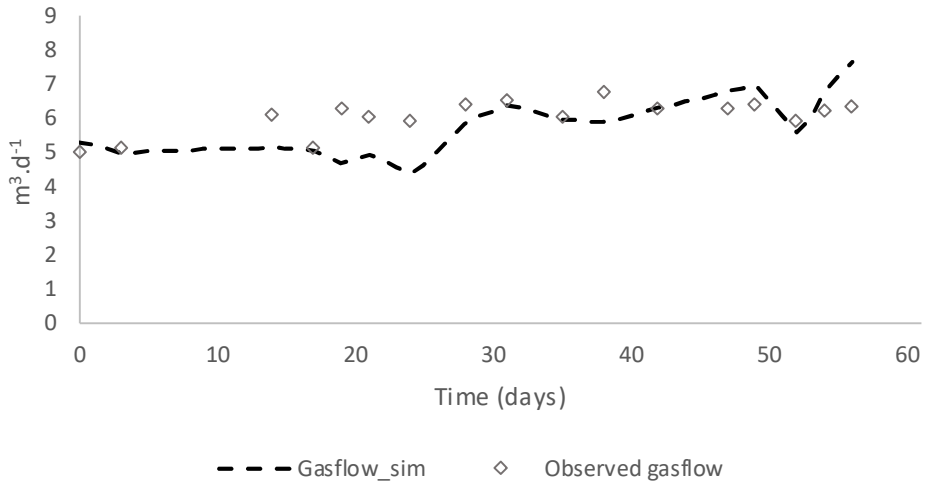
Model Calibration – *Mainstream polyurethane-based anaerobic biofilter with biogas recovery* WWTP – Karmiel, Israel

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

COD EFFLUENT



TOTAL GAS FLOW (HEADSPACE)



Variable	NRMSD
COD_t	0.178
COD_s	0.176
Gas flow	0.133

Good fit to the experimental data → relatively low NRMSD

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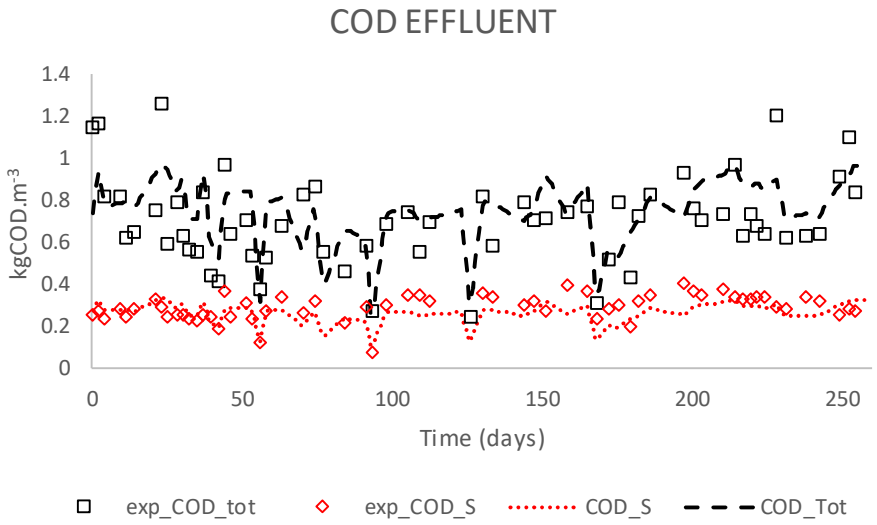
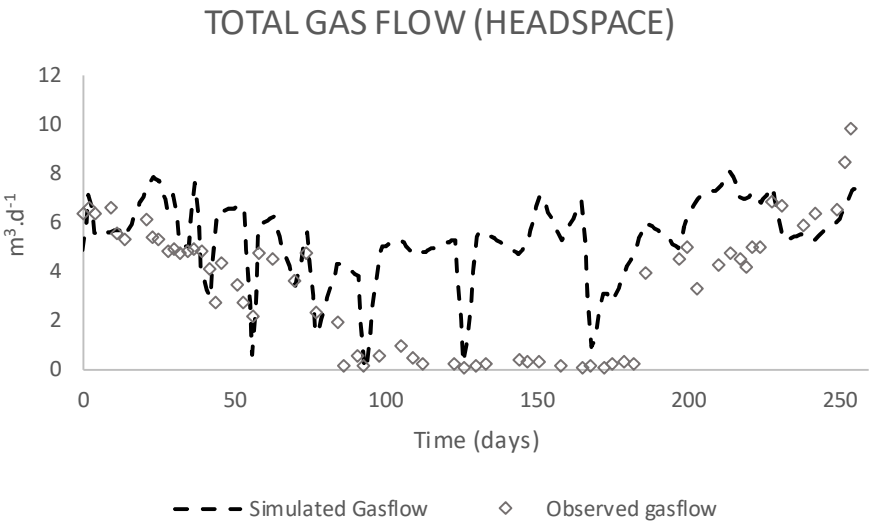
Model Validation – *Mainstream polyurethane-based anaerobic biofilter with biogas recovery*

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.

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

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Framework Programme
of the European Union

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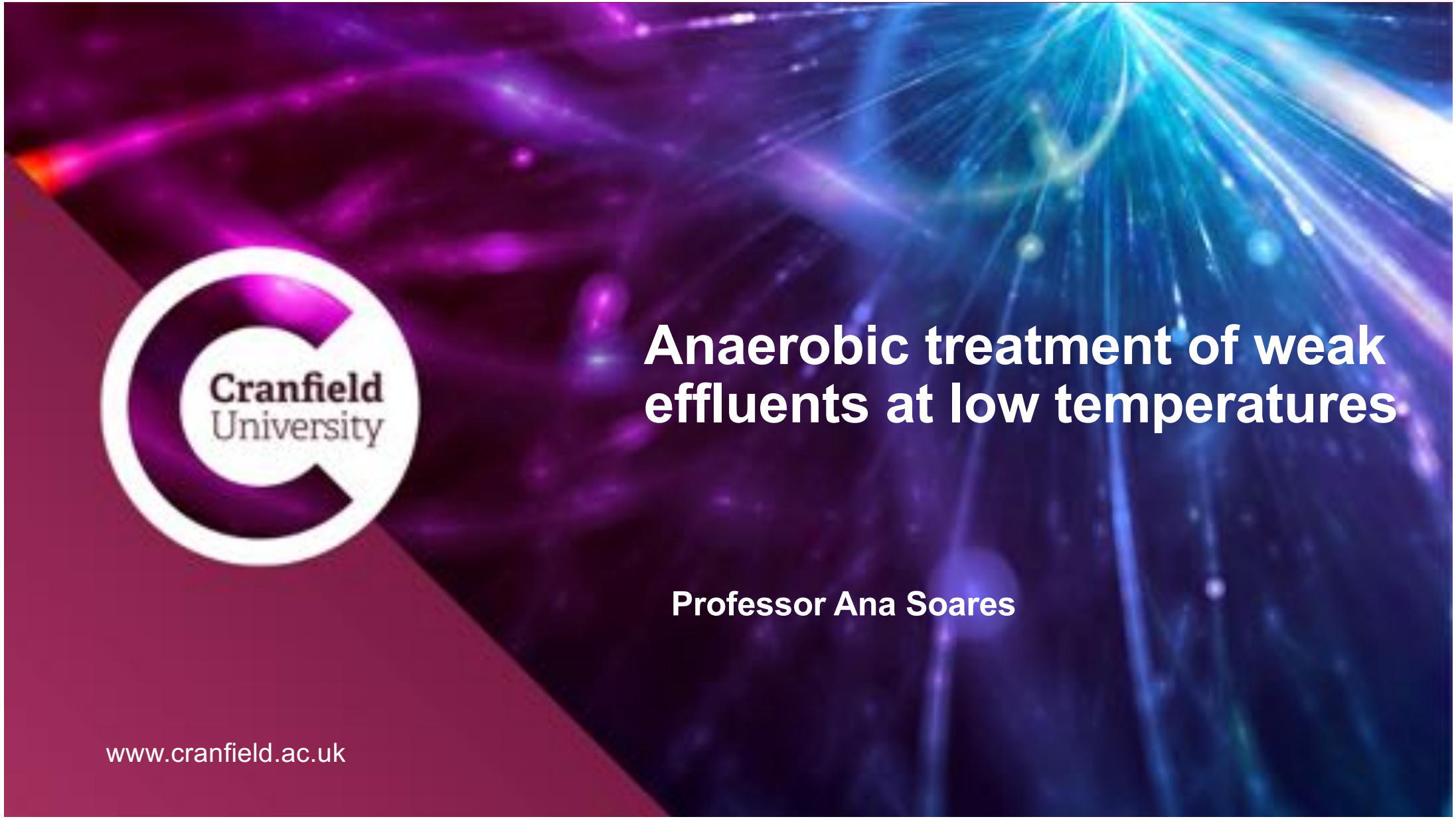
Thank you

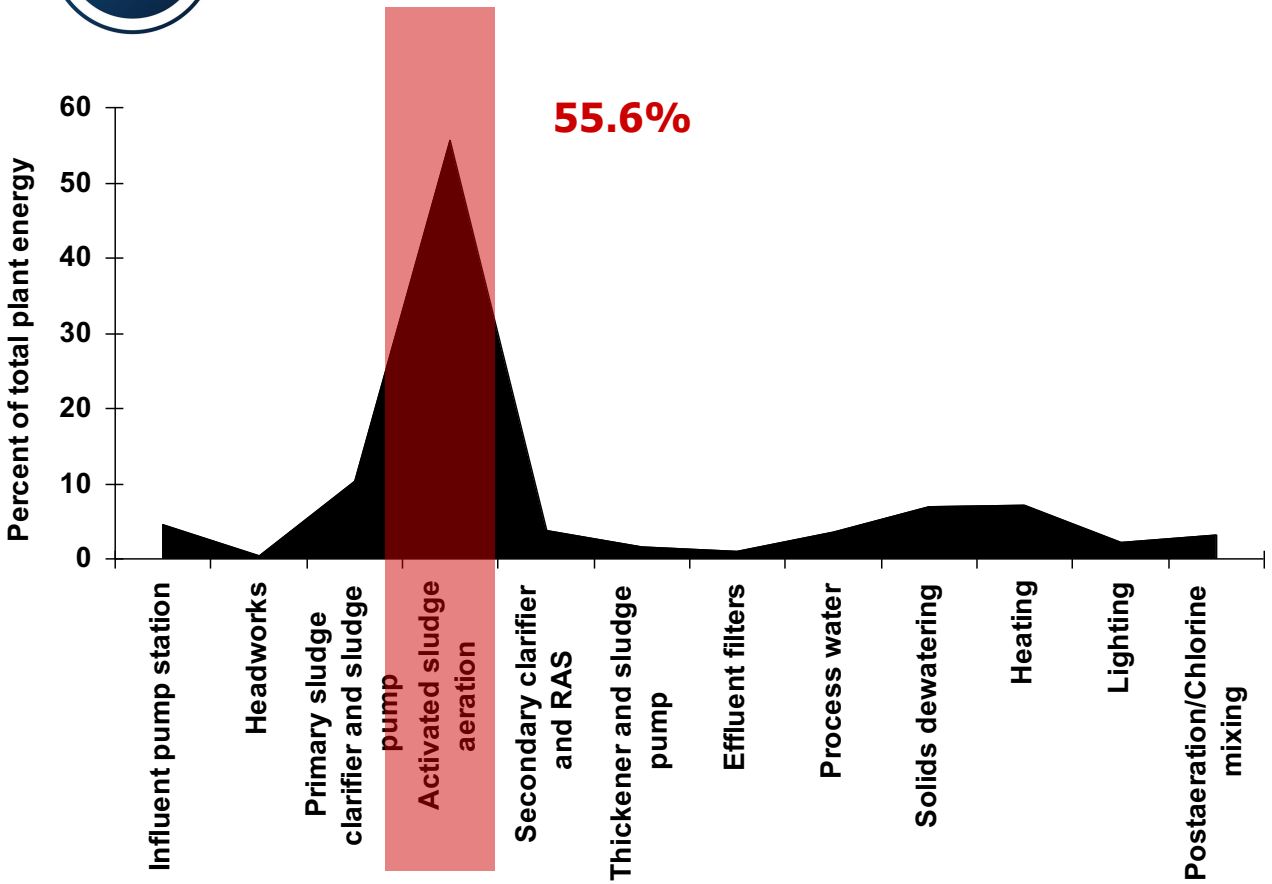


Anaerobic treatment of weak effluents at low temperatures

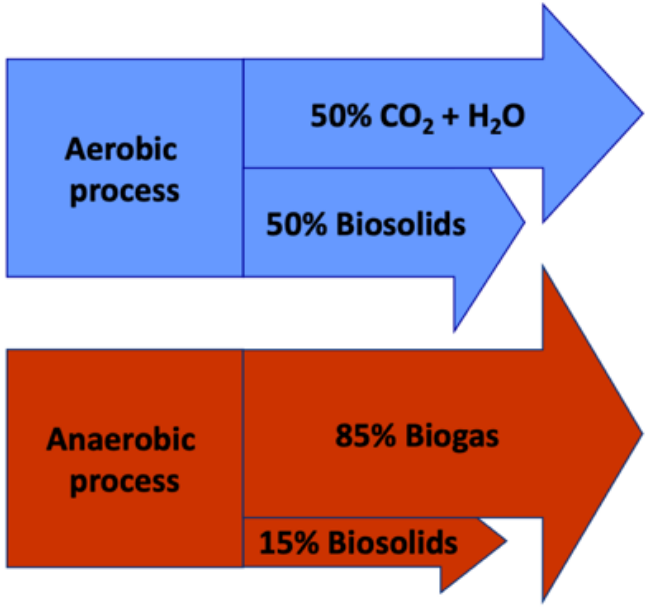
Professor Ana Soares

www.cranfield.ac.uk

Power consumption in wastewater treatment plants

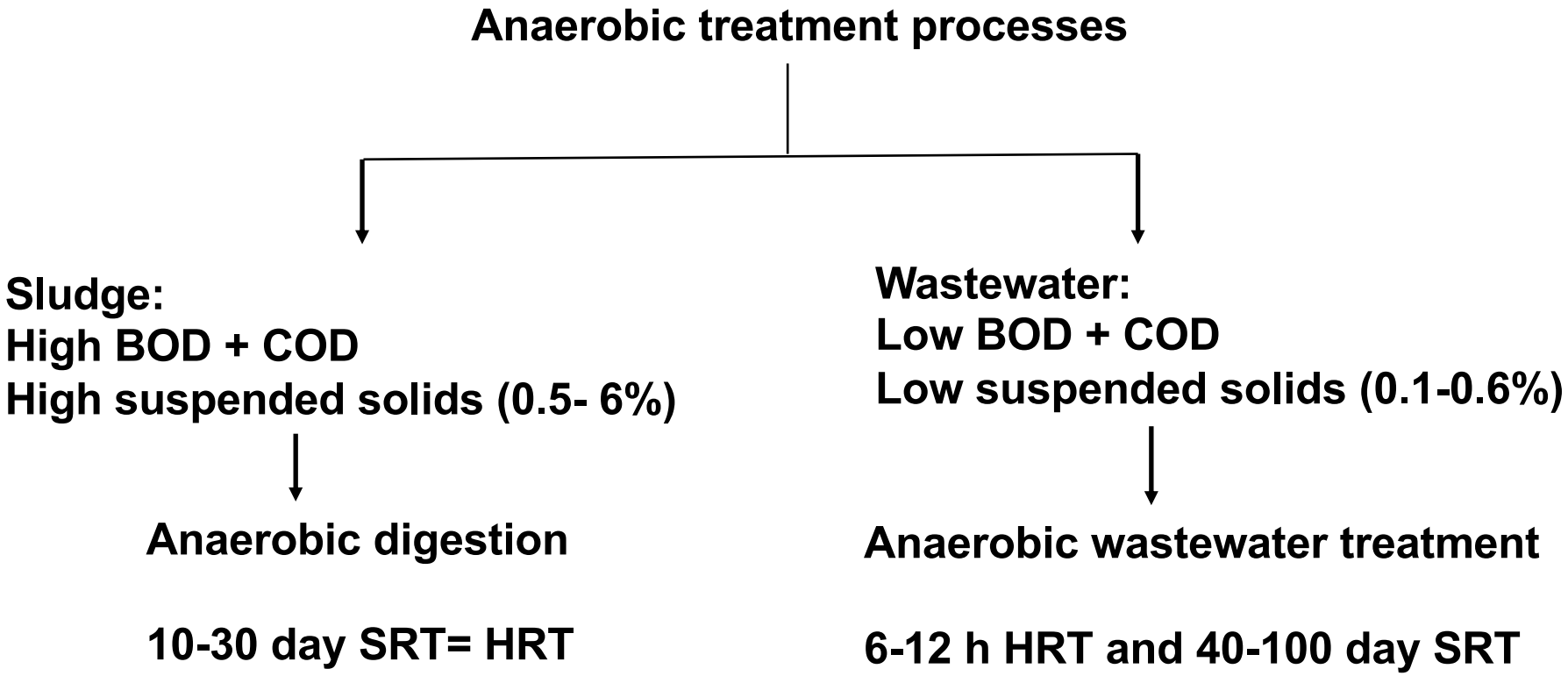


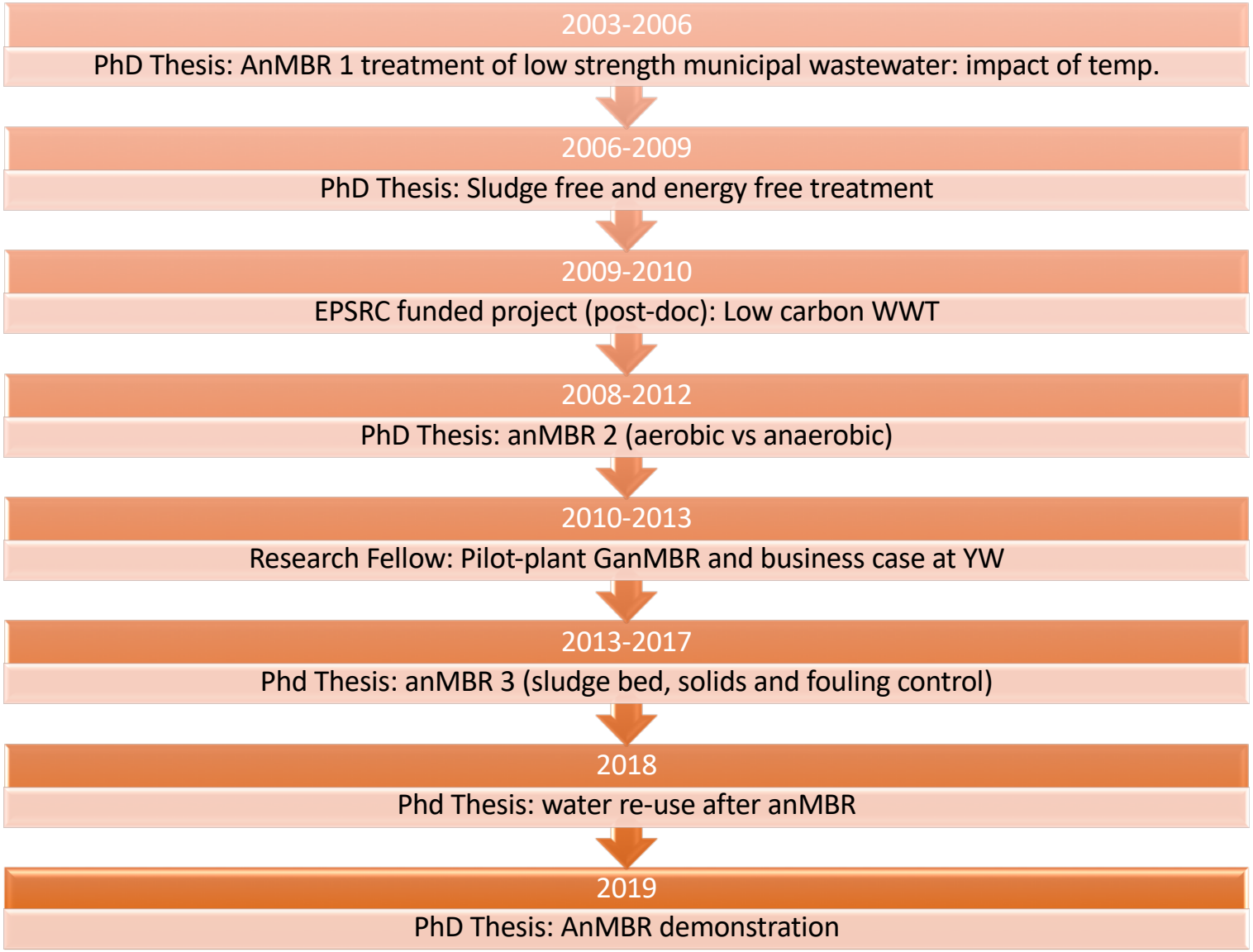
Anaerobic vs. aerobic wastewater treatment



*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

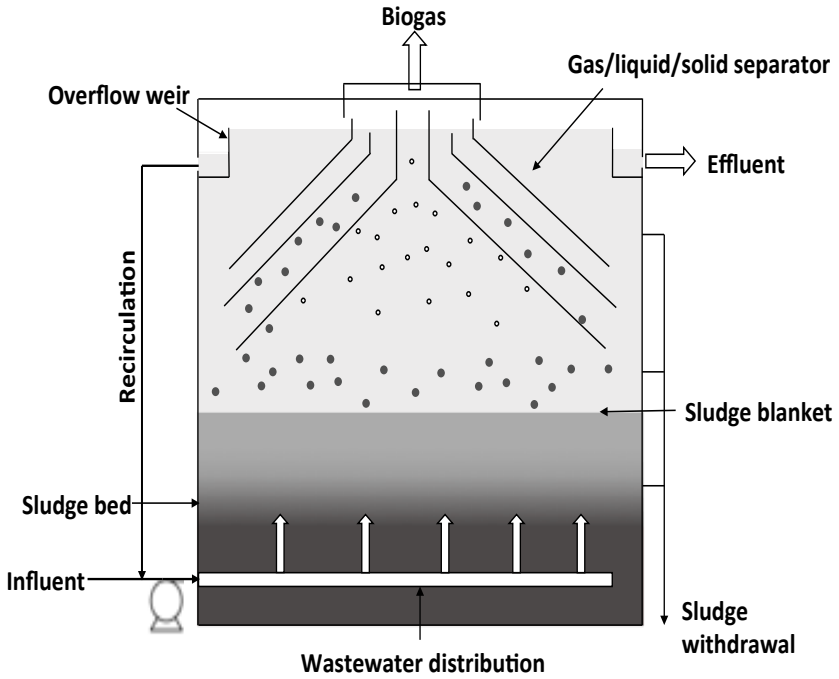
Anaerobic digestion vs anaerobic treatment




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)

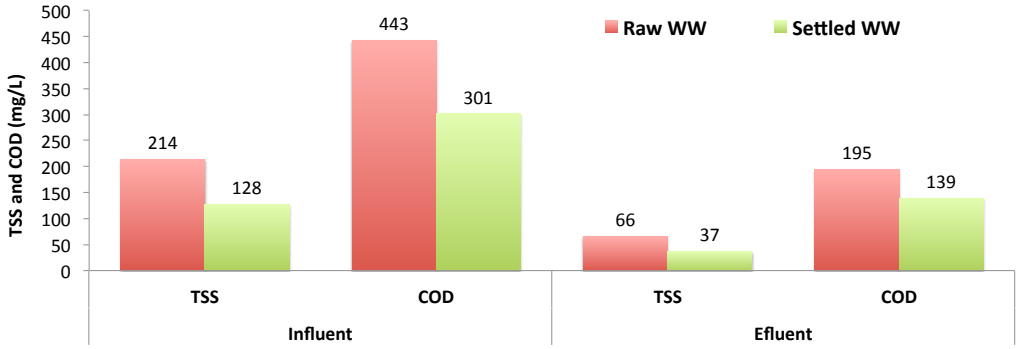
COD_{eff}: 139 mg/L (54% removal)

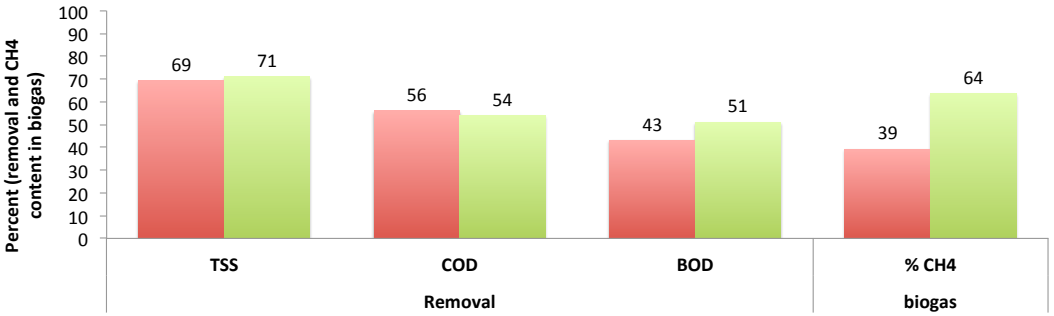
Desired performance:

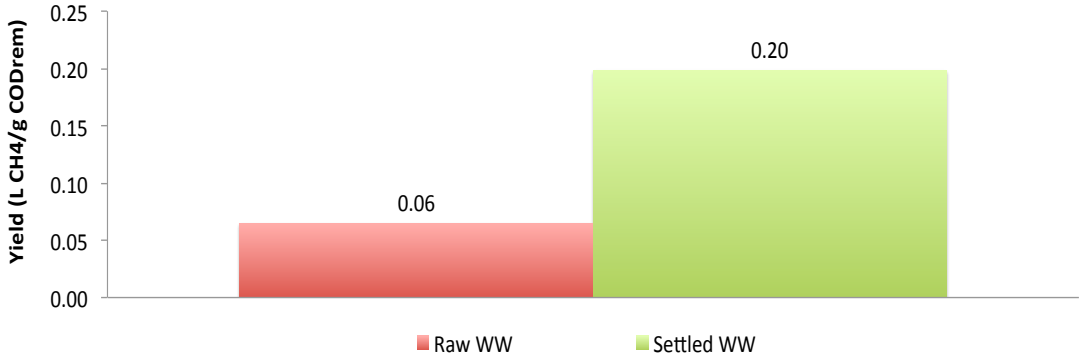
BOD_{eff}: 25 mg/L

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

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



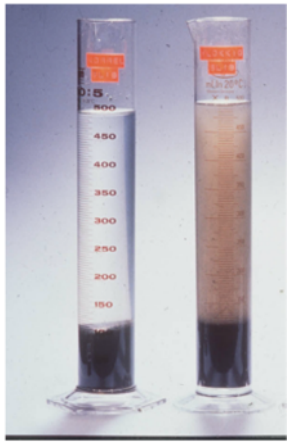




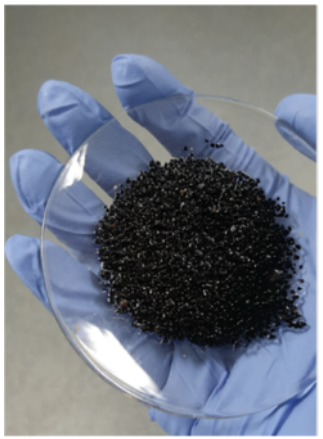
		Granular-UASB	Flocculent-UASB
Hydrolysis rate	%	**23.0 ± 5.6**	**23.1 ± 7.4**
Acidigenisis rate	%	**37.9 ± 4.9**	**54.1 ± 5.5**
Methanogenesis rate	%	**43.1 ± 4.0**	**48.8±5.5**

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



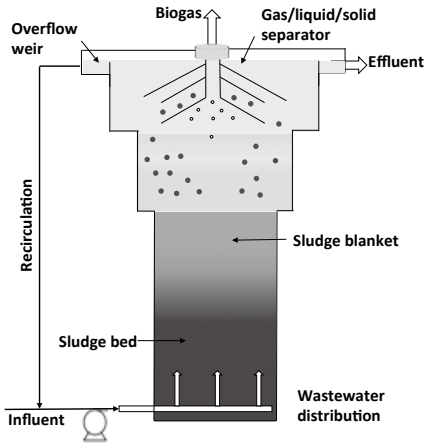
Granular Flocculent

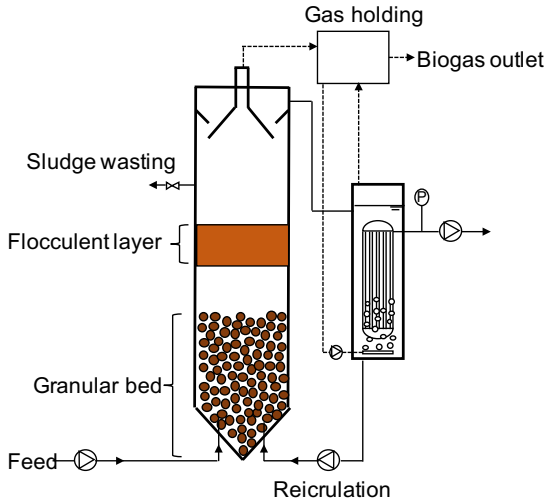


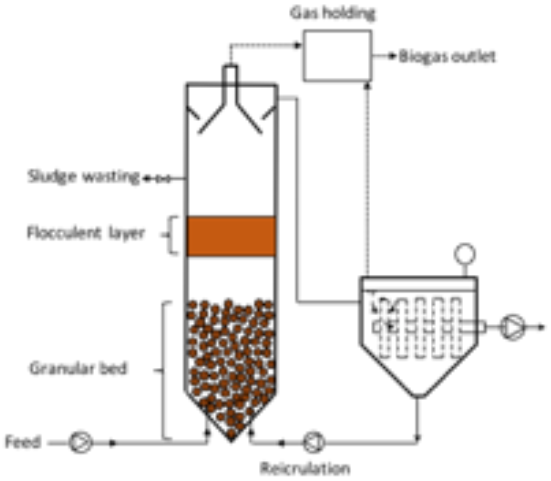
Wang KW, Soares A, Jefferson B, McAdam E. 2019. Comparable membrane permeability can be achieved in granular and flocculent anaerobic membrane bioreactor for sewage treatment through better sludge blanket control. Journal of Water Process. 28:181-189.

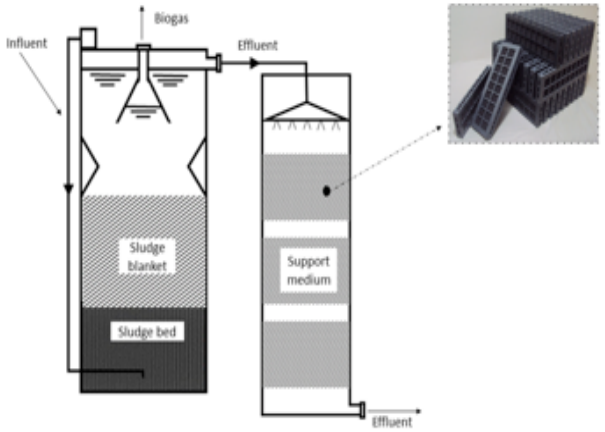
UASB configurations that can enhance solids retention

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









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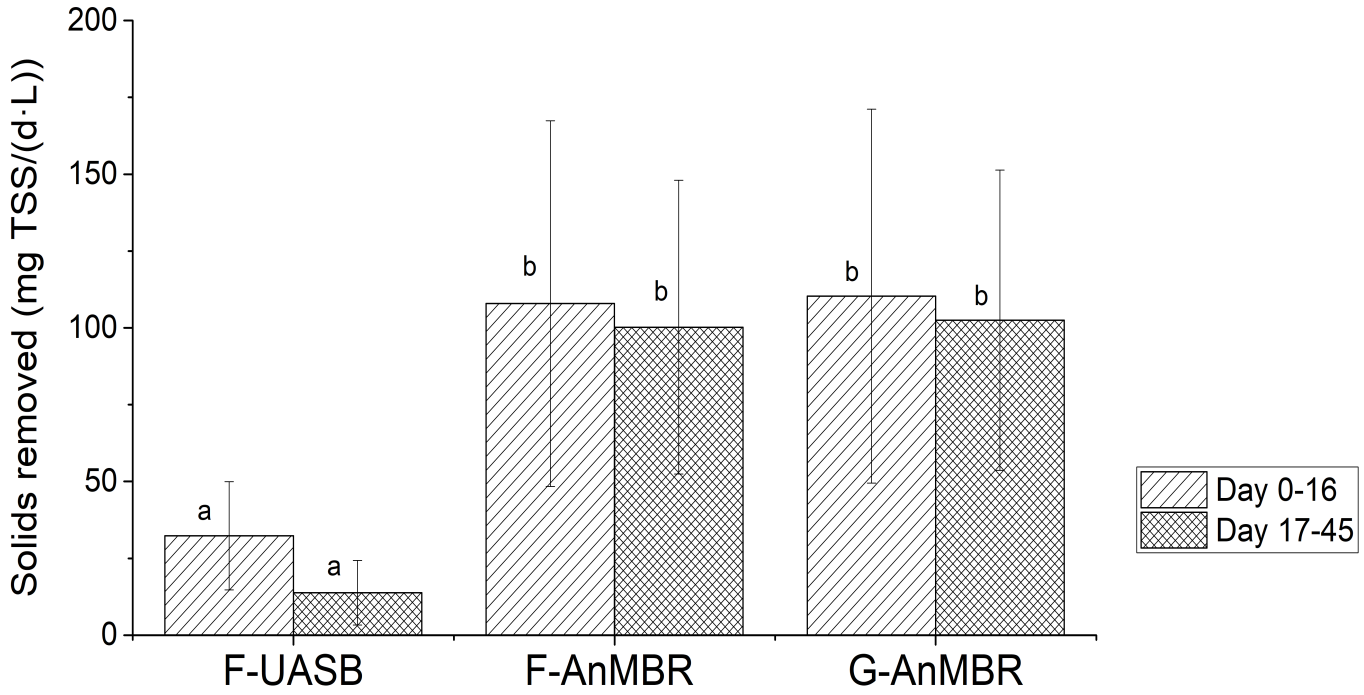
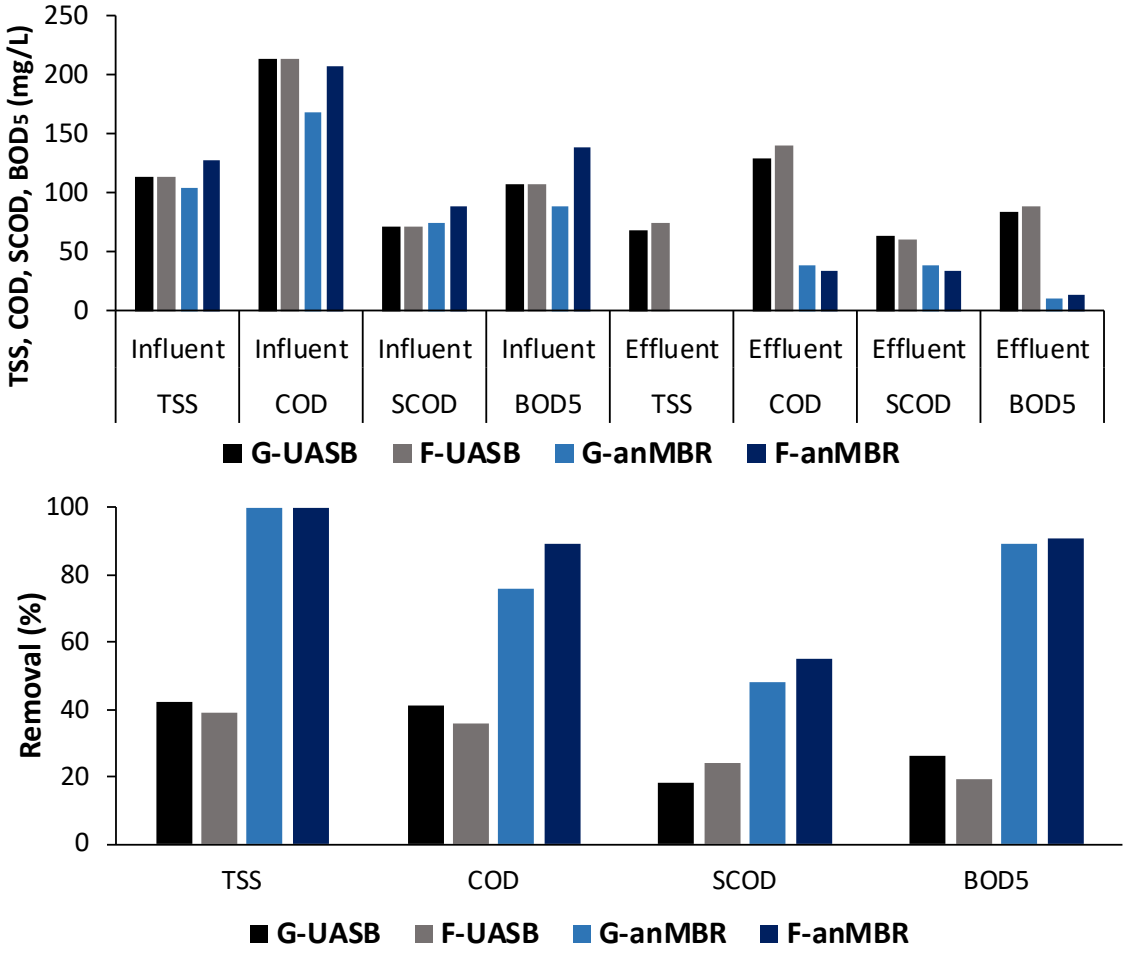
Solids capture in UASB



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.
Spernal (UK)
Waste Water Treatment Plant



Circular solutions for

Water Materials Energy

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

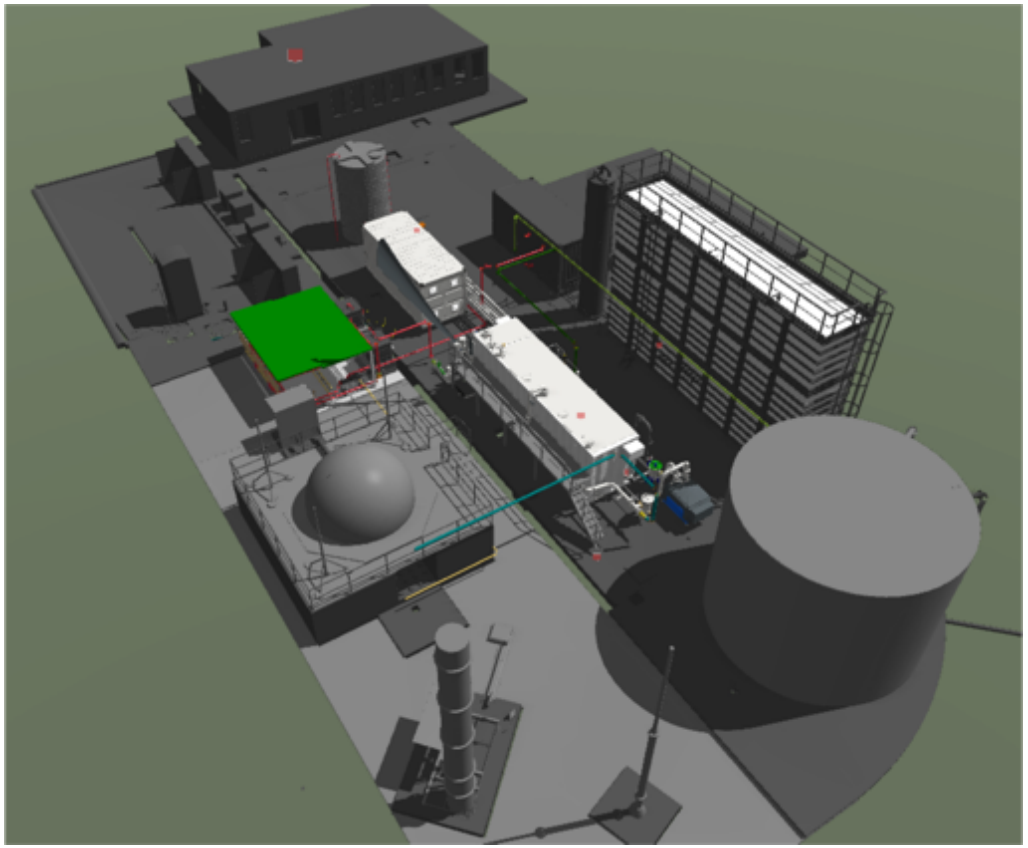
Spernal WWTP serves as Severn Trent Water's "Resource Recovery and Innovation Centre" where emerging technologies compatible with a low energy, circular economy approach will be evaluated.

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).

Building in Spernal



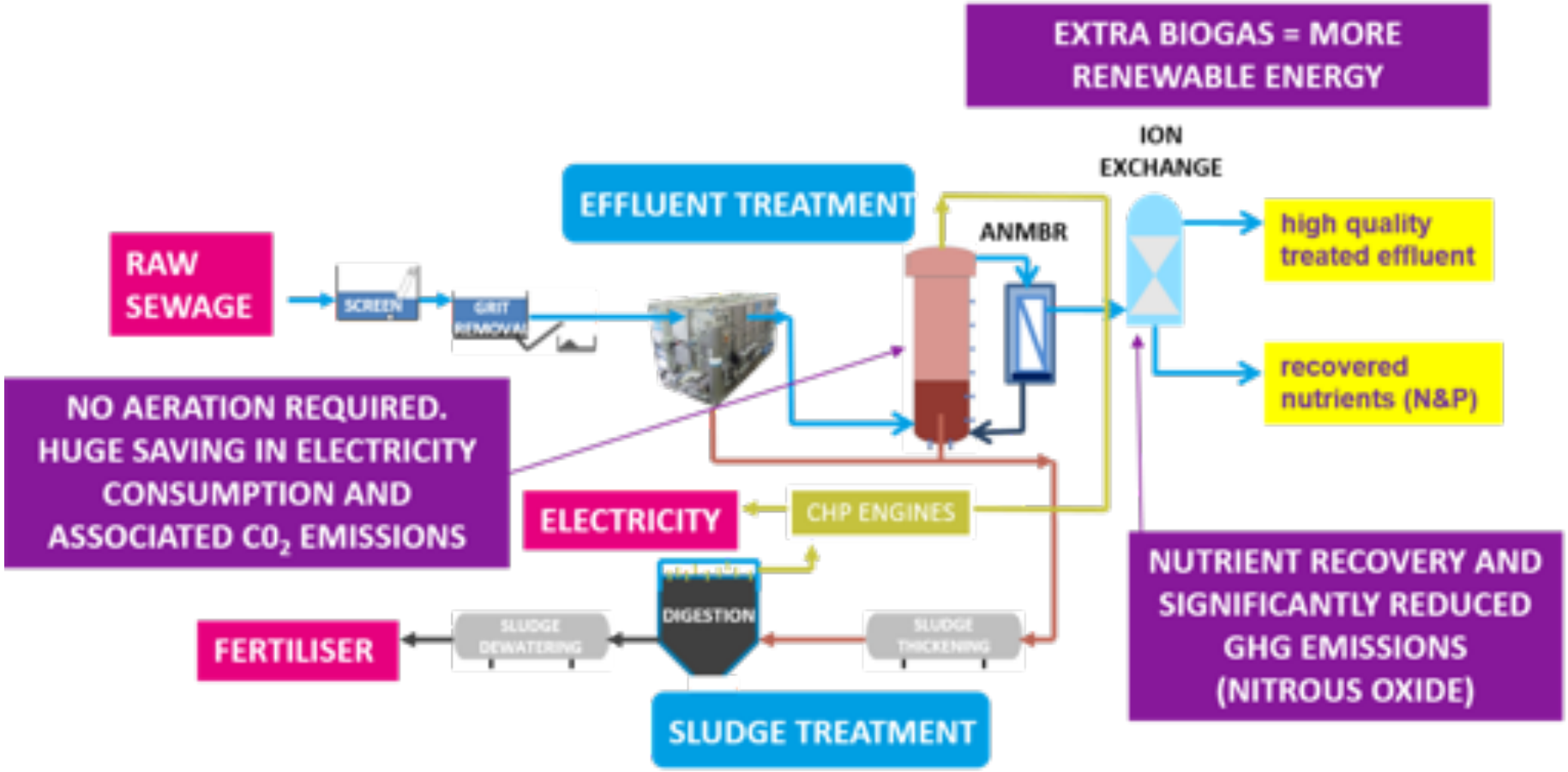
- Construction and commissioning of resource recovery innovation center completed in October 2019 – drone footage on right
- AnMBR to be commissioned in Summer 2020 – fabrication of the UASB reactors (Waterleau) shown on left

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.

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



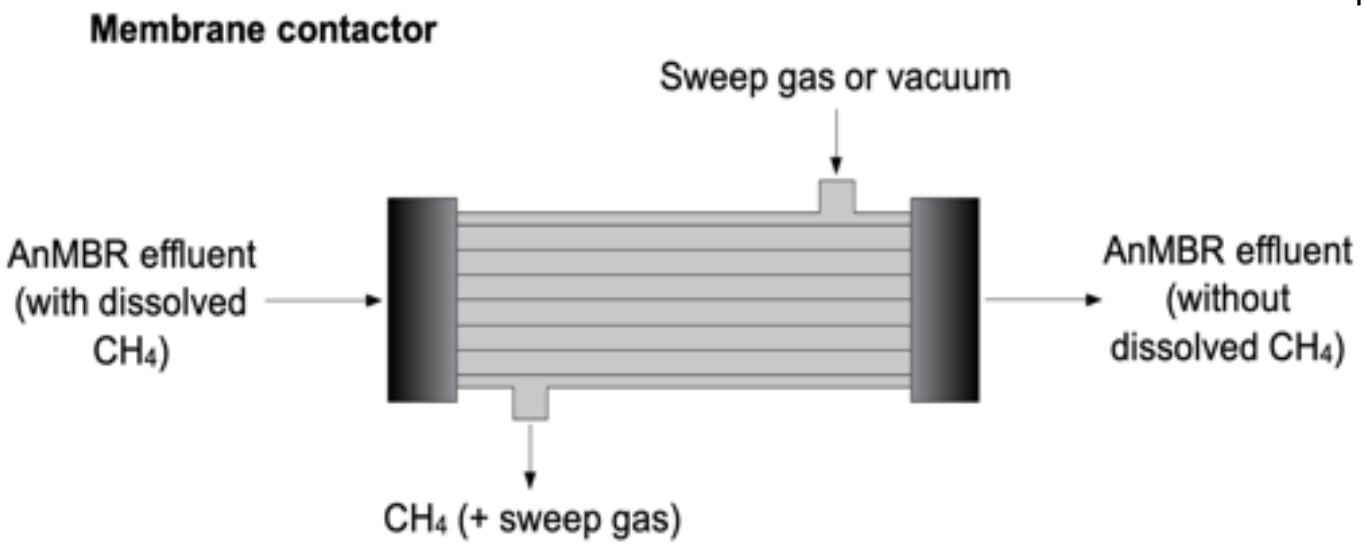
Gas sensors and dissolved methane probe to assist on the measurement of energy production in the AnMBR

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

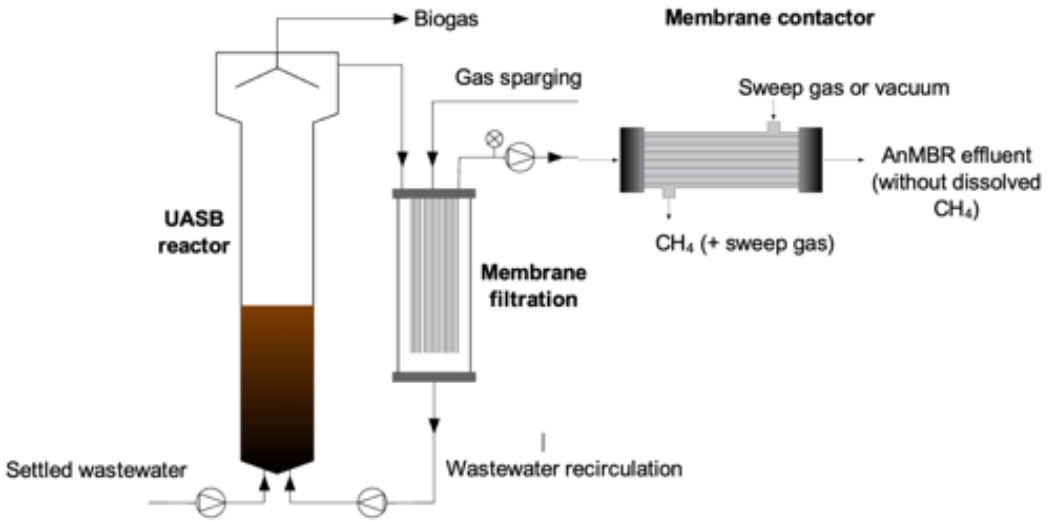
Applying a higher pressure to the water stream relative to the gas stream creates the driving force for dissolved gas in the water to pass through the membrane pores.

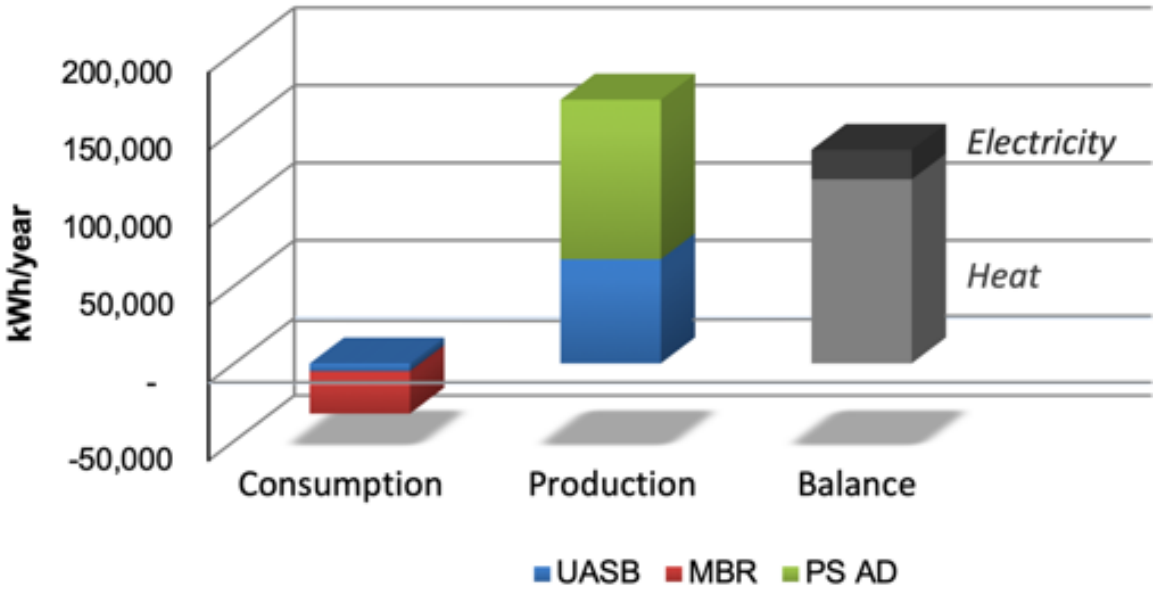


- **Technology provider – 3M (Membrana)**
- **The methane will be sent to the gas bag**

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

ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

Online seminar on heat recovery

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

February, 26th 2021

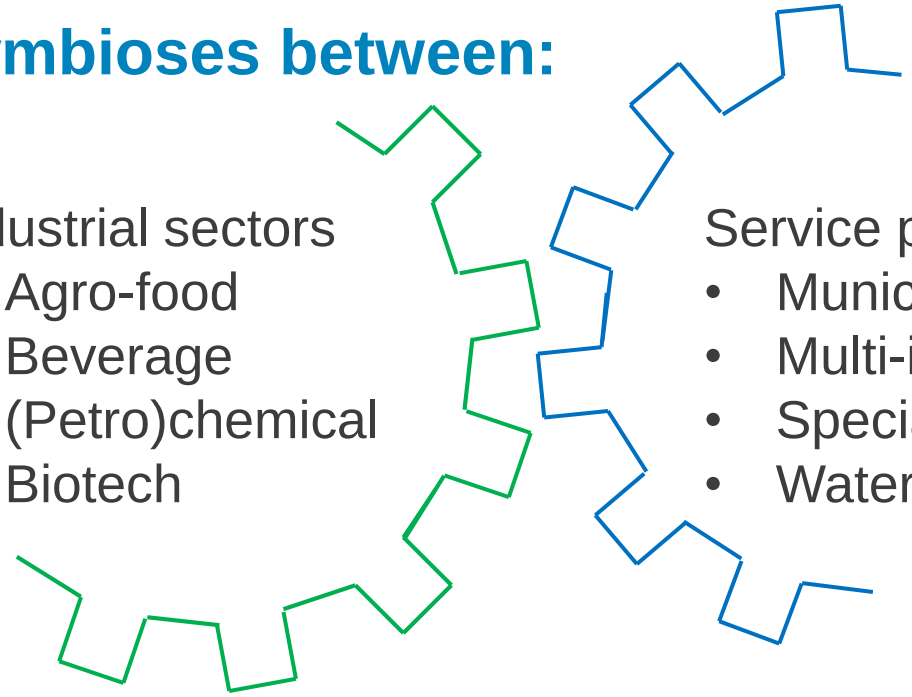


Ultimate (June 2020 – May 2024):

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



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





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

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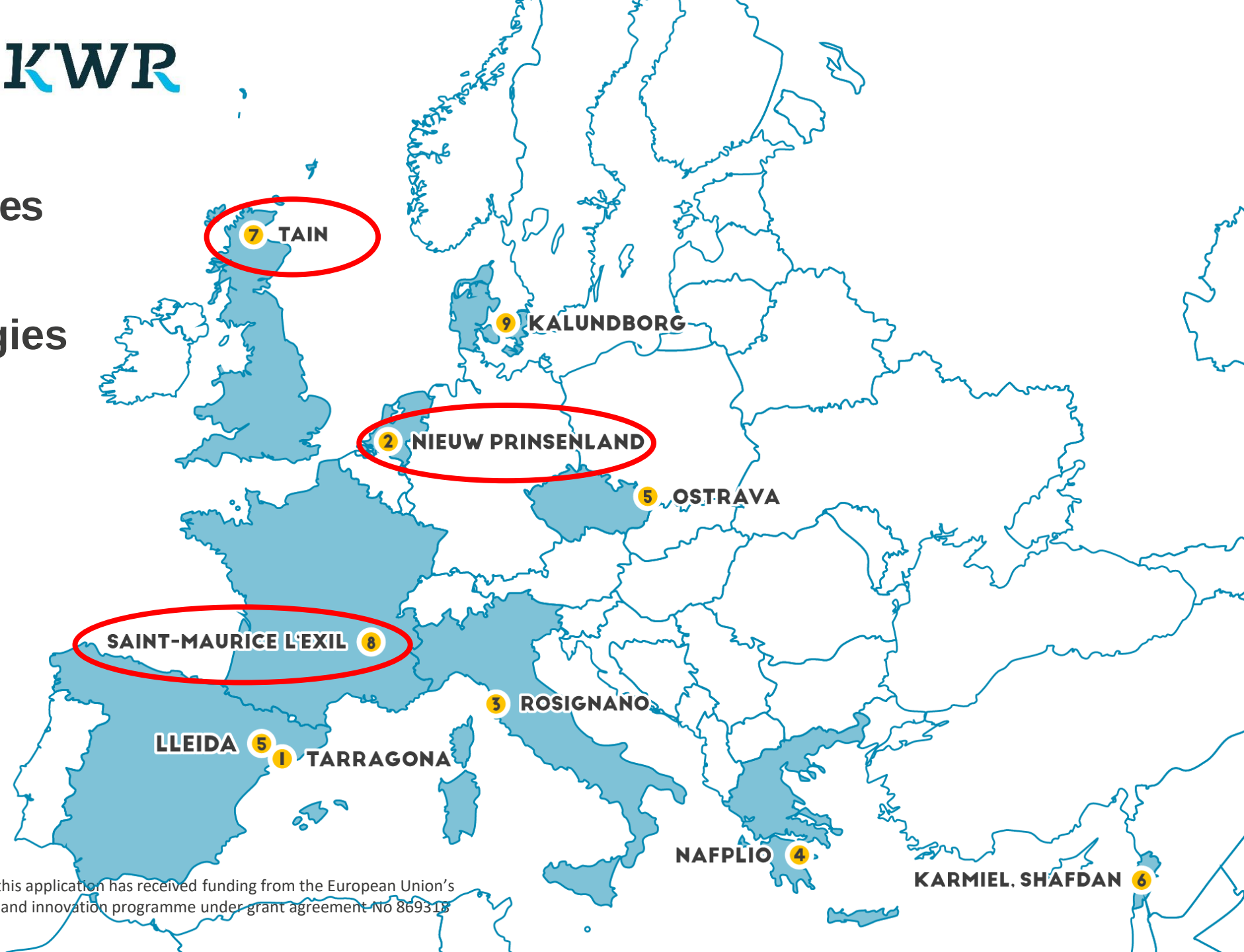

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Online seminar on heat recovery

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

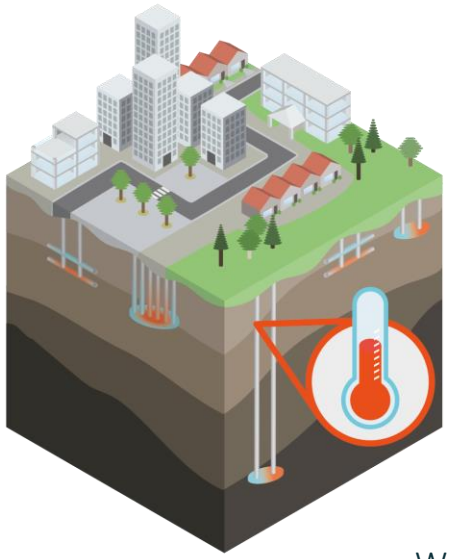
Methodology

- 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?

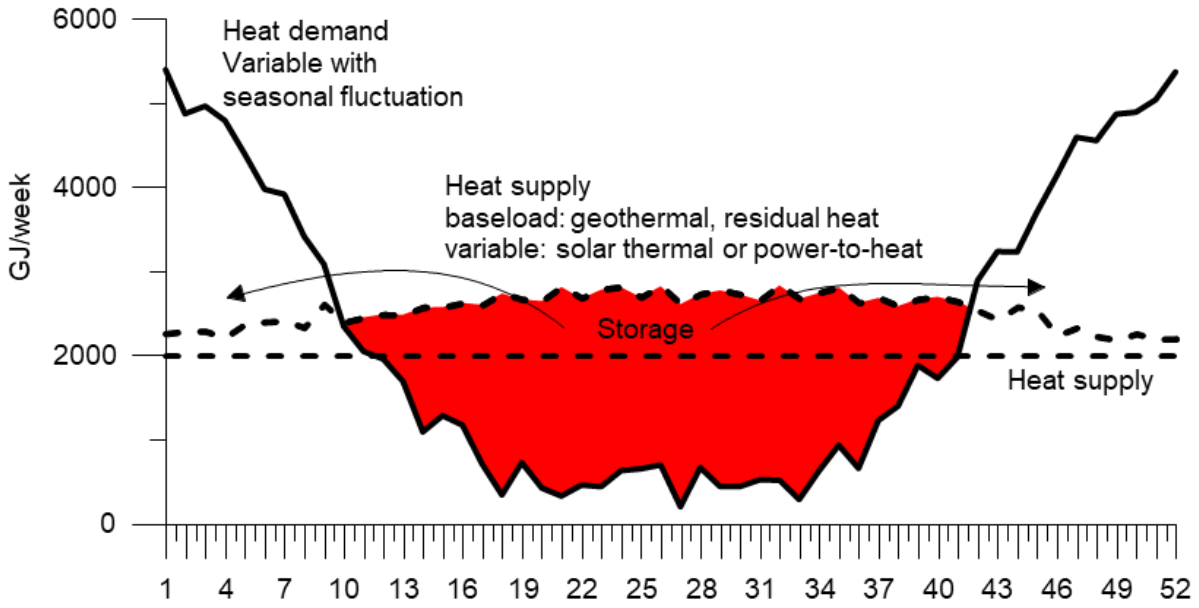
- Match heat demand and supply
- Seasonal storage, optimal use of sustainable energy

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

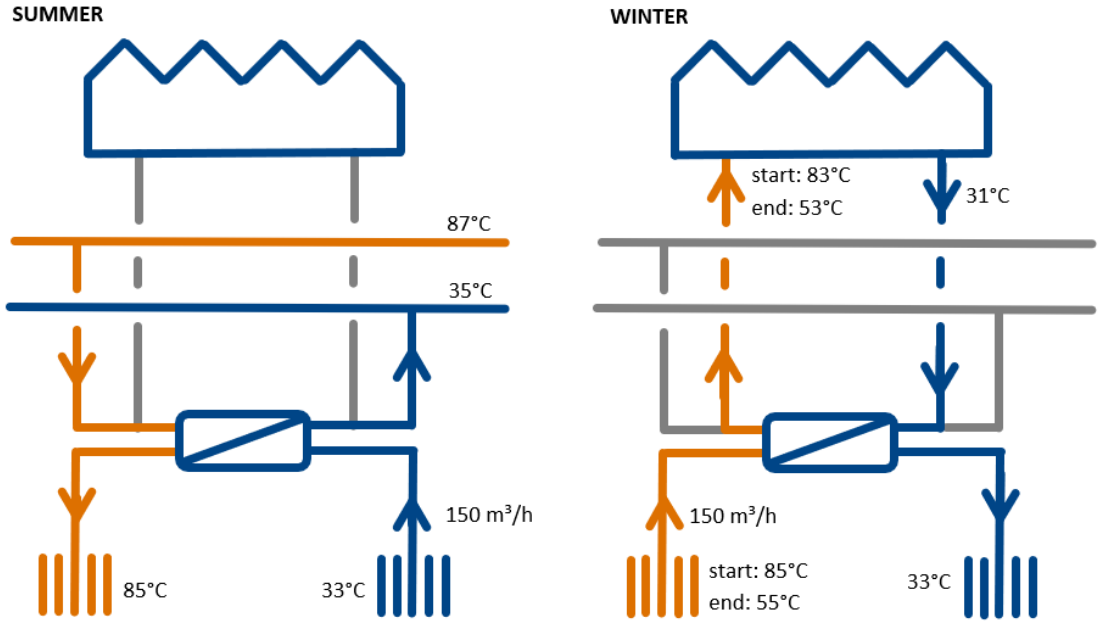
HT-ATES:

- 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:

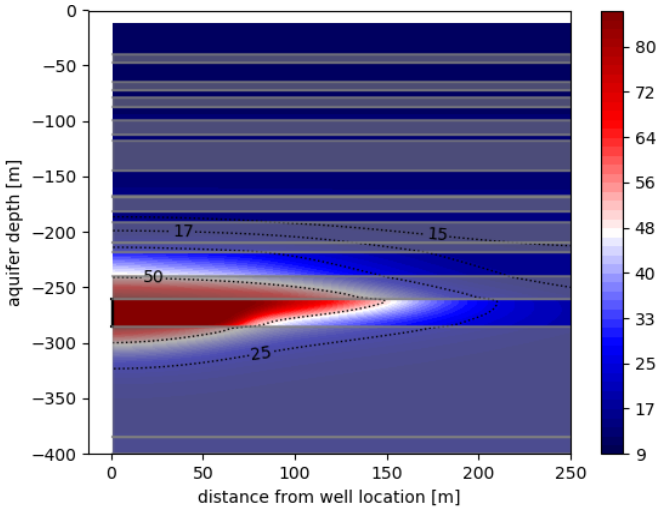
- HEATSTORE, Nextgen, WINDOW, WarmingUP
- HT-ATES is not a proven technique yet

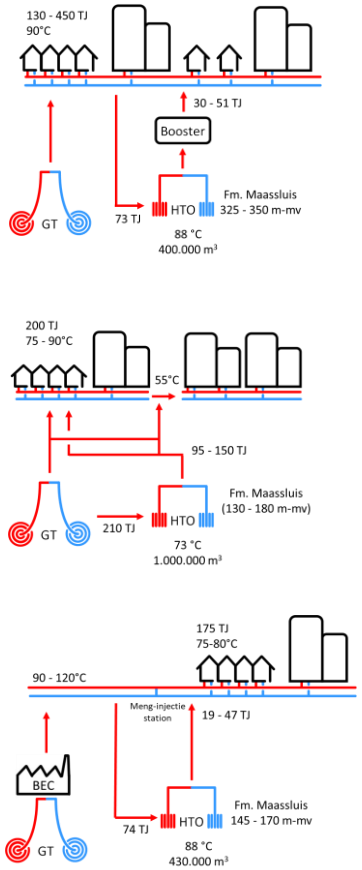


Website Heatstore (EU Geothermica)

Results from current research







Sustainable energy for greenhouse area Westland

Combination of geothermal system and HT-ATES:

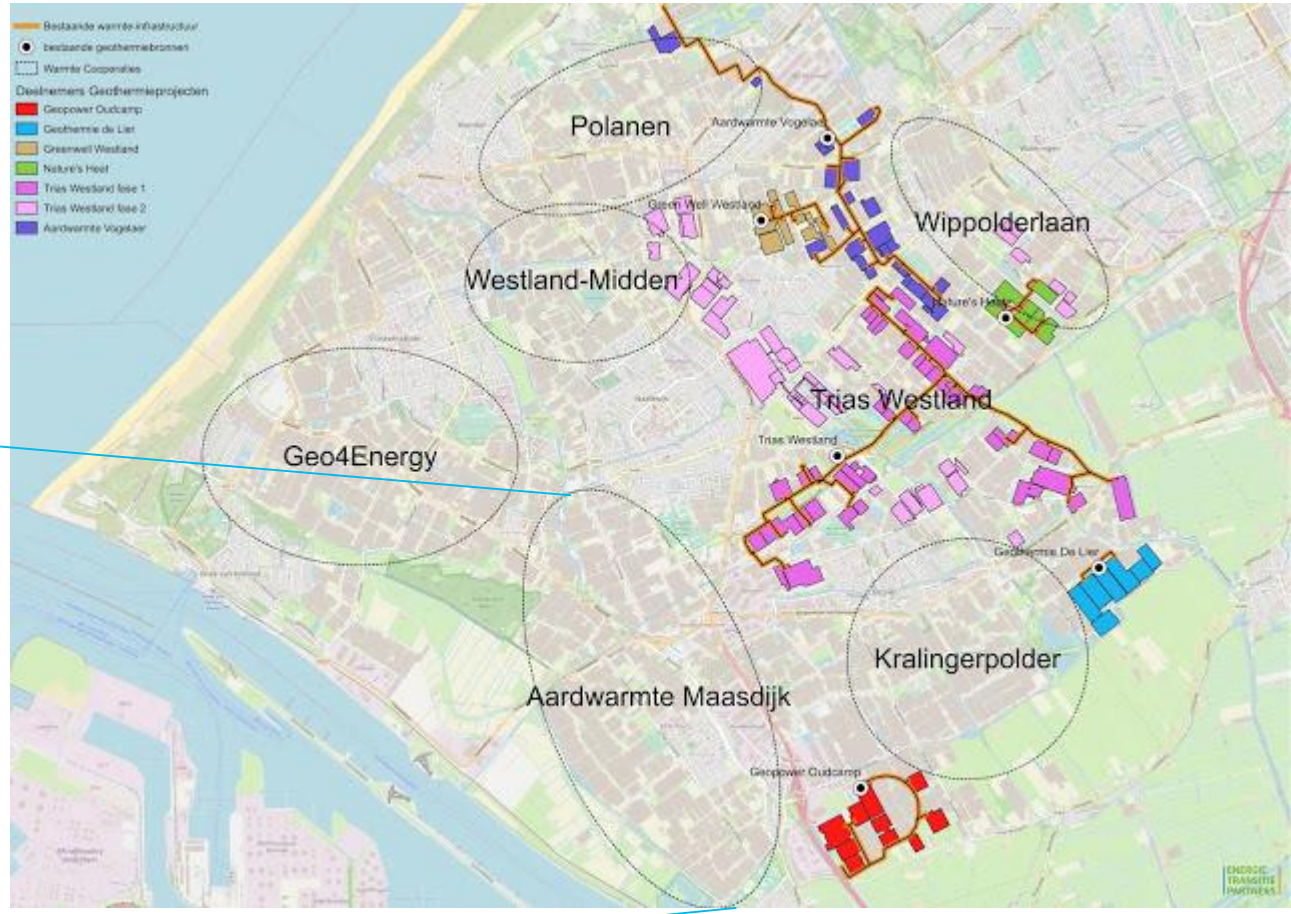
- Expected to be a winning combination!

Development of geothermal energy systems:

- Trias Westland
- Polanen
- Maasdijk







Pilot Westland (Maasdijk) determine suitable aquifers

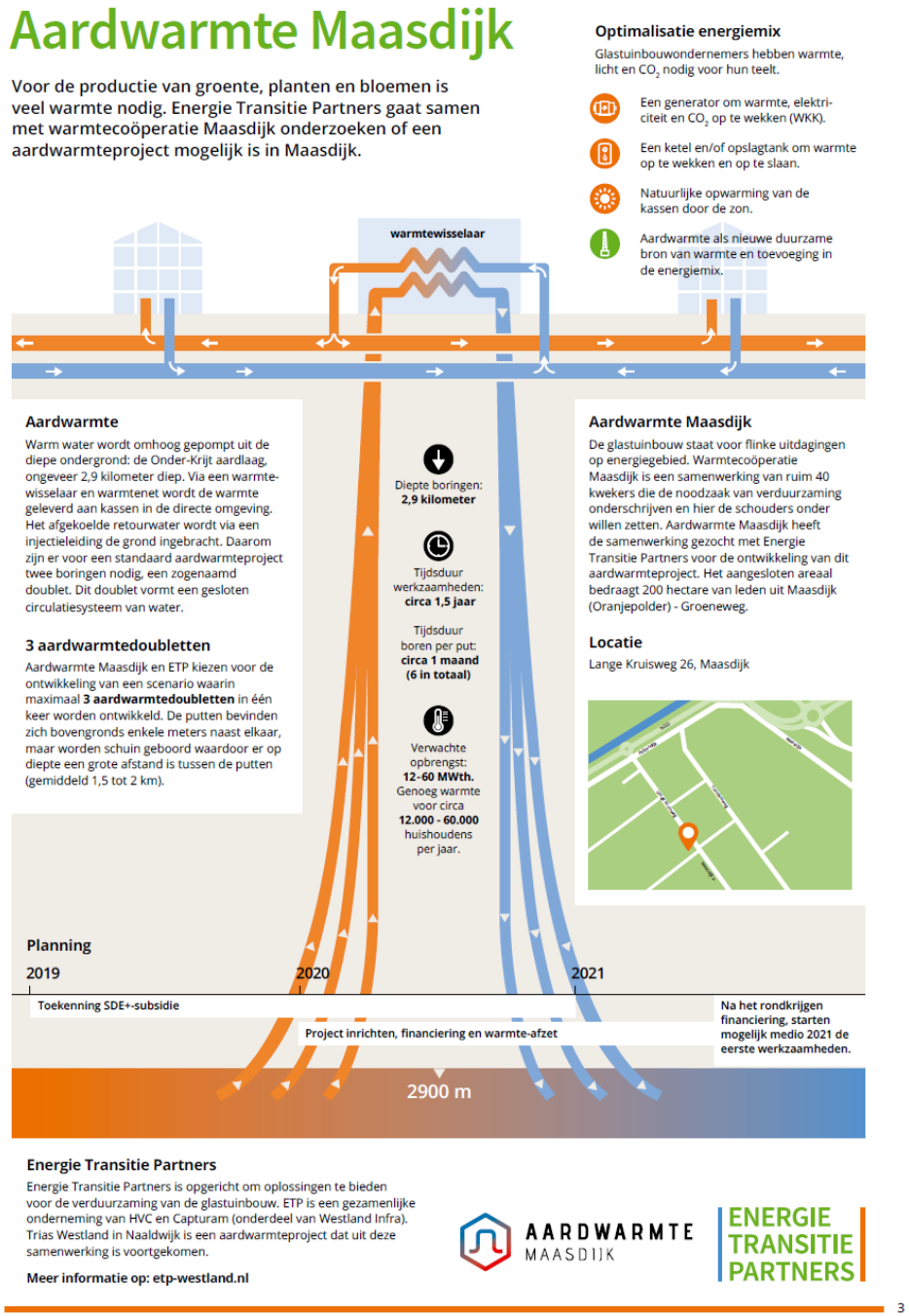
Determine suitable aquifers:

- 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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Martin Bloemendal
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ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

CS7 – Tain (Glenmorangie distillery)

Cranfield University

Aquabio

Meeting: October, 30th 2020



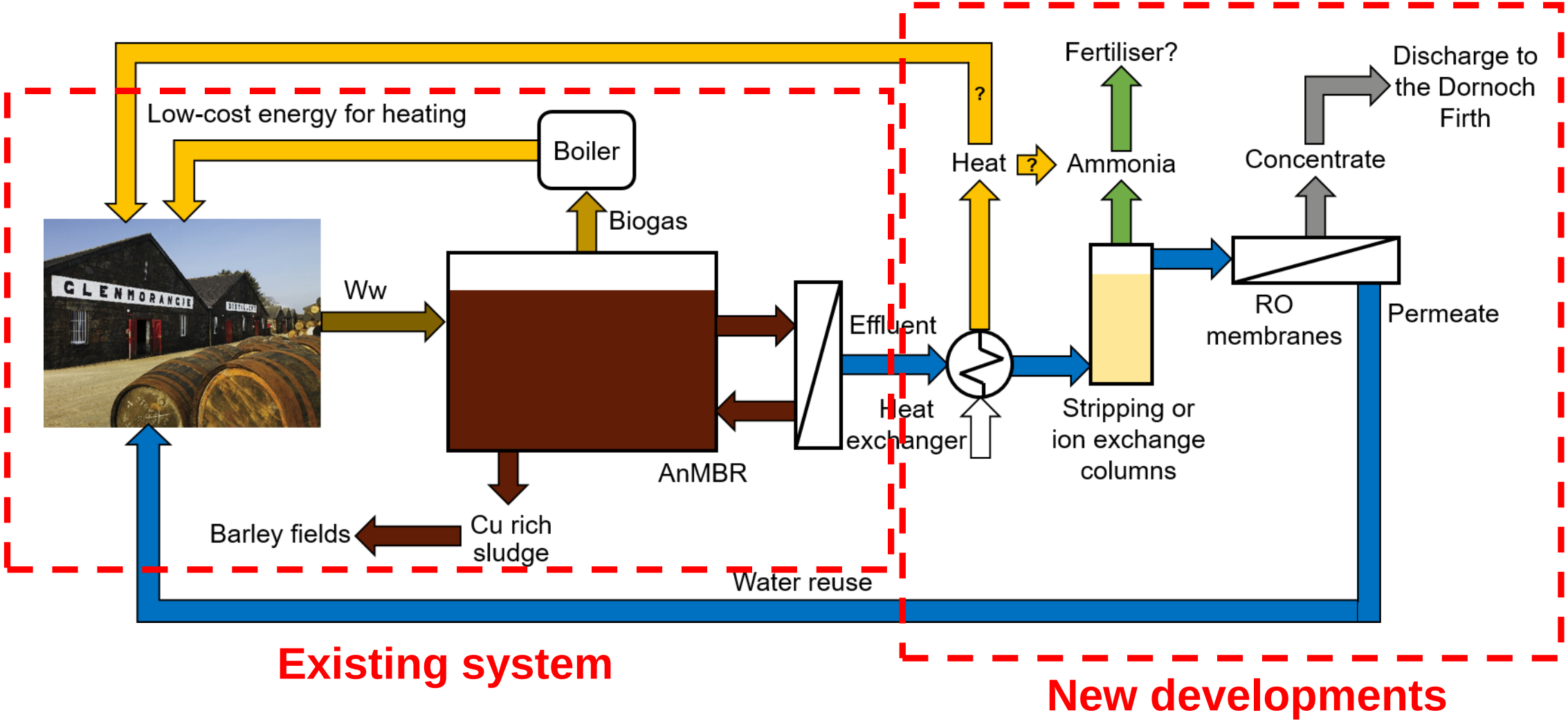
CS7


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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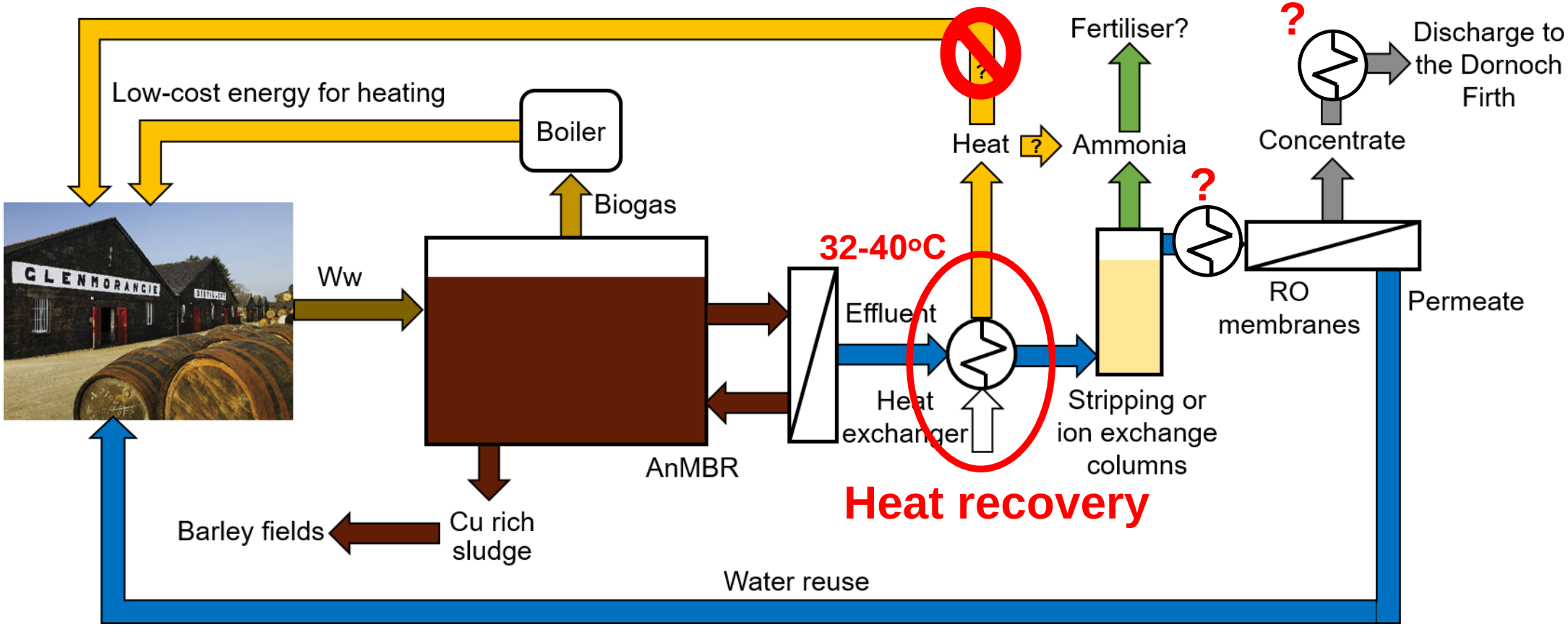
Treatment systems



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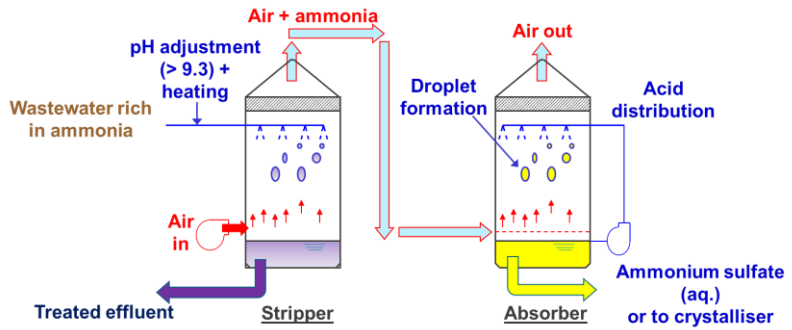
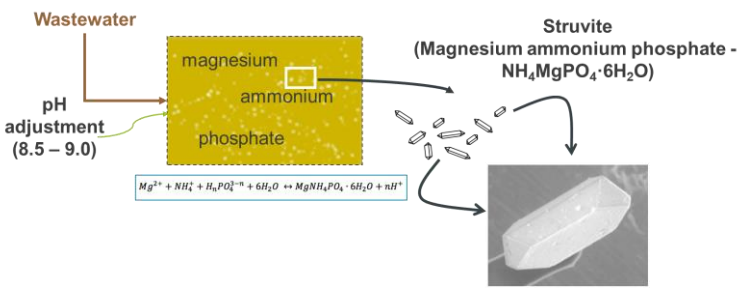
Impact of temperature: Ammonia recovery

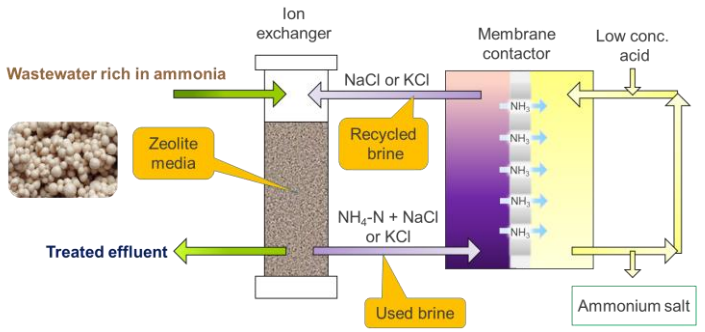
Stripping

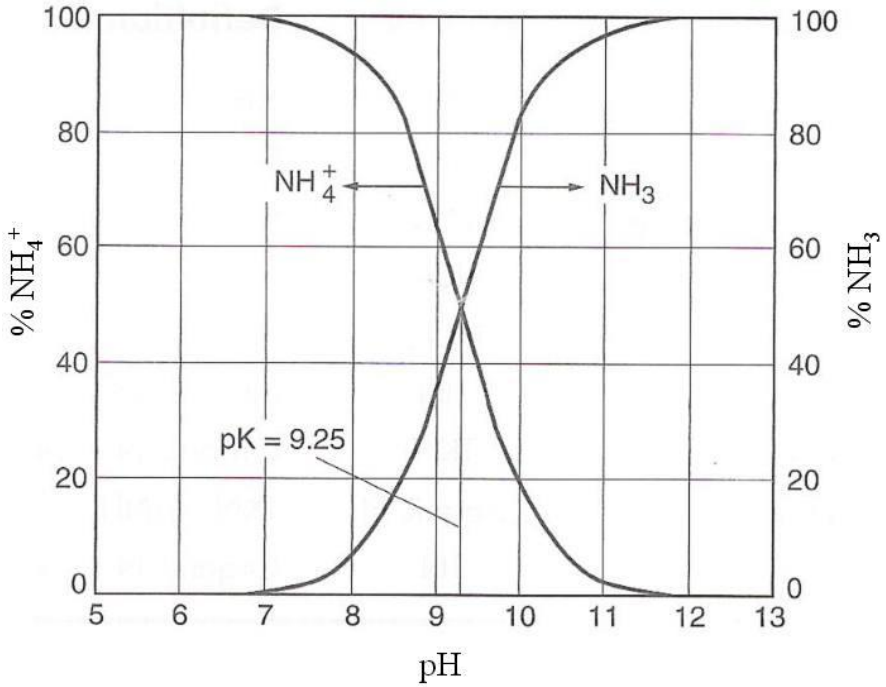


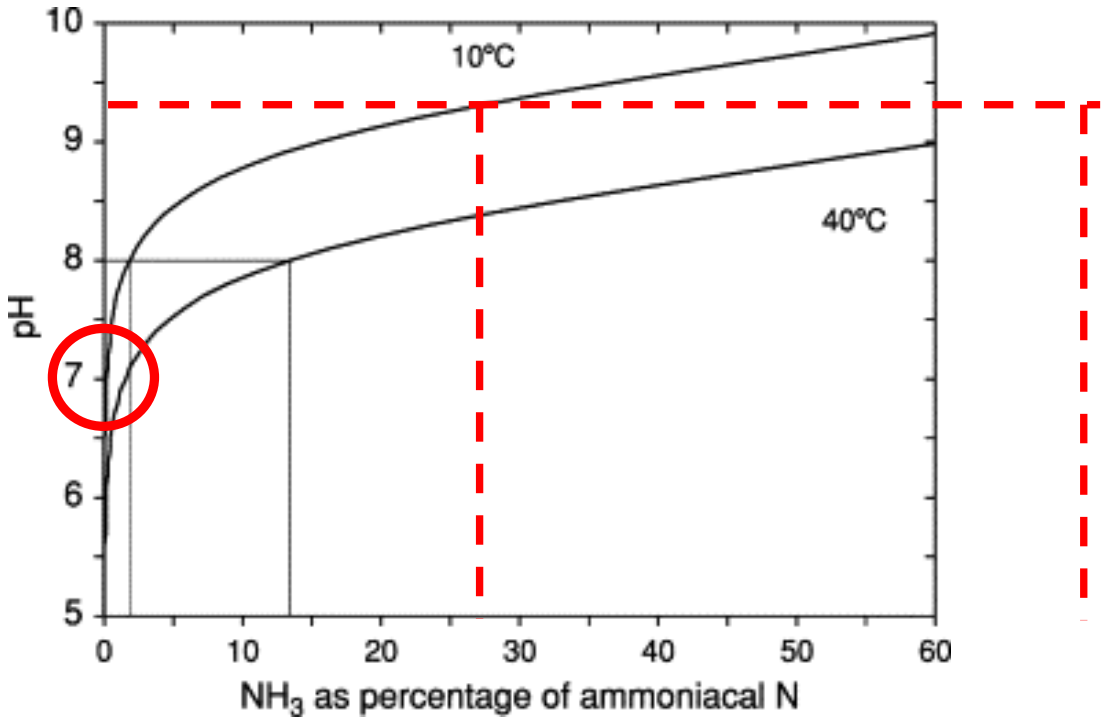
Precipitation



Ion exchange







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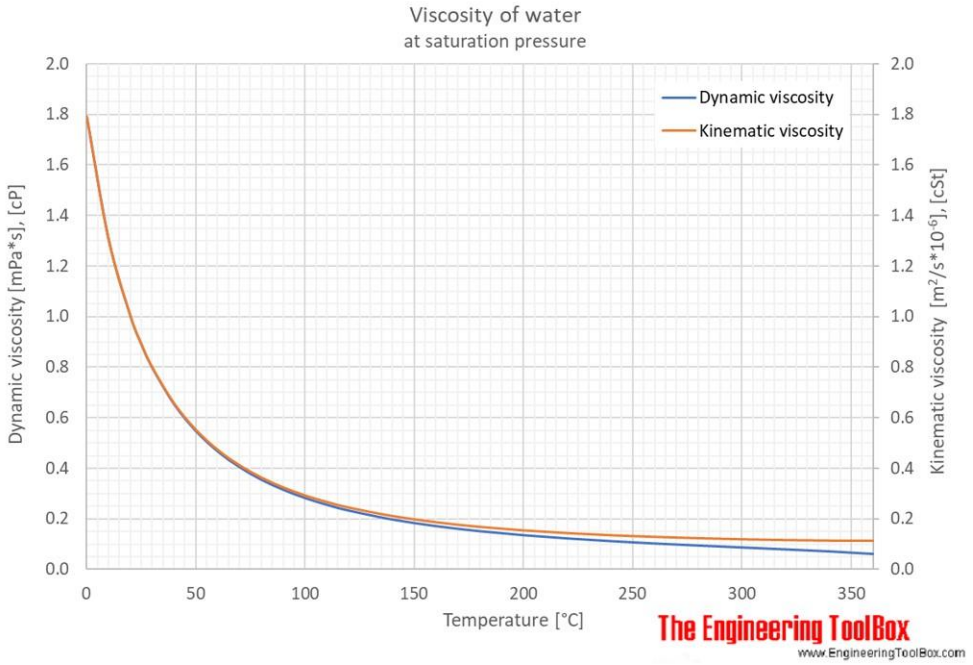
https://www.sciencedirect.com/topics/earth-and-planetary-sciences/ammonia

Impact of temperature: RO membranes

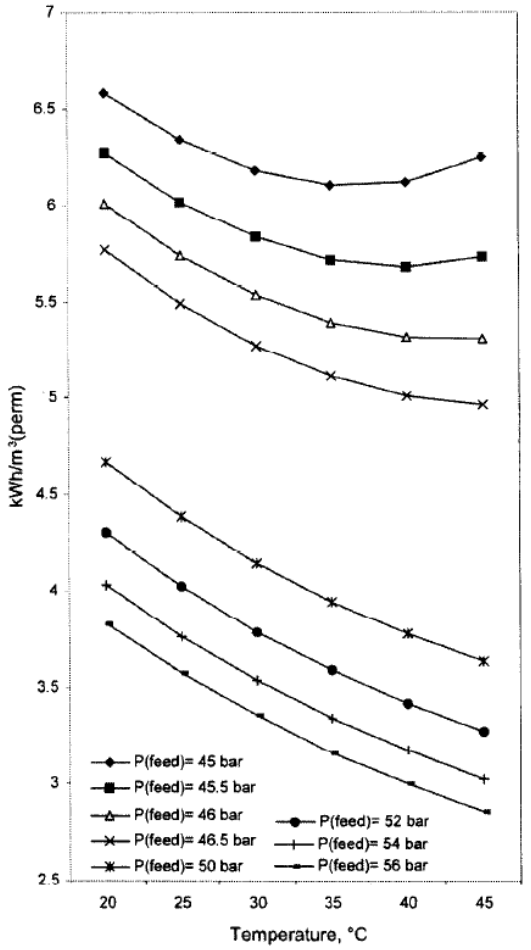
Flux $J = \frac{Q_p}{A} = \frac{P - \pi}{\eta \cdot R}$ Pressure, Resistance, Viscosity



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



Contents

1. **Situation before ULTIMATE**

2. **Objectives of ULTIMATE**



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

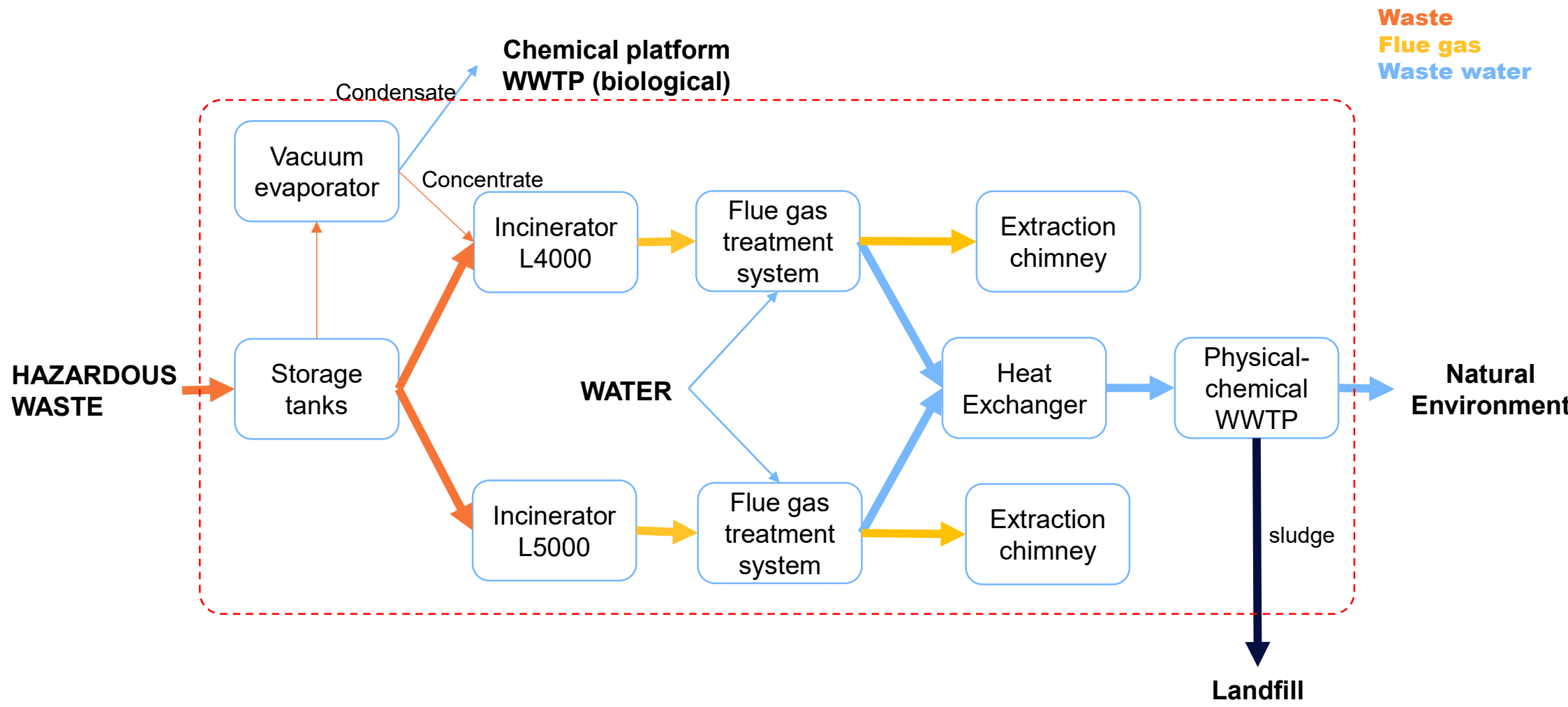
1.

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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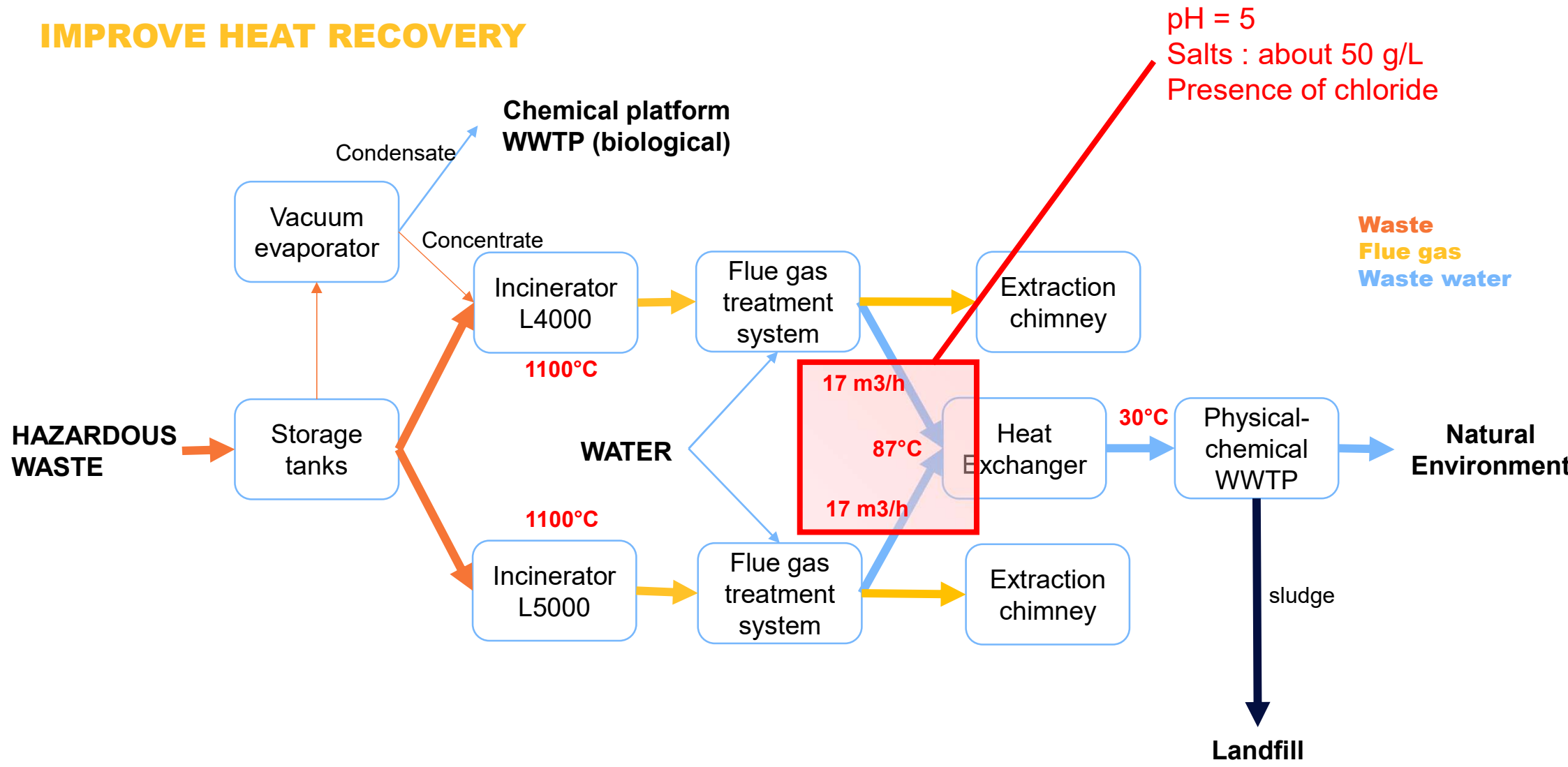
2.

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**
- **…**

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

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 (€)**

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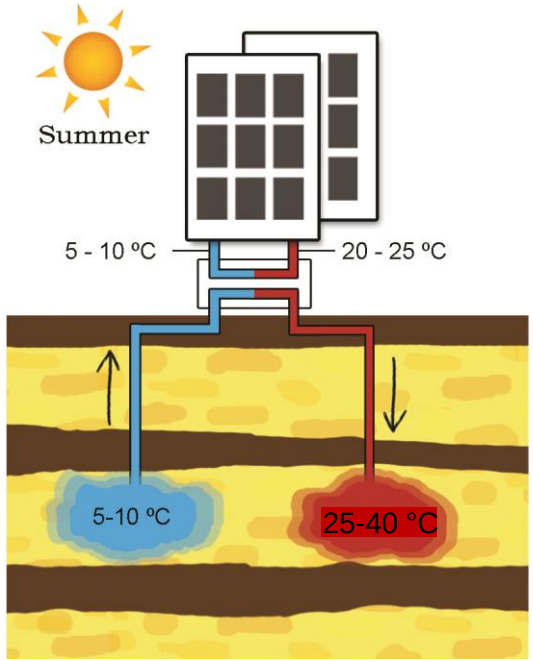
THANKS FOR YOUR ATTENTION



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



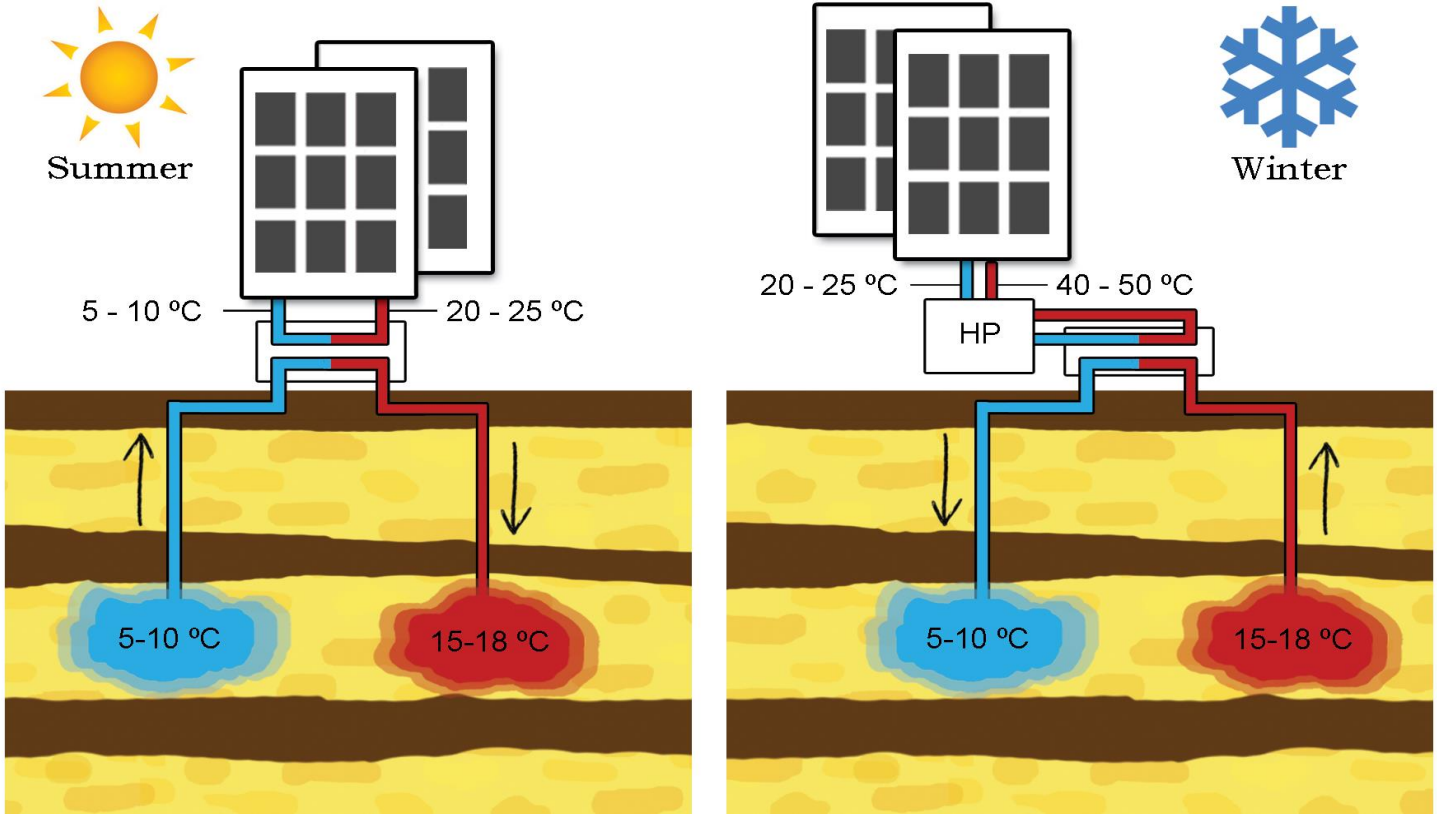
Adji Cress *(Zanthoxylum)*

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

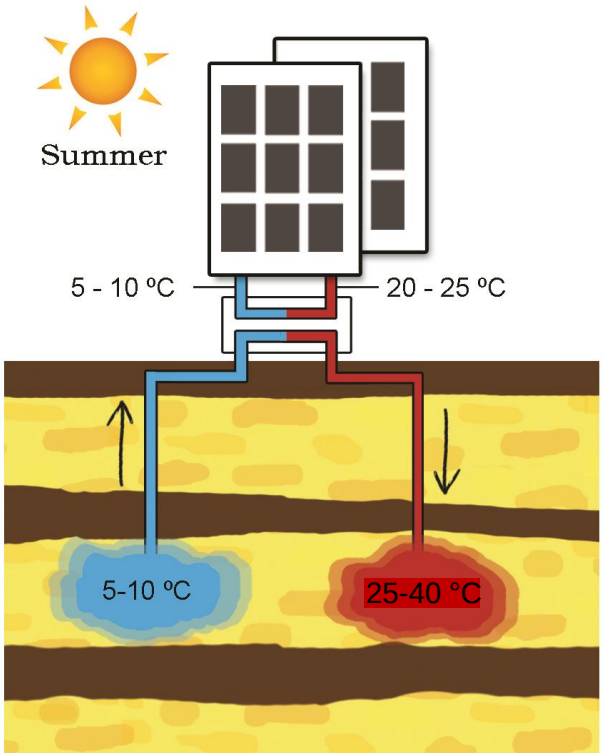


KWR

TU Delft

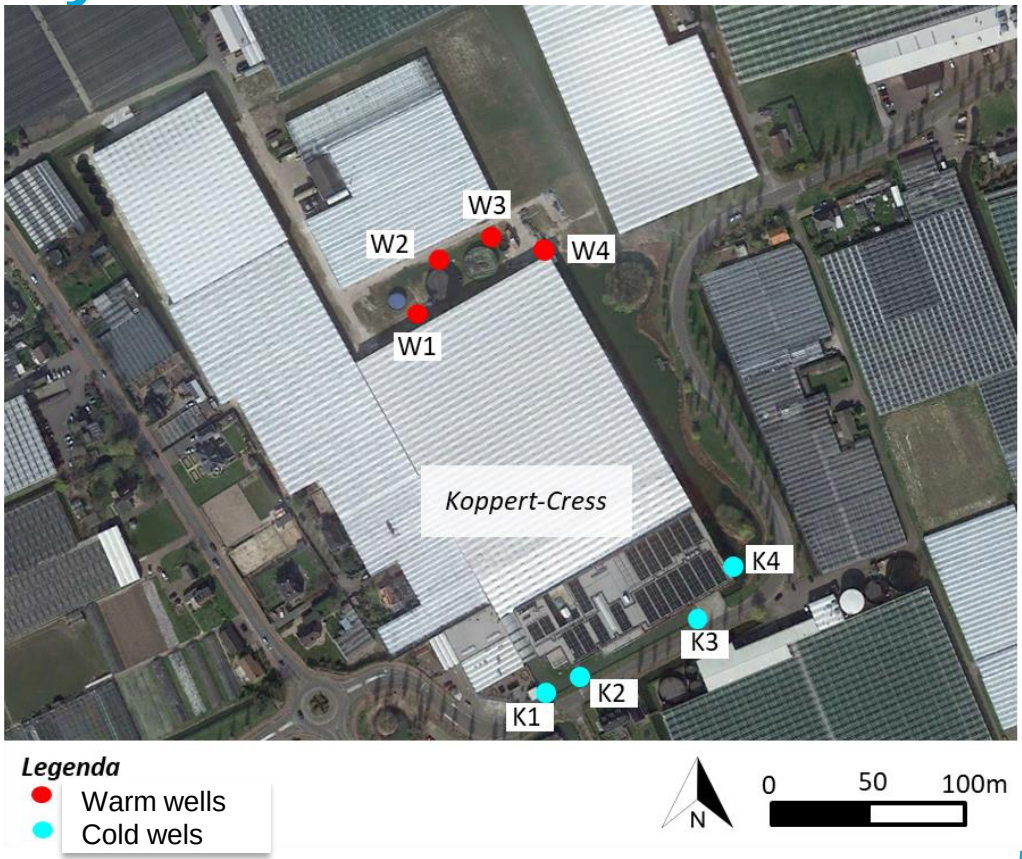
Koppert-Cress: HT-ATES pilot

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

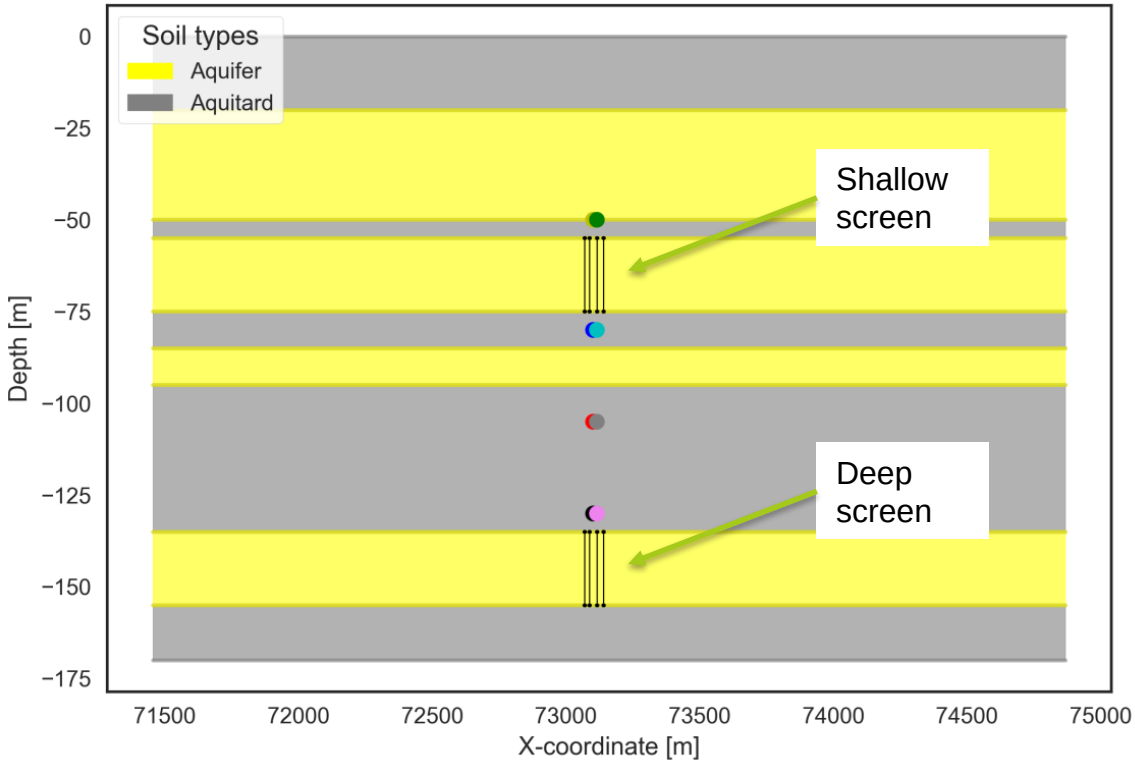


KWR
TU Delft

The ATES system of KC



The ATES system of KC



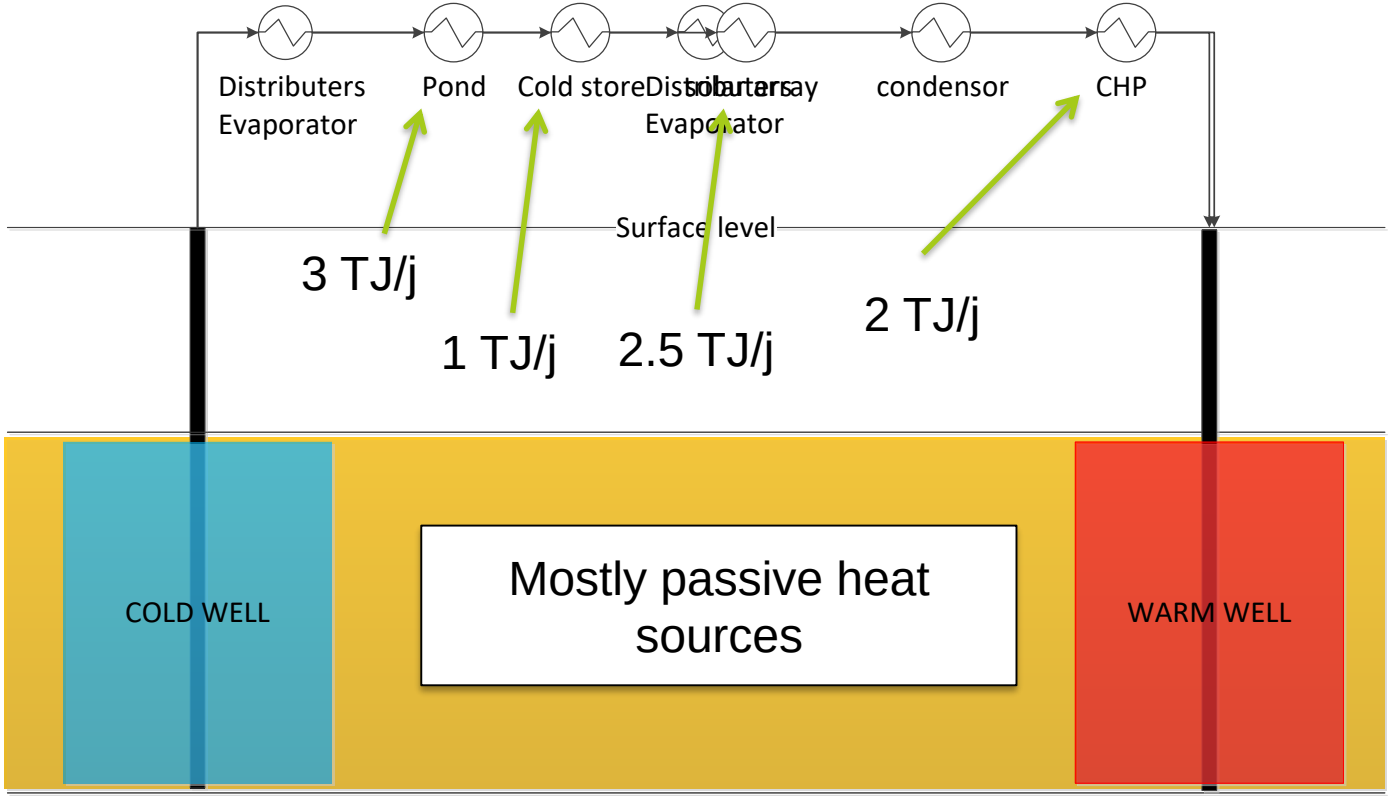
The transition to HT-ATES

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

KWR

TU Delft

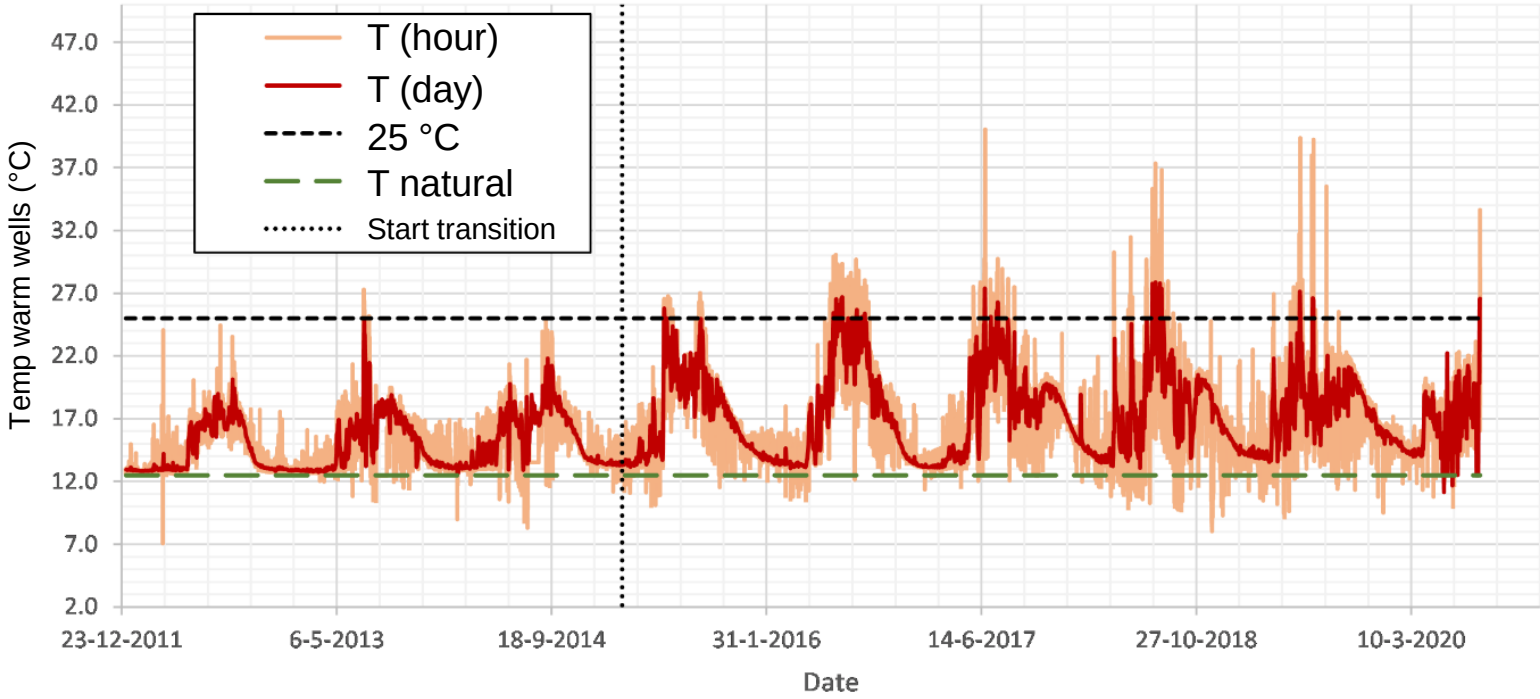
Extra heat and higher temperature



KWR

TU Delft

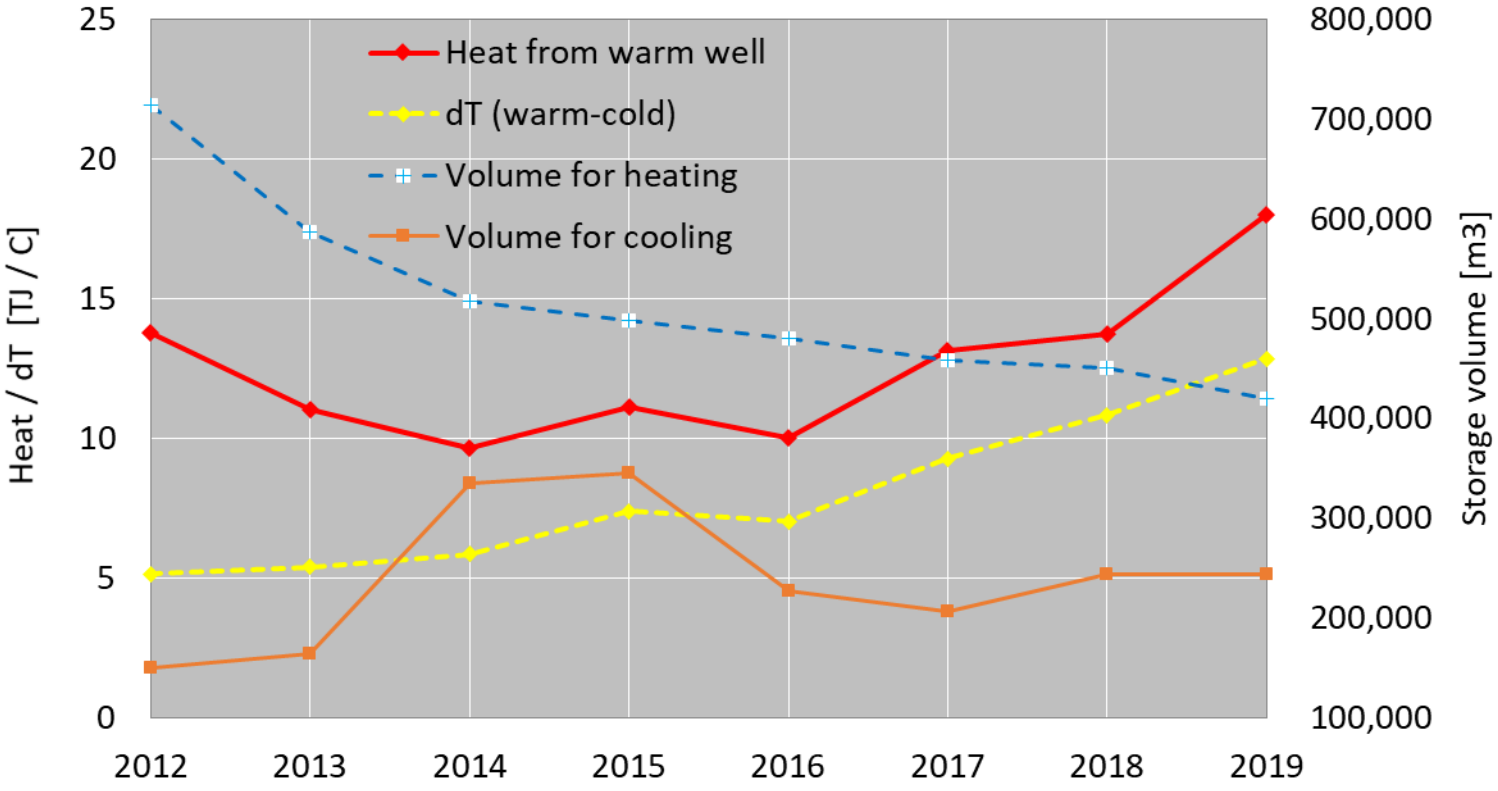
Increasing T_{in} & ΔT



KWR

TU Delft

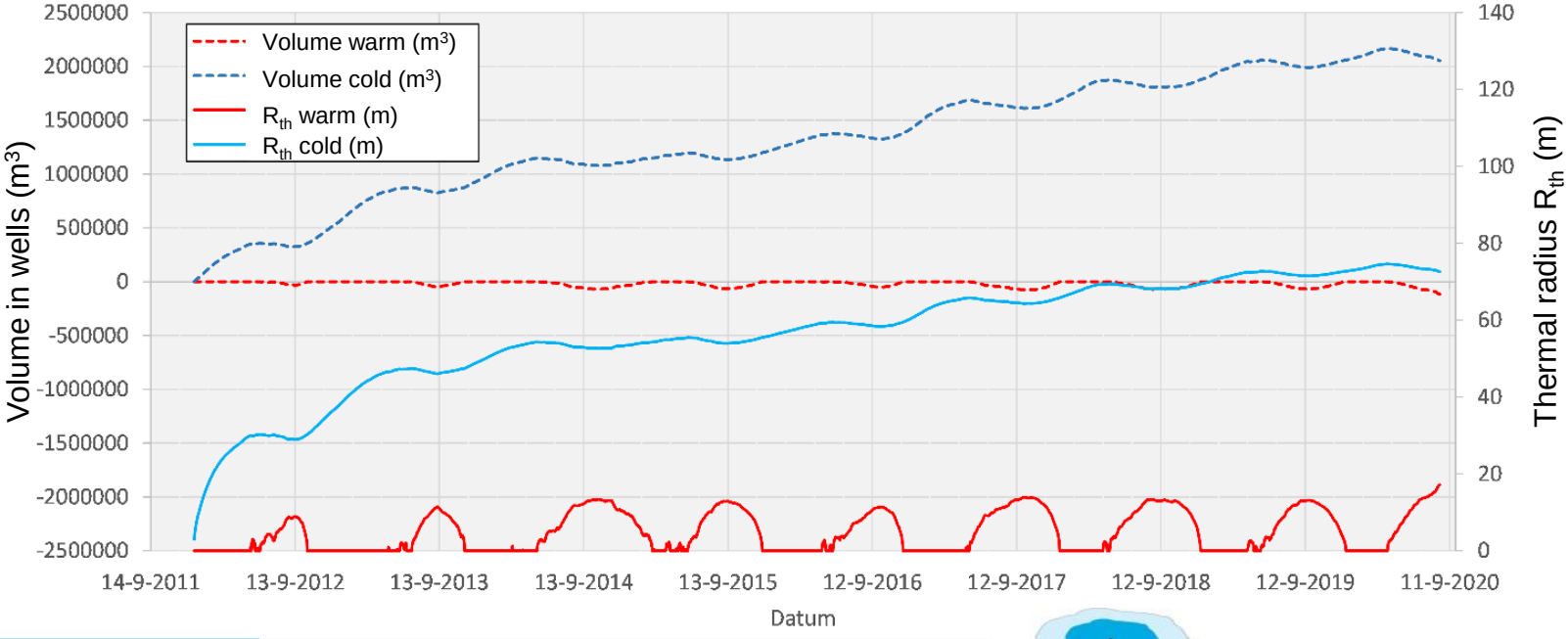
Increasing T_{in} & ΔT

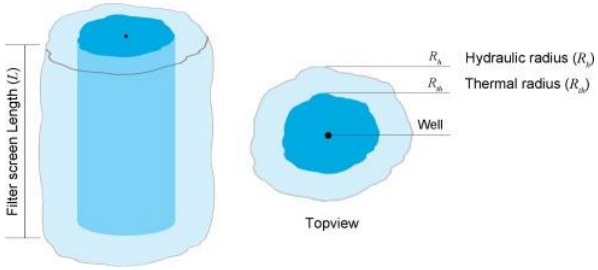


KWR

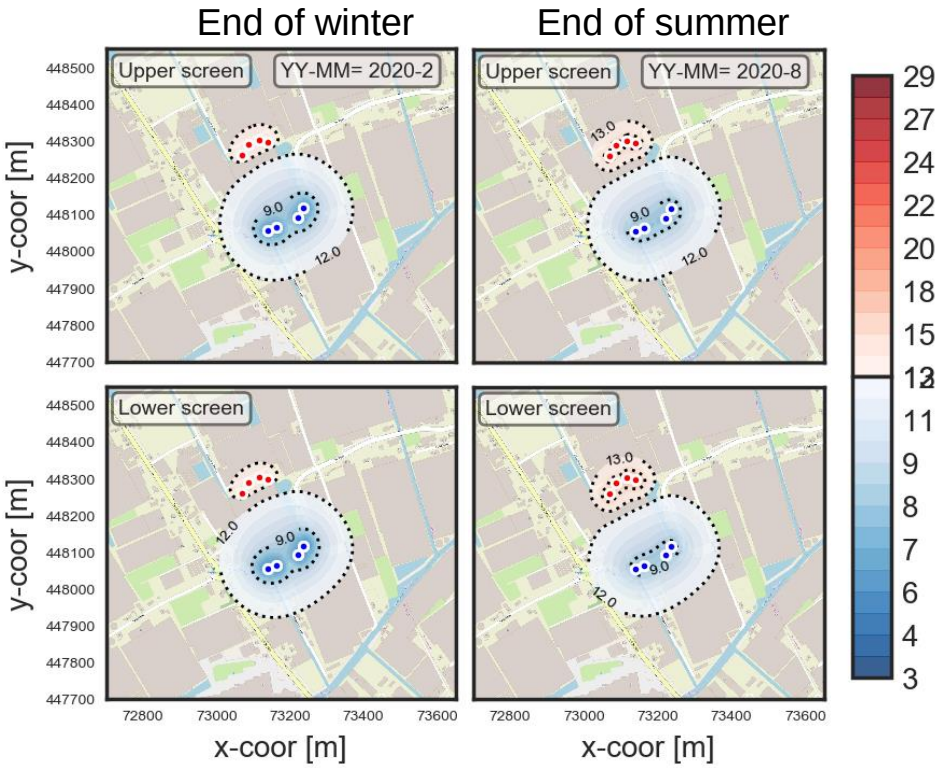
TU Delft

ATES system not in balance



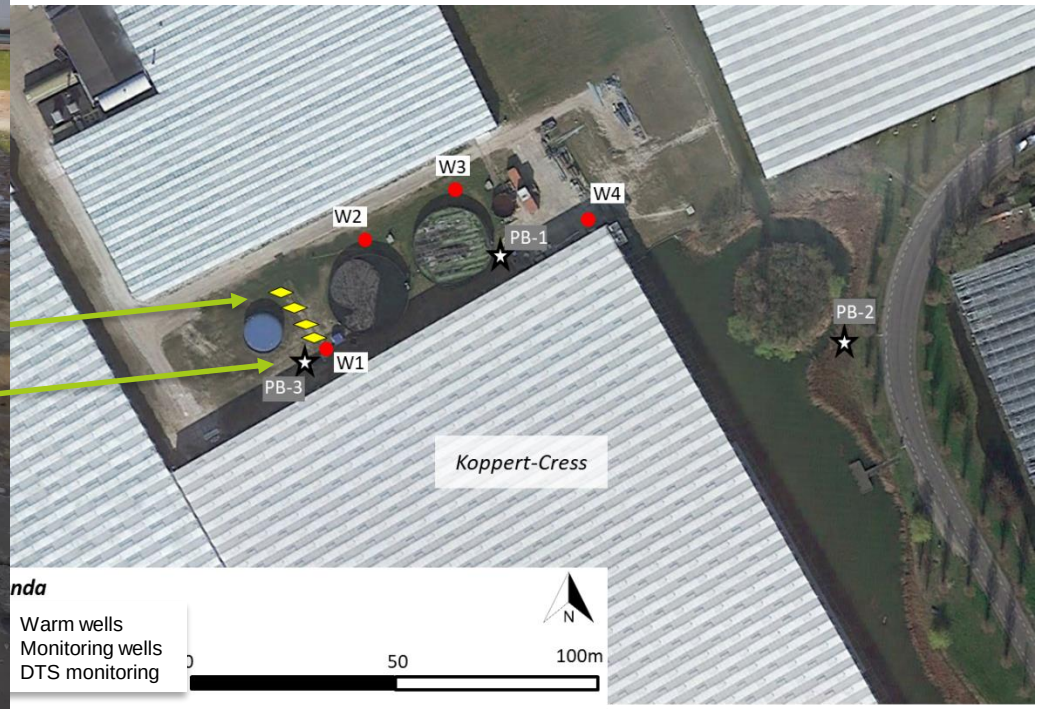


ATES system not in balance

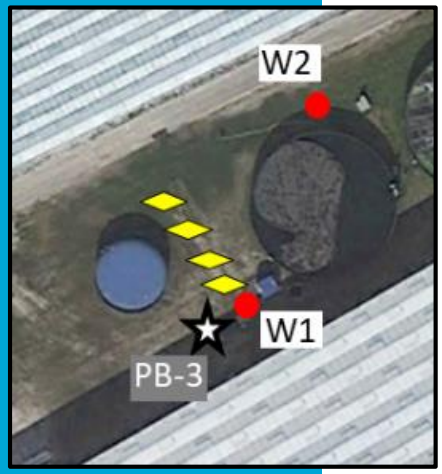


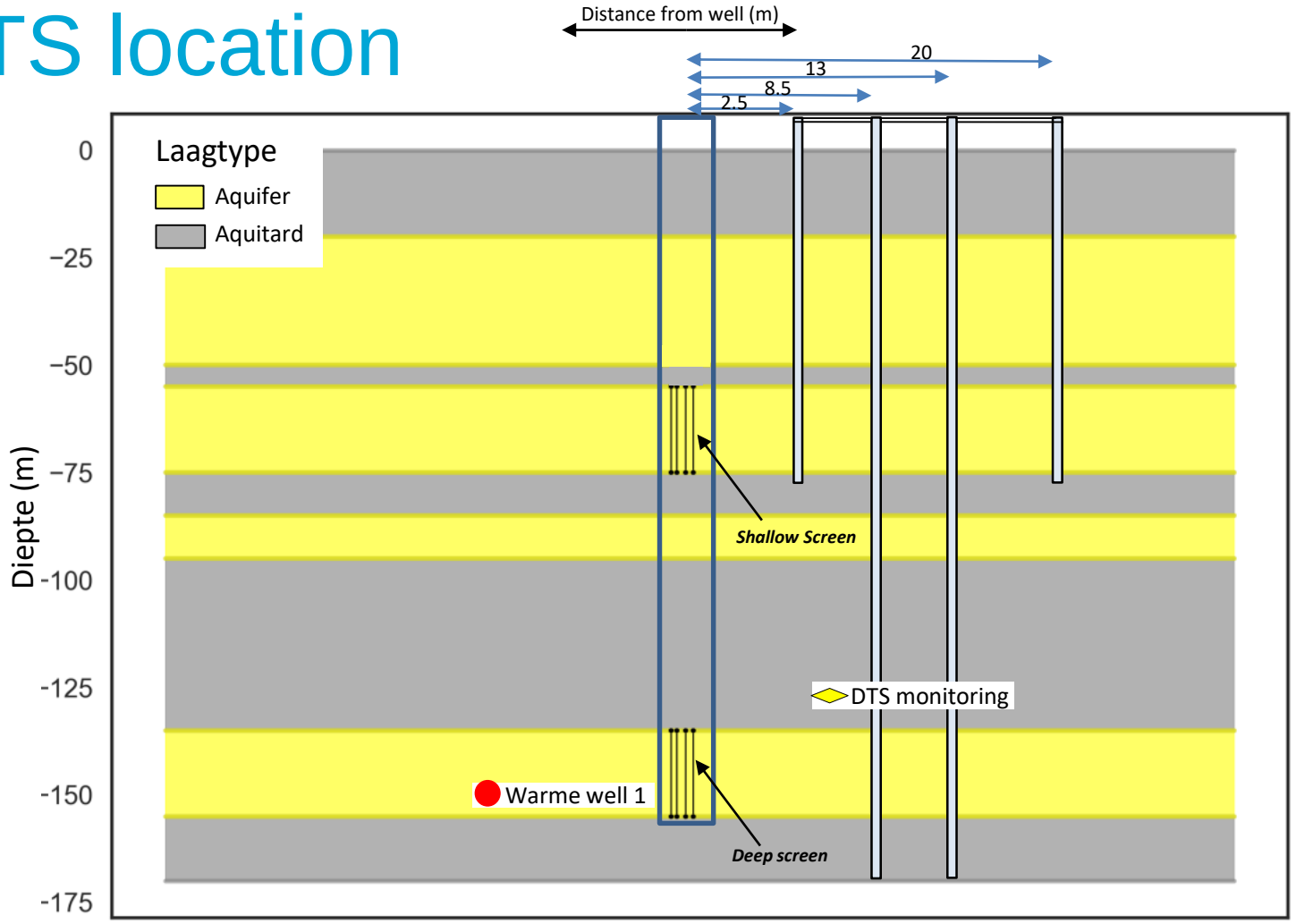
nitoring system





DTS location





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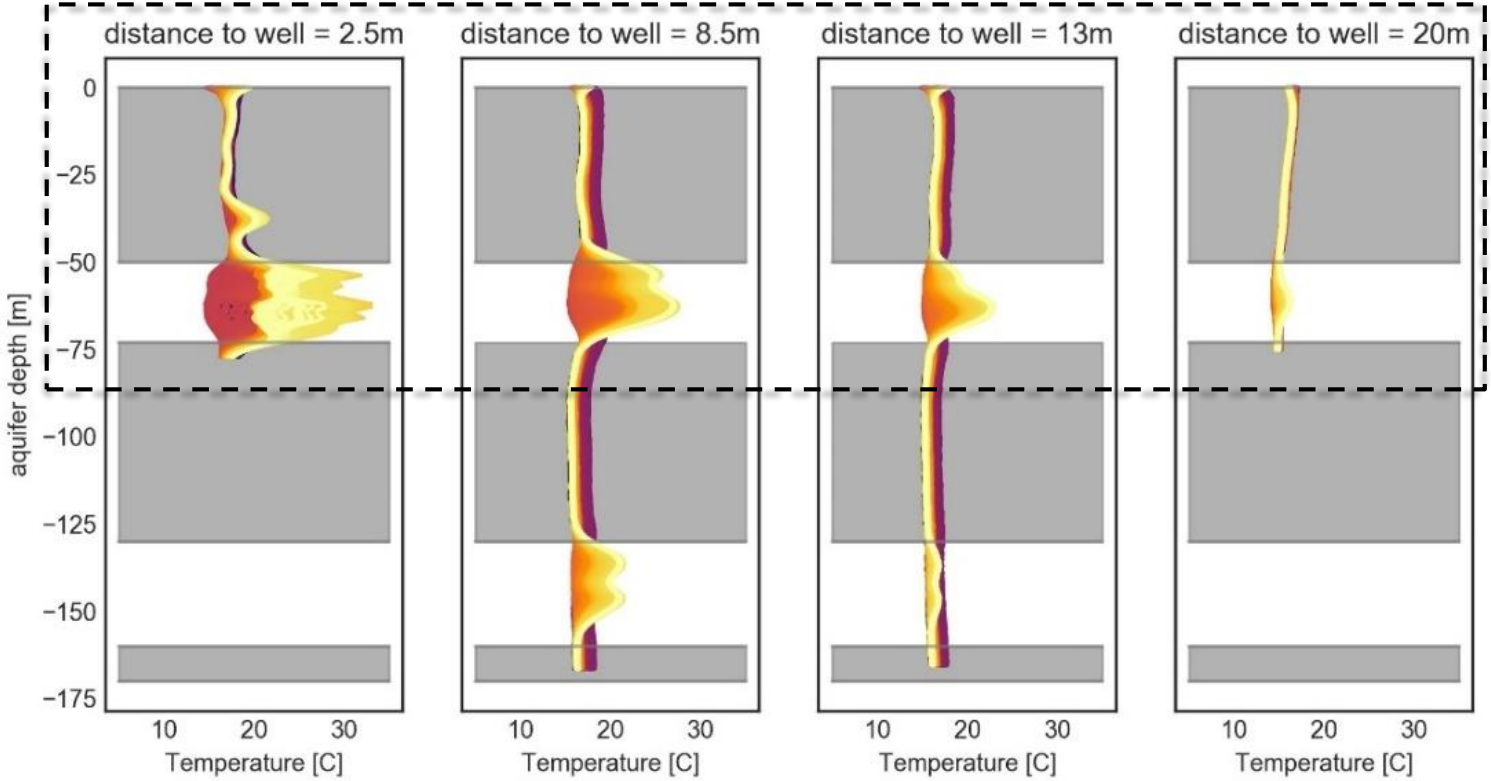
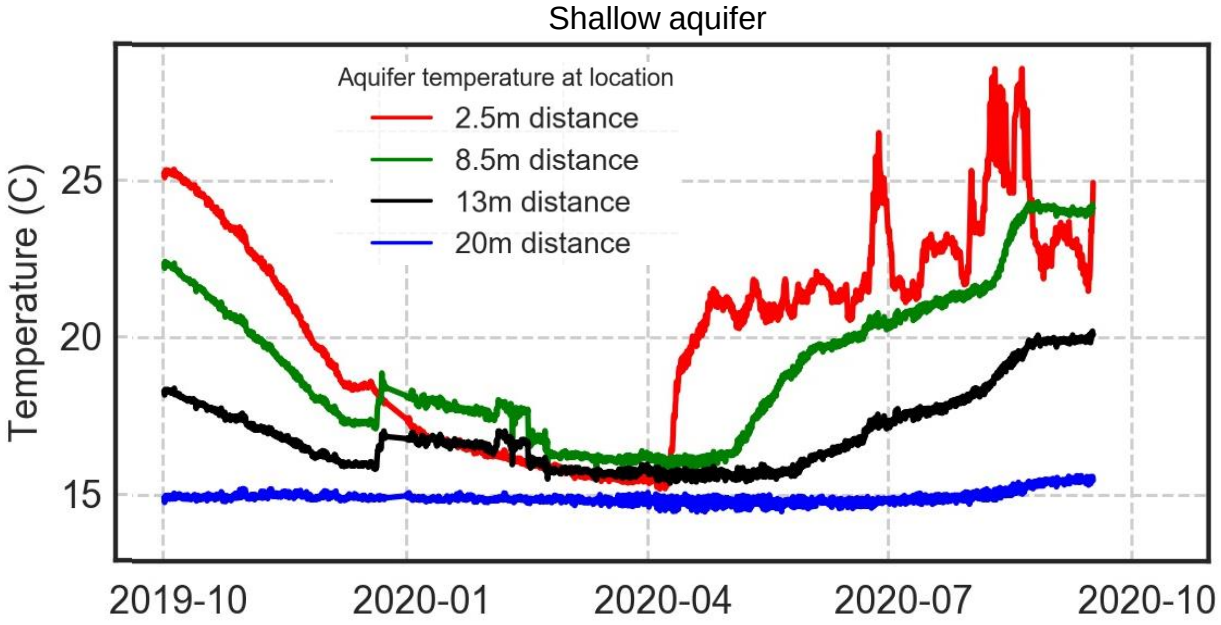
DTS monitoring



Summer 2020

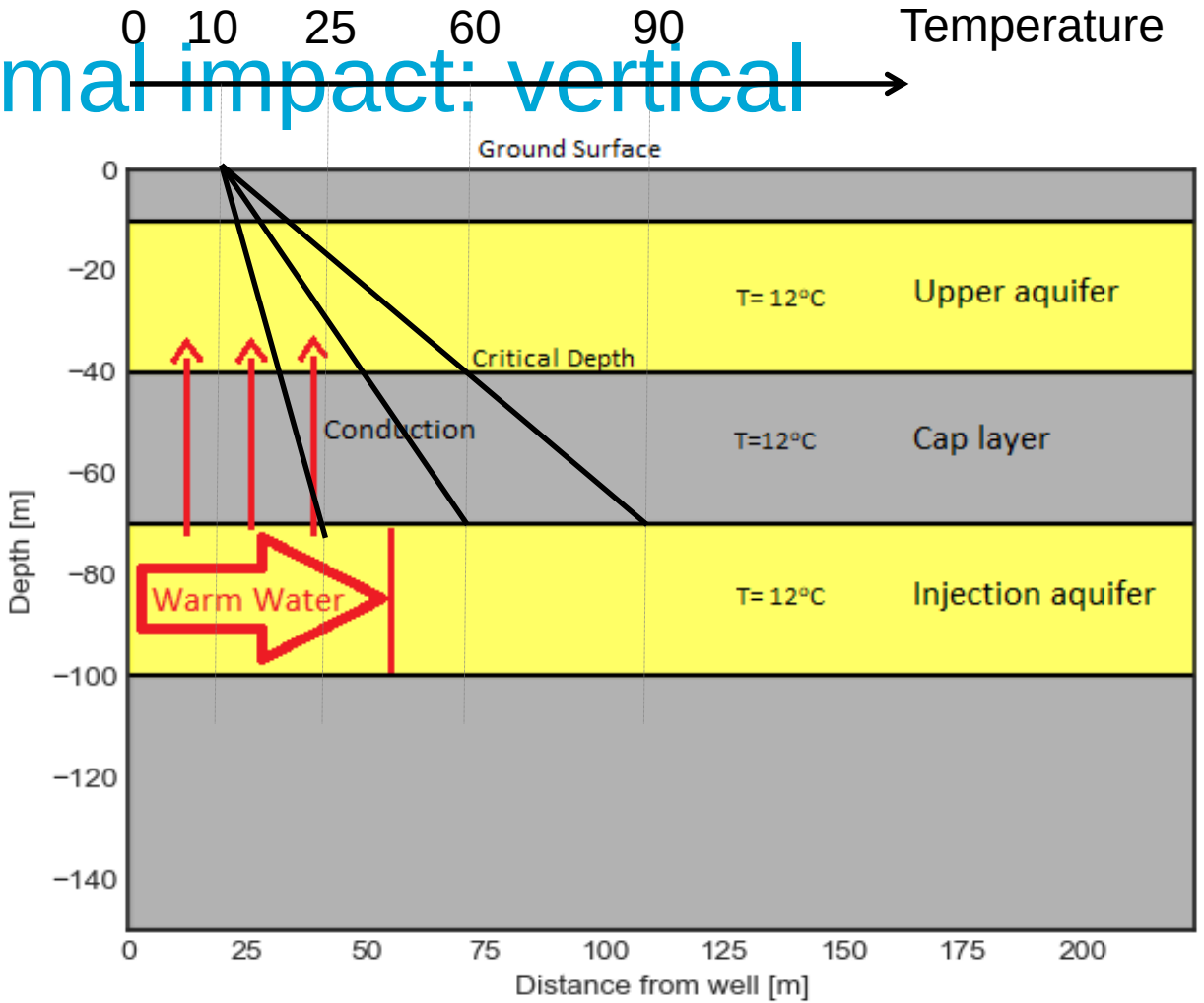
Thermal impact: horizontal



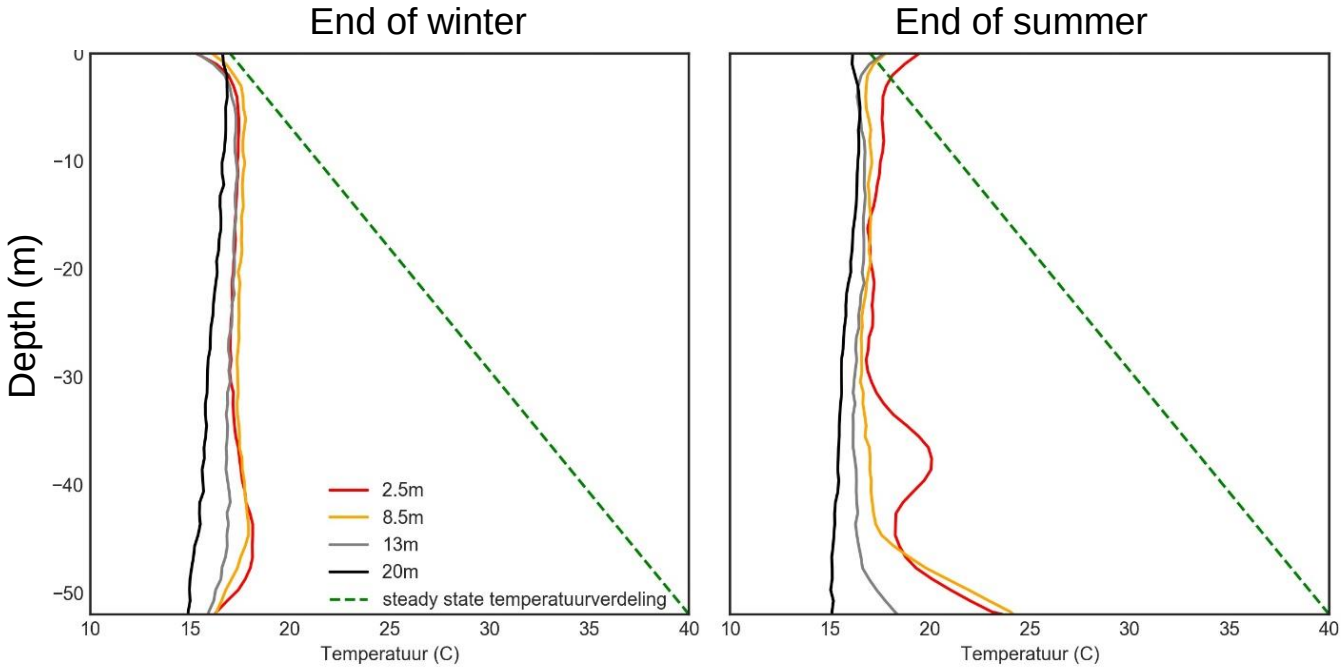
Long-term horizontal impact is small

Thermal impact: vertical

<u>Reference:</u>
Steady state conduction through clay layer



Thermal impact: vertical



Long-term vertical impact is small

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

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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!

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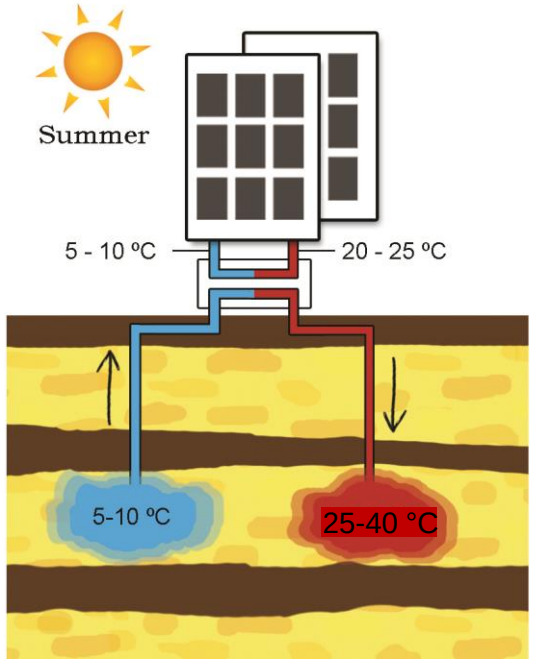
(HT-)ATES system of Koppert-Cress

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



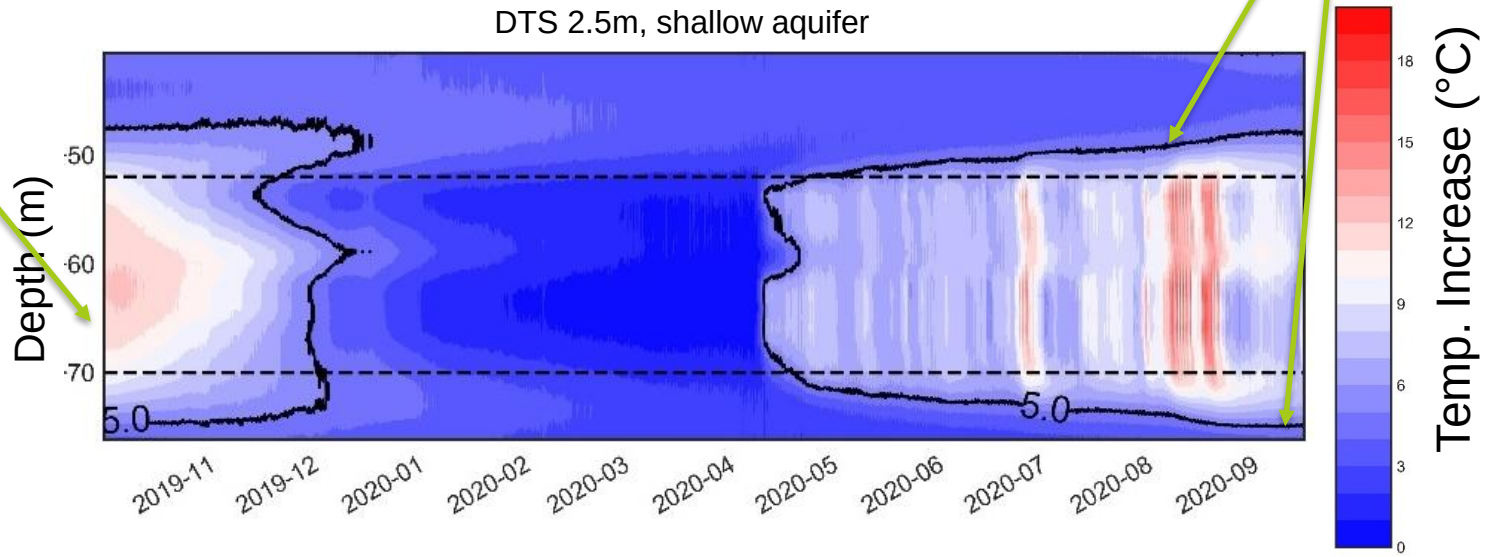
The content of this presentation: *Bloemendal, J.M.Beernink, S. Bel, N. van Hockin, A.E.Schout, G. (2020). Transitie open bodemenergiesysteem Koppert-Cress naar verhoogde opslagtemperatuur. Evaluatie van energiebesparingen en grondwatereffecten. KWR RAPPORT - KWR 2020.156*

Contributions from: Stijn Beernink & Niels Hartog

Thermal impact: vertical

aquifer

aquitards



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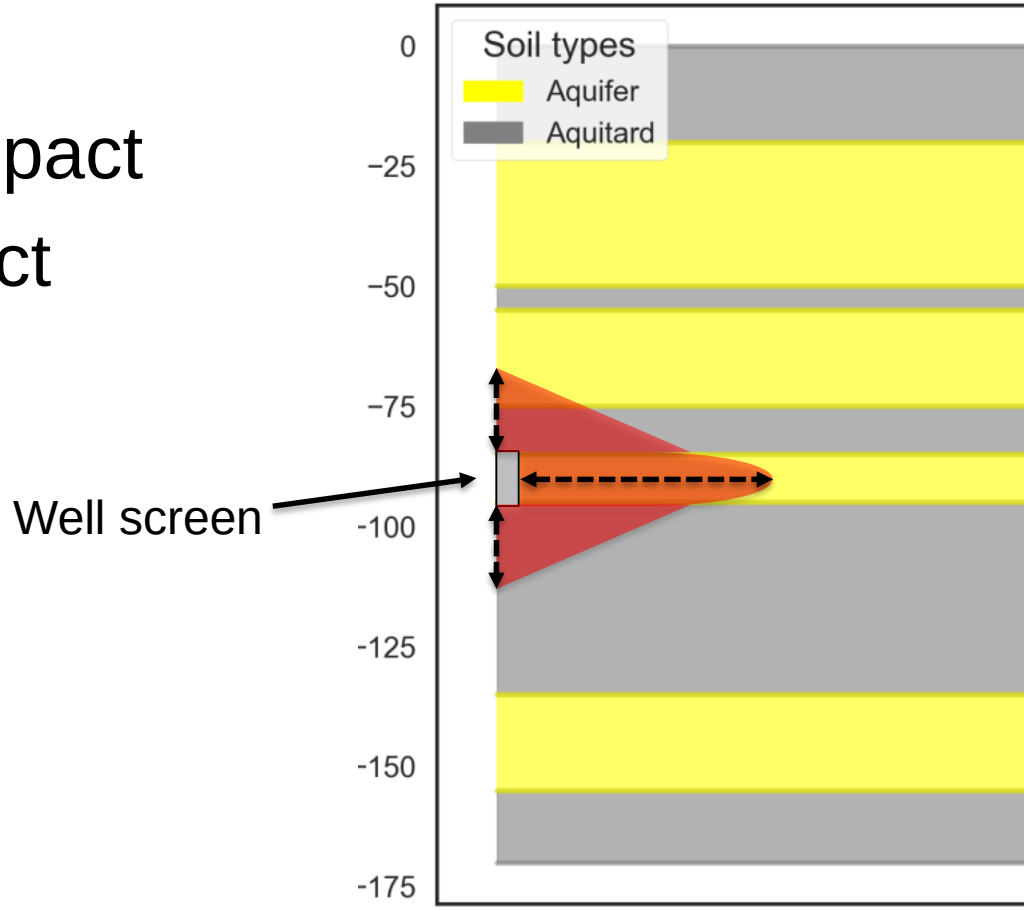
From temperature data to thermal impact

- Horizontal impact
- Vertical impact



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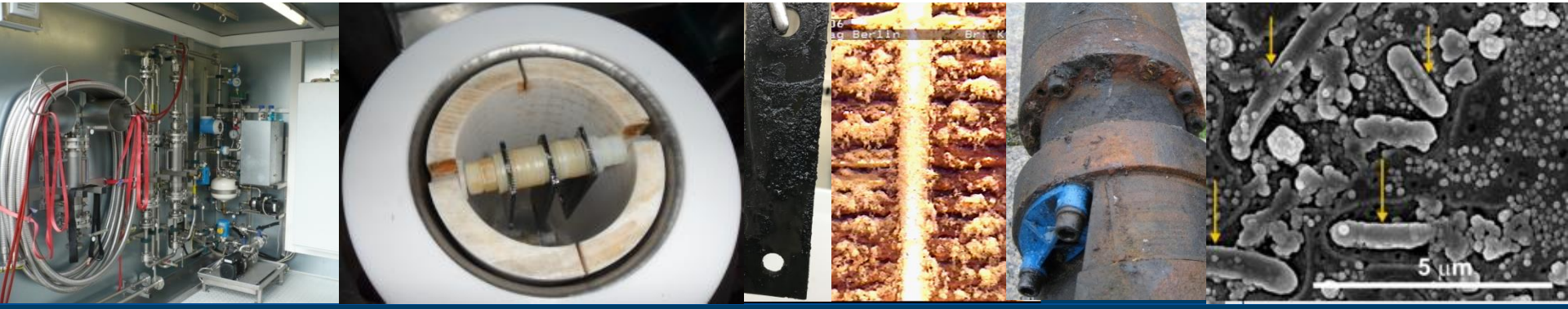
How to avoid corrosion and scaling in ATES systems in Germany?

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

Hochschule Merseburg



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



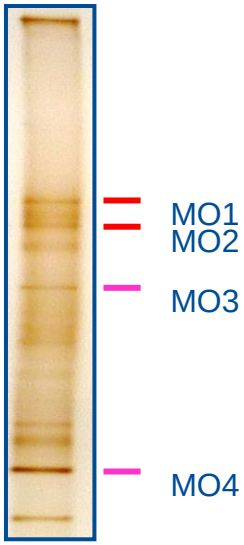
DNA

PCR



DNA-Fragment Amplification

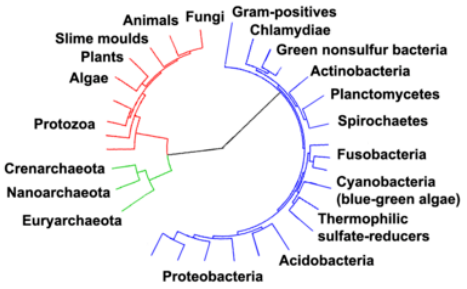
Genetic Fingerprinting



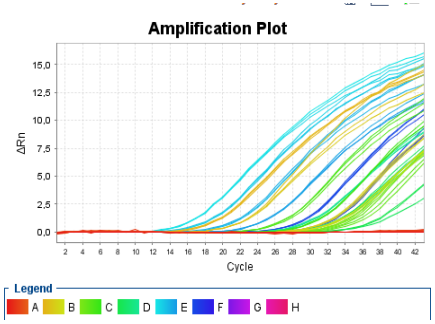
MO1
MO2
MO3
MO4

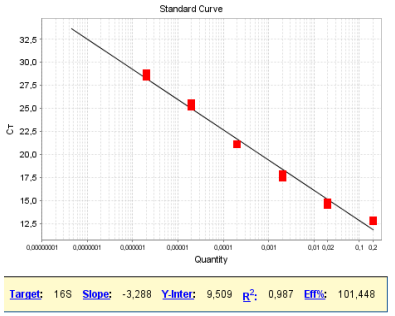
Sequenzing

DNA Data base



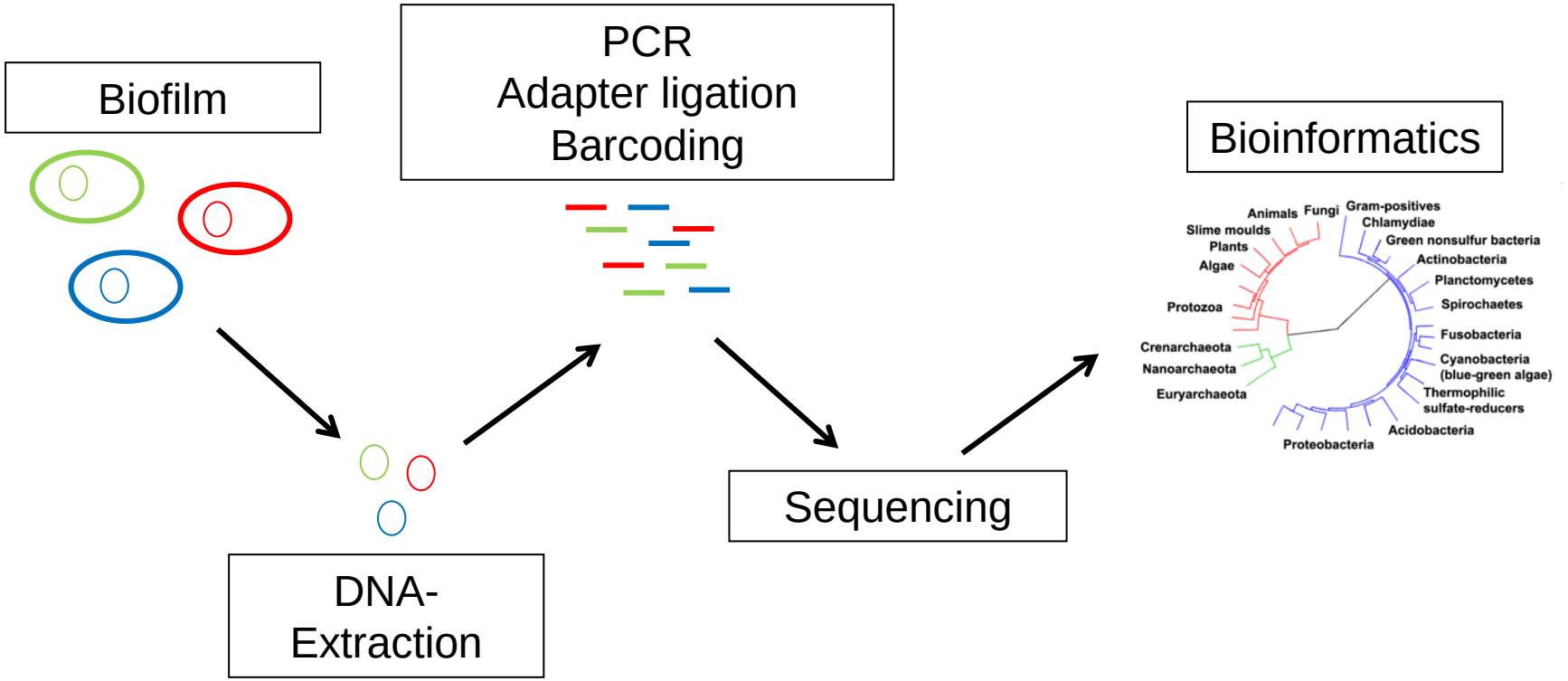
Quantitative real-time PCR





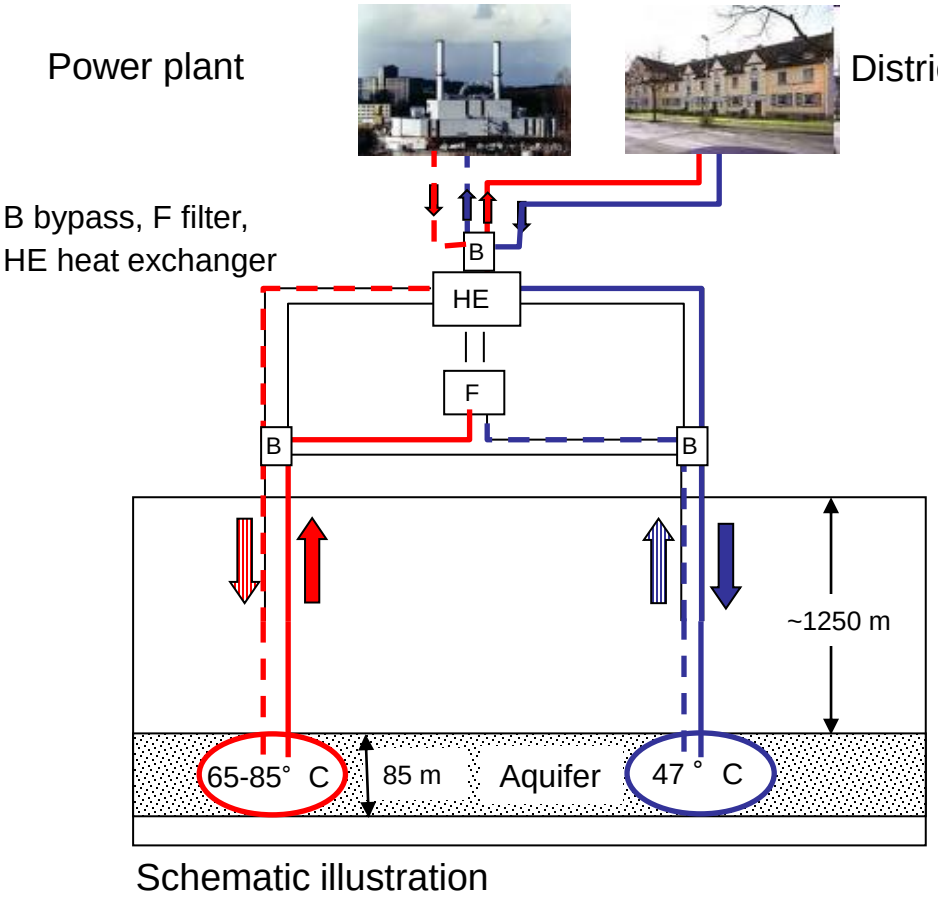
- Relative quantification related to the total community
- Absolute quantification of species or groups

Microbiom analysis of Fluids and Biofilms



gefördert vom Bundesministerium für Wirtschaft und Energie aufgrund eines Beschlusses des dt. Bundestags
Projektträger Jülich Forschungszentrum Jülich
HOME HOCHSCHULE MERSEBURG(FH) 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

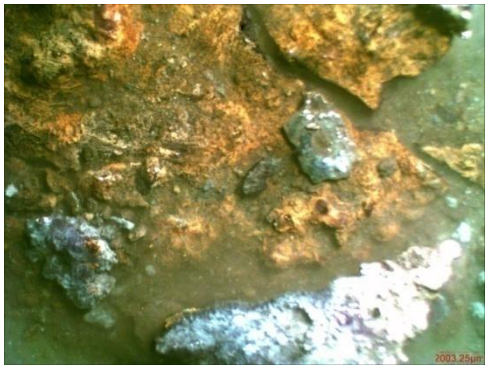
2007-2011	T [°C]	pH [-]	Na^+ [g l^{-1}]	Cl^- [g l^{-1}]	NO_3^- [mg l^{-1}]	SO_4^{2-} [mg l^{-1}]	Fe^{2+} [mg l^{-1}]
Cold well (CW)	46.7	6.1	47.0	78.5	b.d.l.	912	16.9
Warm well (WW)	73.2	6.0	47.2	78.5	b.d.l.	983	14.7

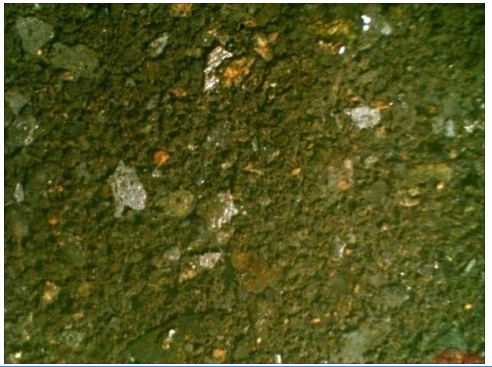
Corrosion and Scaling in the “cold well”



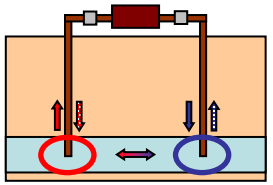
Microorganismen involved?







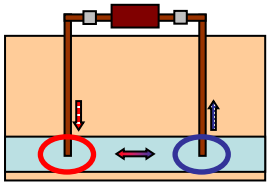
Effects of plant downtime



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 [µg 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)

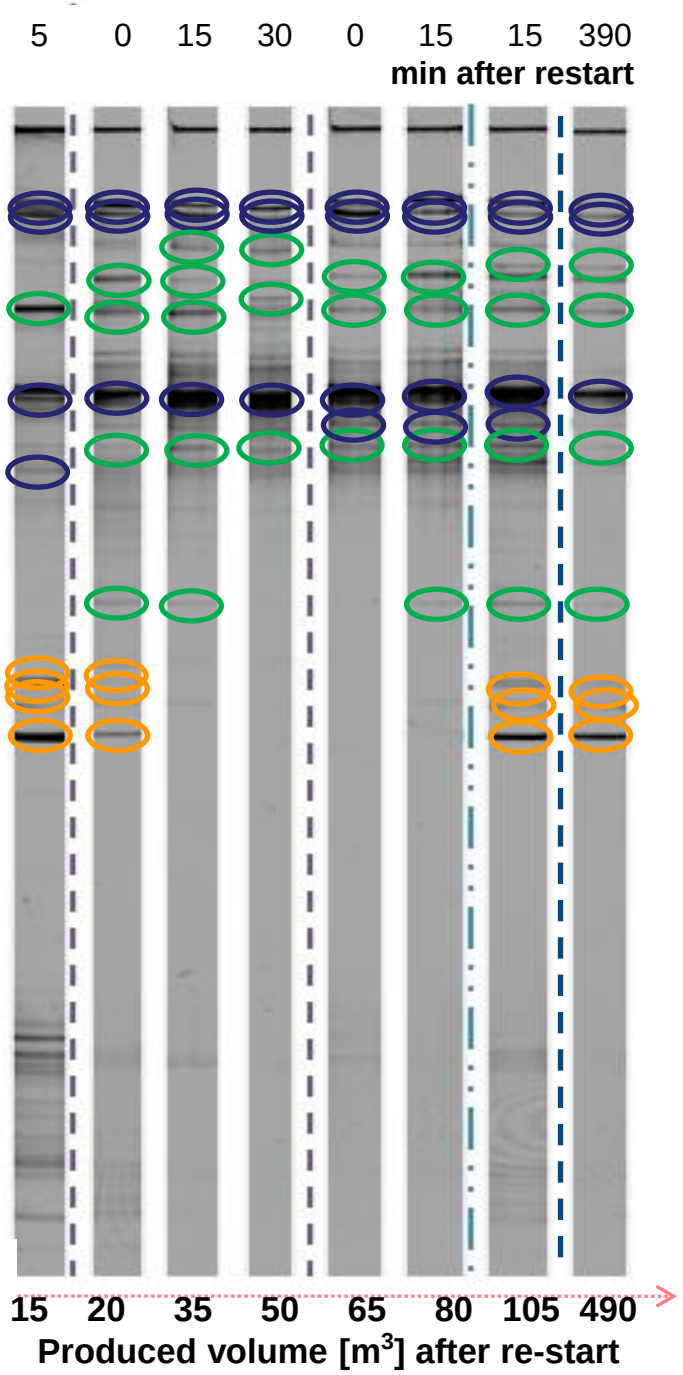
Fermentative bacteria

Sulfur oxidizing bacteria (SOB)

→ Oxygen ingress

→ Sulfur cycling

→ Increased corrosion rates

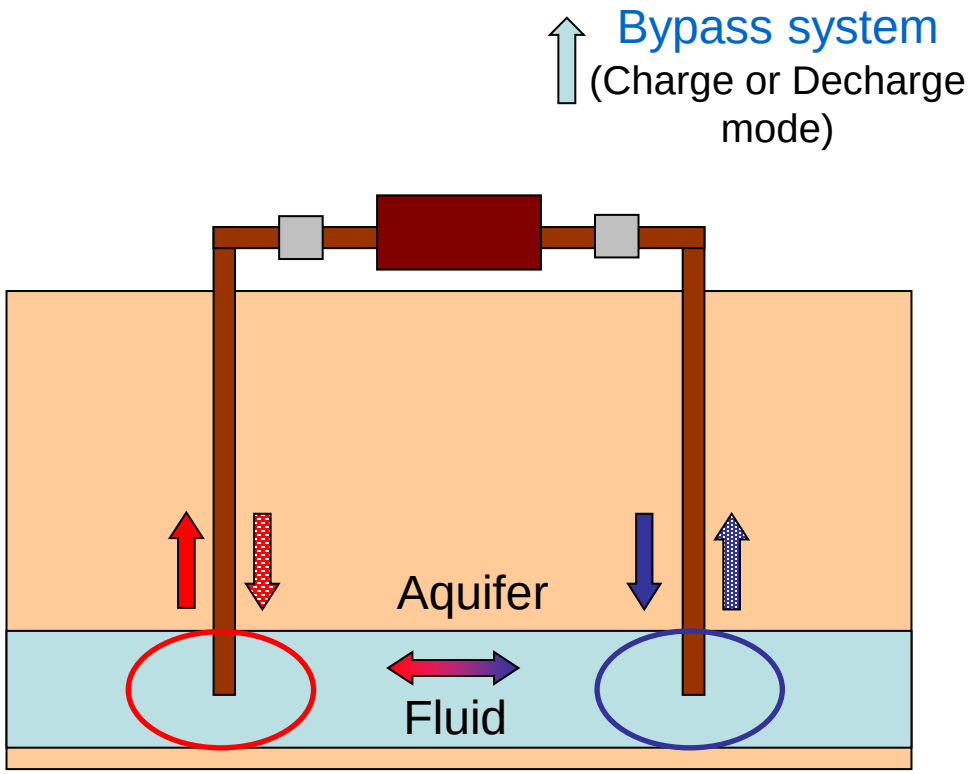


Short stop of operation (< 3h)

Long stop of operation (19h)

Westphal *et al.* 2016

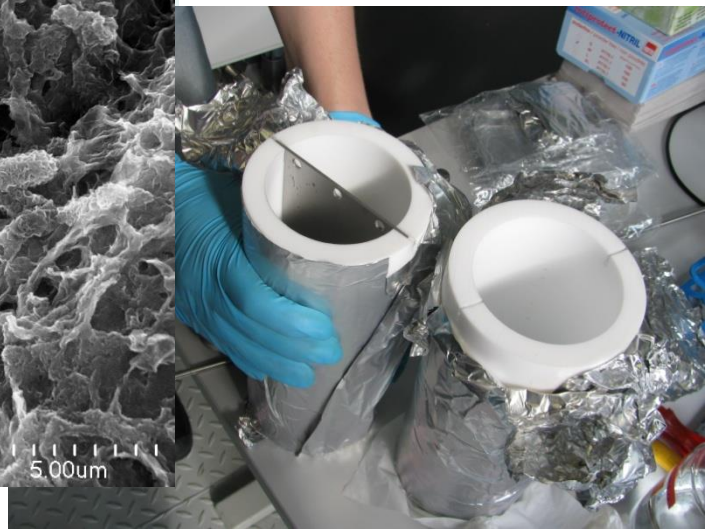
Geothermal Heat Store Neubrandenburg



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



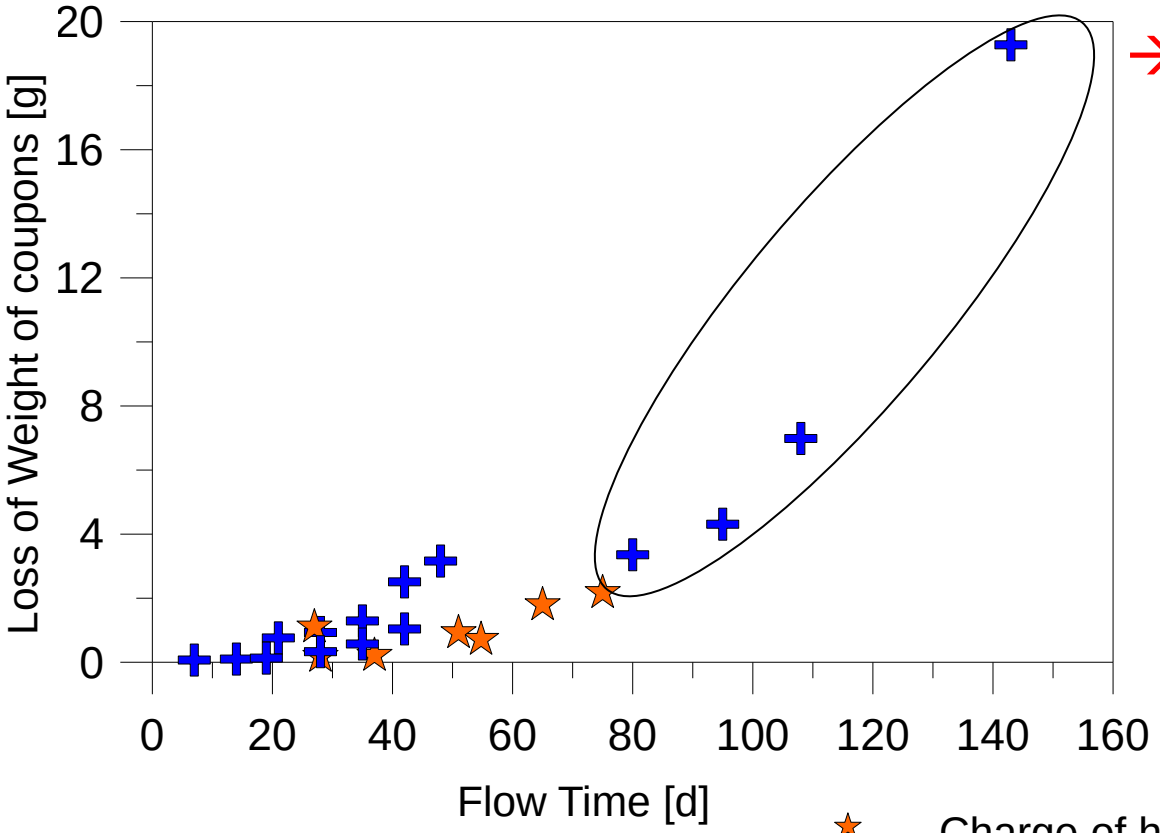


Cooling capacity:

50 kW

Kleyböcker *et al.* 2017

Corrosion over Exposure Time (Flow Time)



→ Change of flow direction and different plant down times



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HOME HOCHSCHULE MERSEBURG(FH) University of Applied Sciences

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



Vessel A:
Coupons: 2
Temperature: 40 ^{o}C

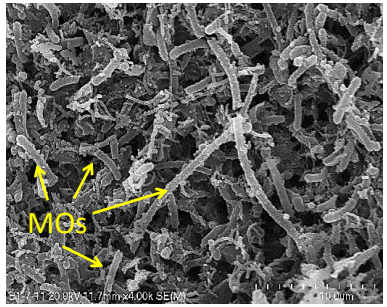
Vessel B:
Coupons: 2
Temperature: 40 ^{o}C & every 14 days: 78 ^{o}C (6 h)

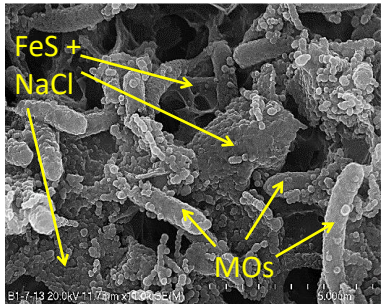
Kleyböcker *et al.* 2017

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

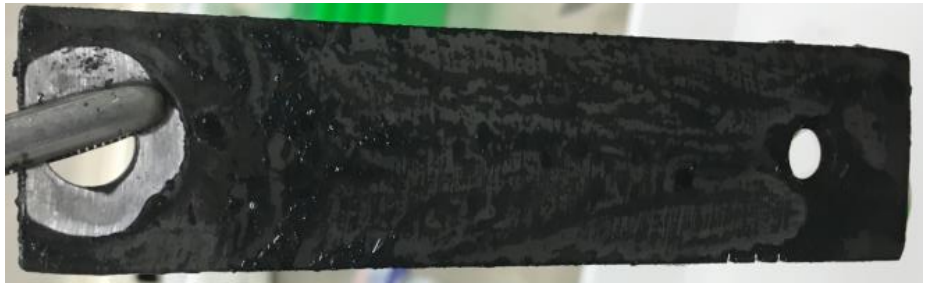
Vessel 1: T= 40 °C







Vessel 2: T= 40 °C & 78 °C (6 h)



→ Thinner biofilm layer after shock temperature

Kleyböcker *et al.* 2017

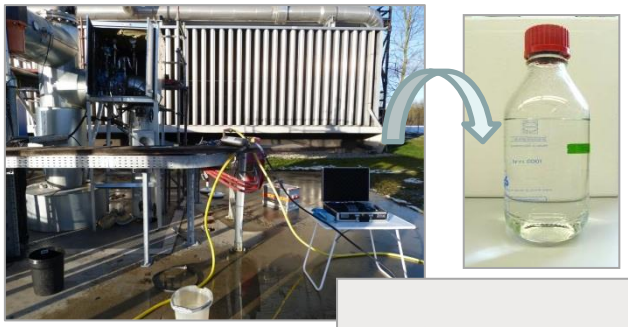
Summary - Heat Store Neubrandenburg

- 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

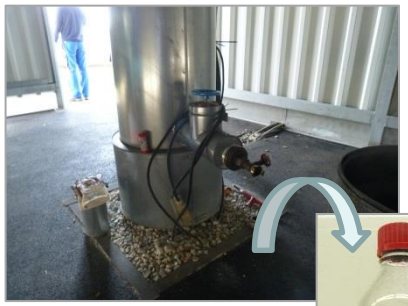




After heat exchanger



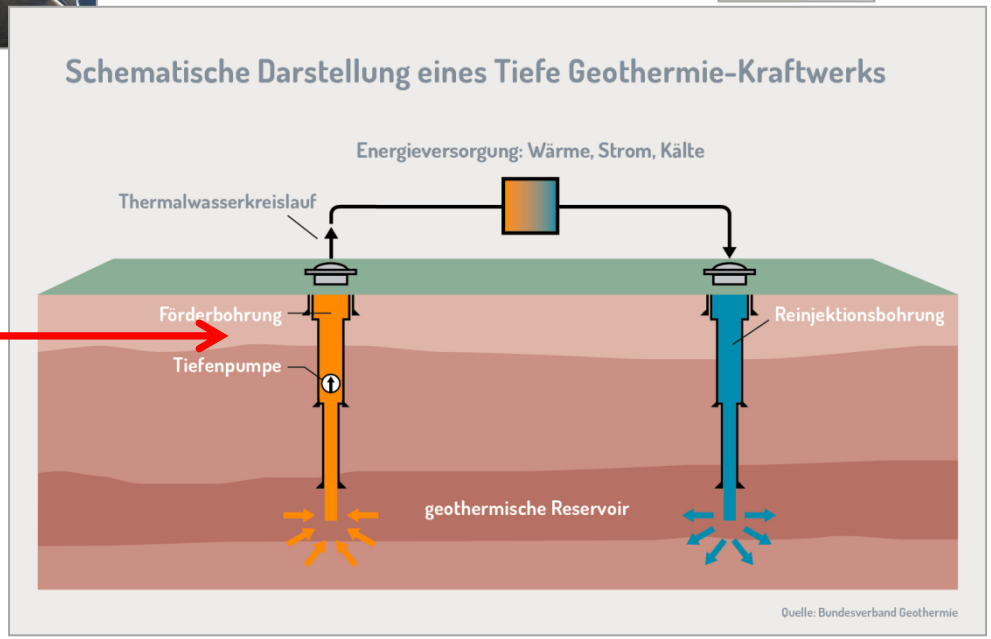
Injection well



Dosage of Inhibitor



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

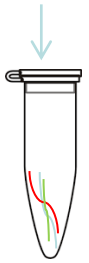


Otten *et al.* 2021

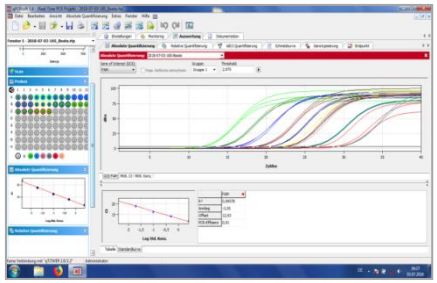
Increase of bacteria after heat extraction and inhibitor dosage

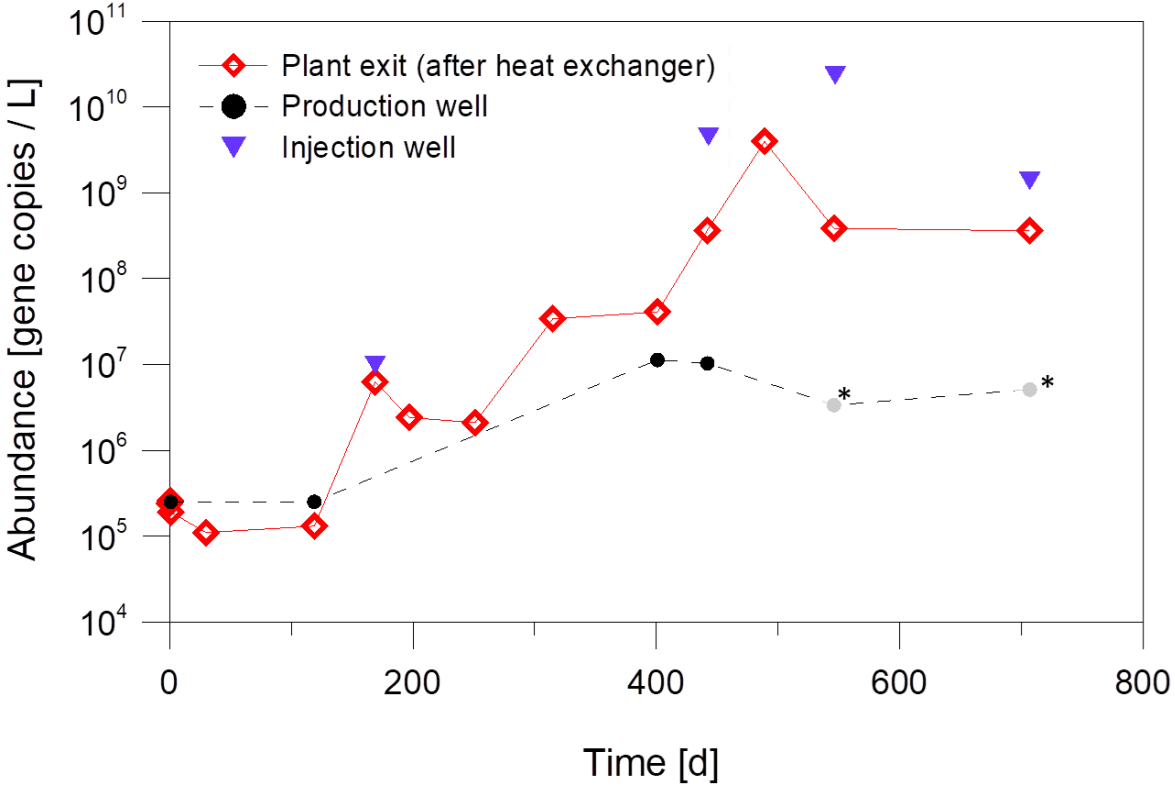
quantitative PCR (16S rRNA Bacteria)











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.

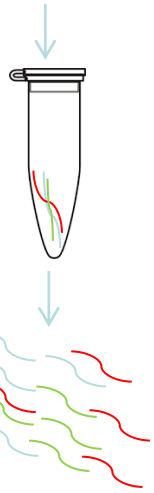
* below the sample specific detection limit

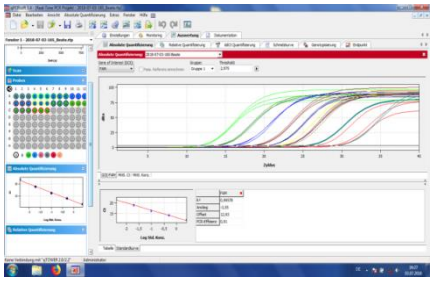
Otten *et al.* 2021

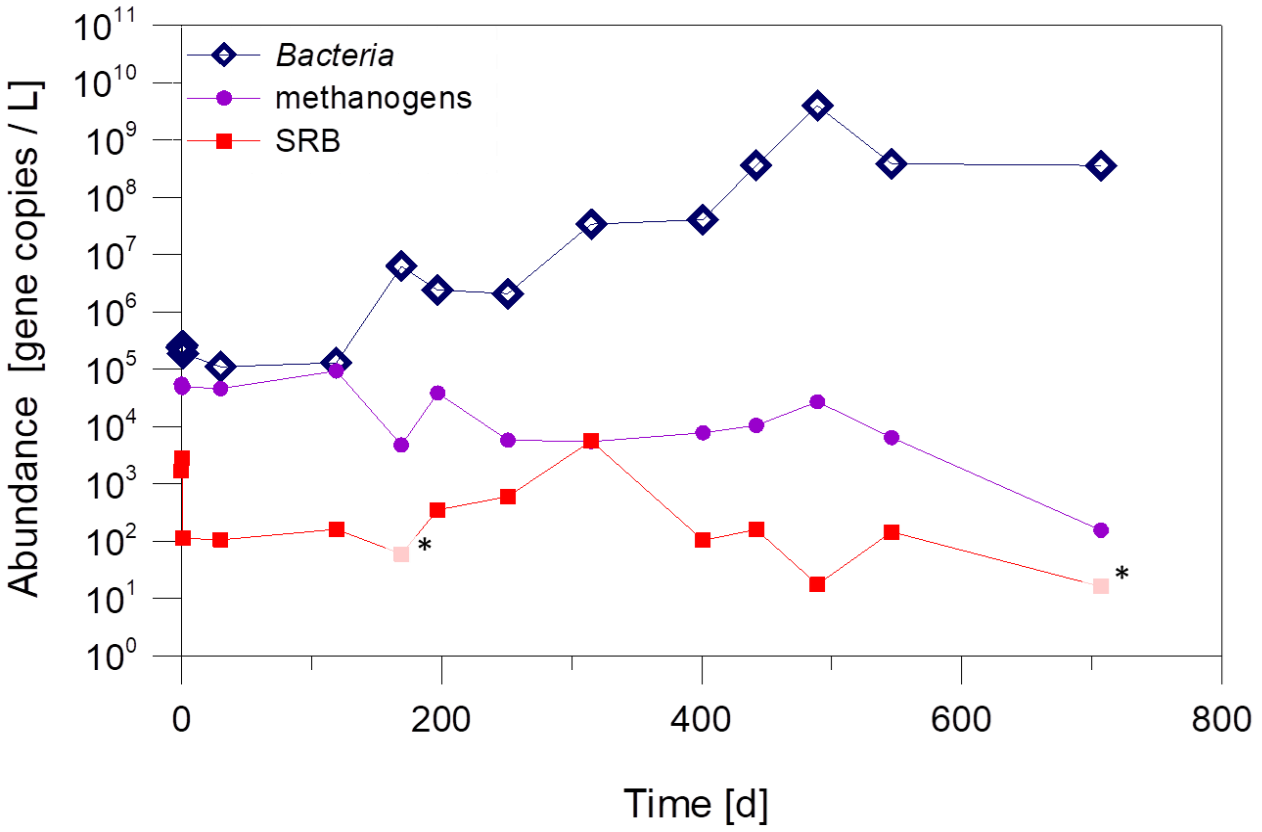
Increase of bacteria after heat extraction and inhibitor dosage

(qPCR of Bacteria, Sulfate-reducing bacteria and Archea)









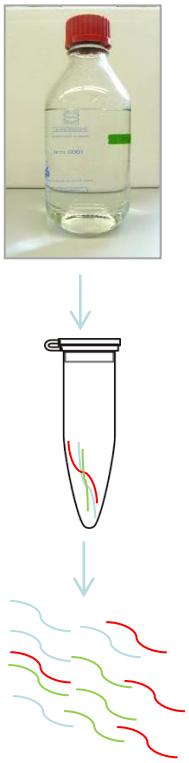
Quantification with qPCR with primers for the 16S rRNA gene (*Bacteria* and methanogenic archaea) and the *dsrA*-gene for sulfate-reducing bacteria.

* below the sample specific detection limit

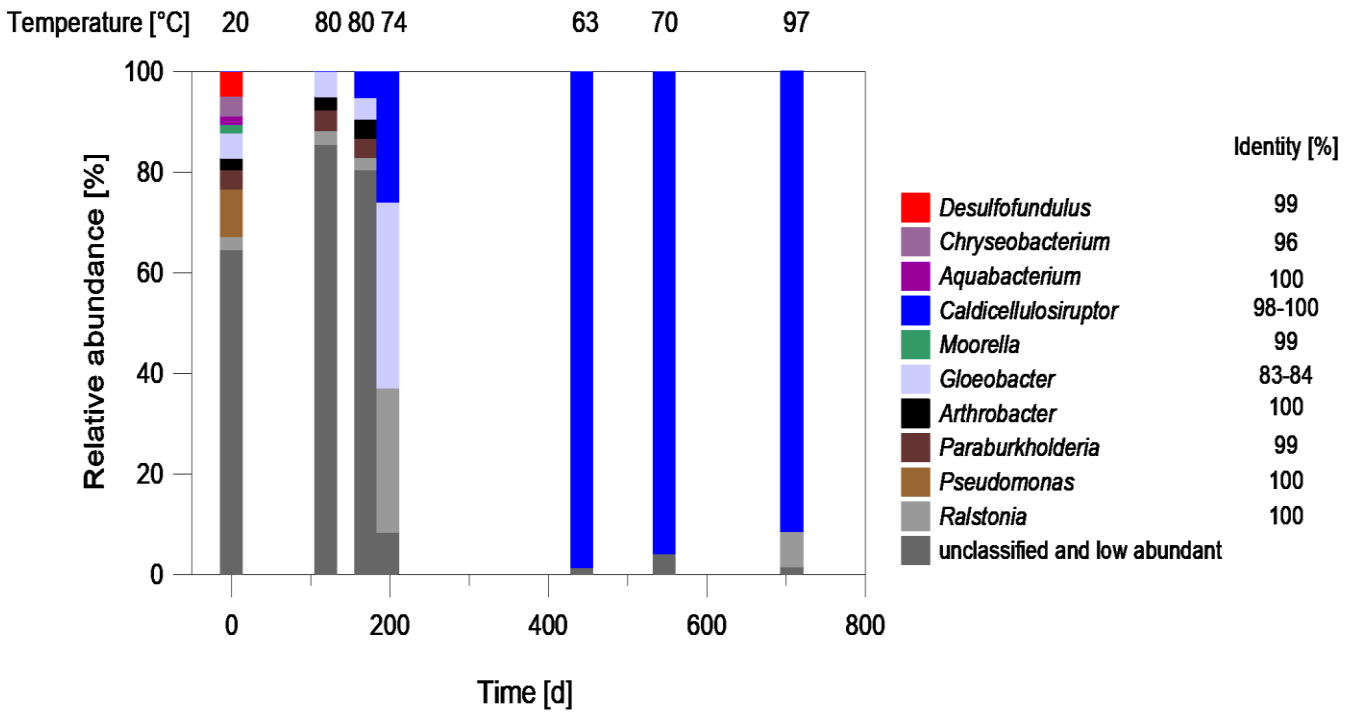
Otten *et al.* 2021

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 University of Applied Sciences
TU berlin
SWM Stadtwerke München
GTN Ingenieure & Geologie
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.

ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

Online seminar
Nutrient recovery

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



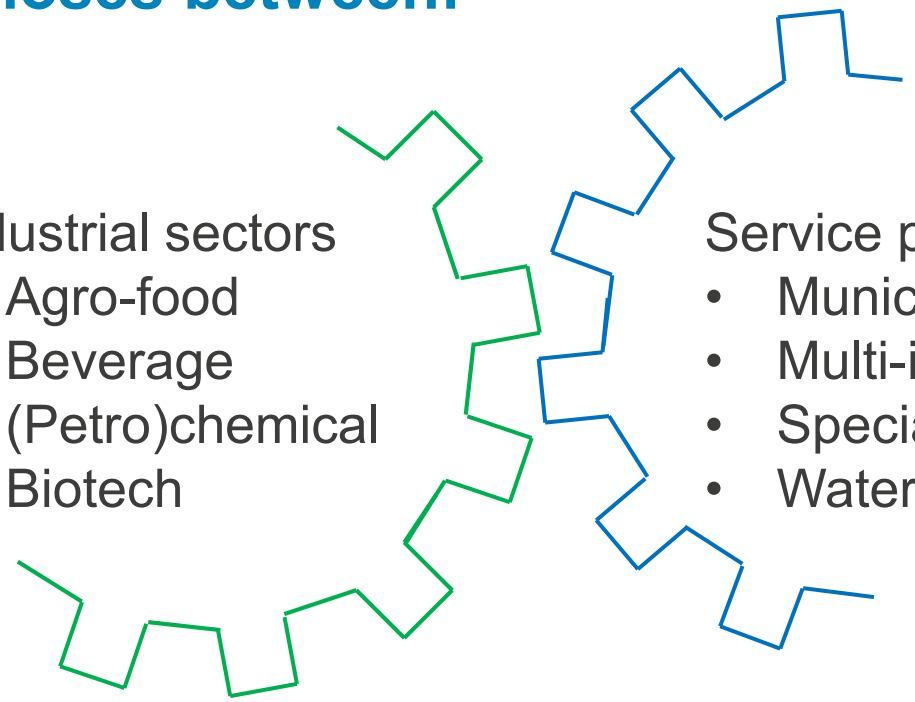
December, 17th 2020.

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

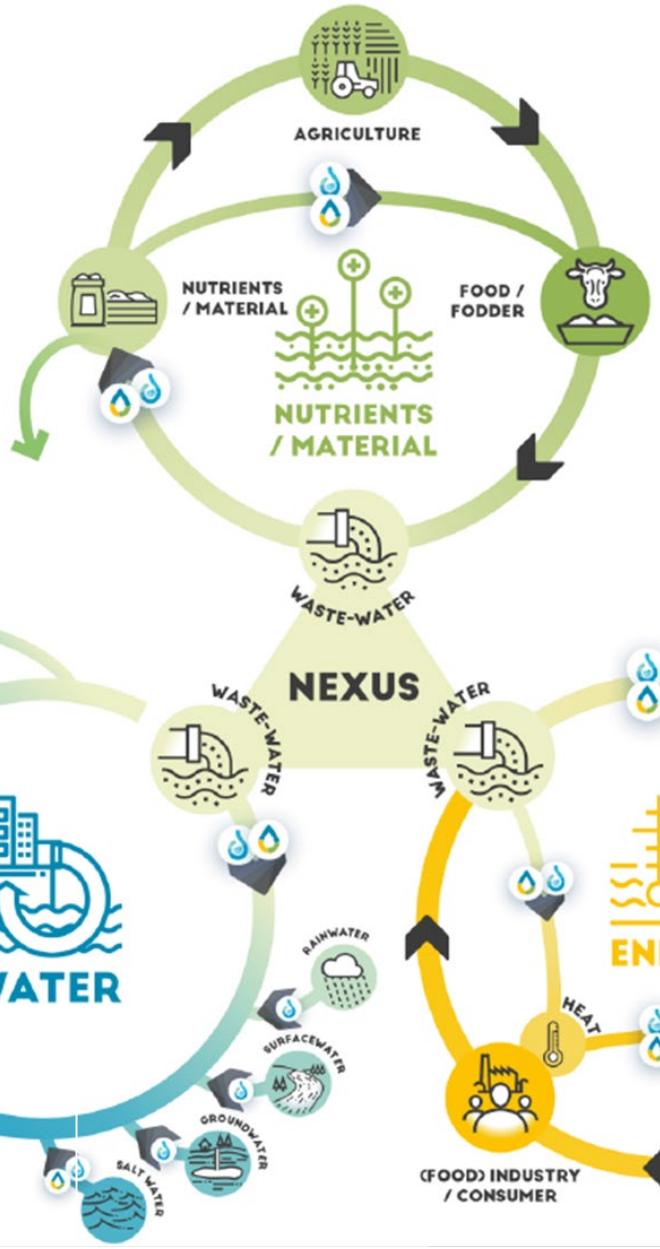
27 Partners

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

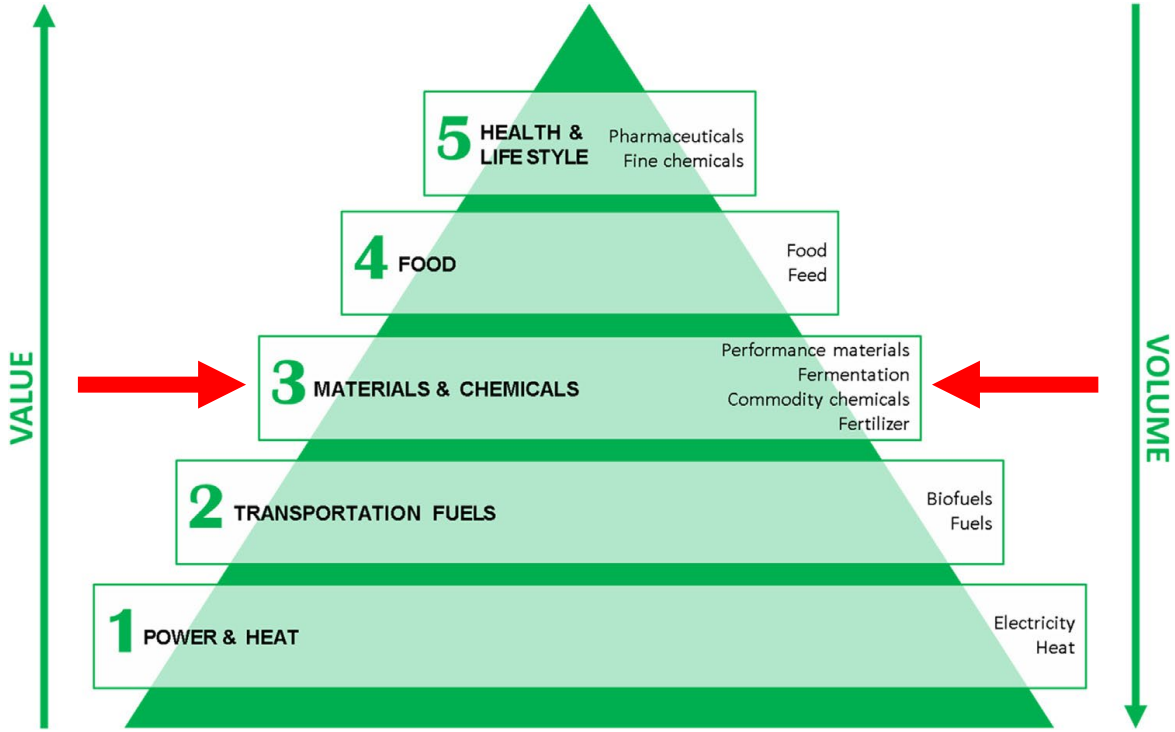
- Membrane technologies
- Adsorption technologies
- Advances oxidation processes


A. Kleyböcker

KOMPETENZZENTRUM Wasser Berlin

- Biogas technologies
- Heat Recovery
- Digitalization

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

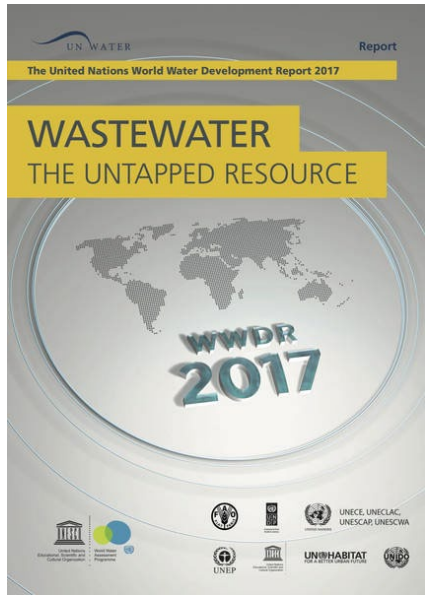


The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

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"***





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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



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Agenda

15:15 **Nutrient recovery in CS2**: KWR expertise in Nutrient recovery and conceptual presentation of Nutrient recovery in CS2

T*avishi 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)



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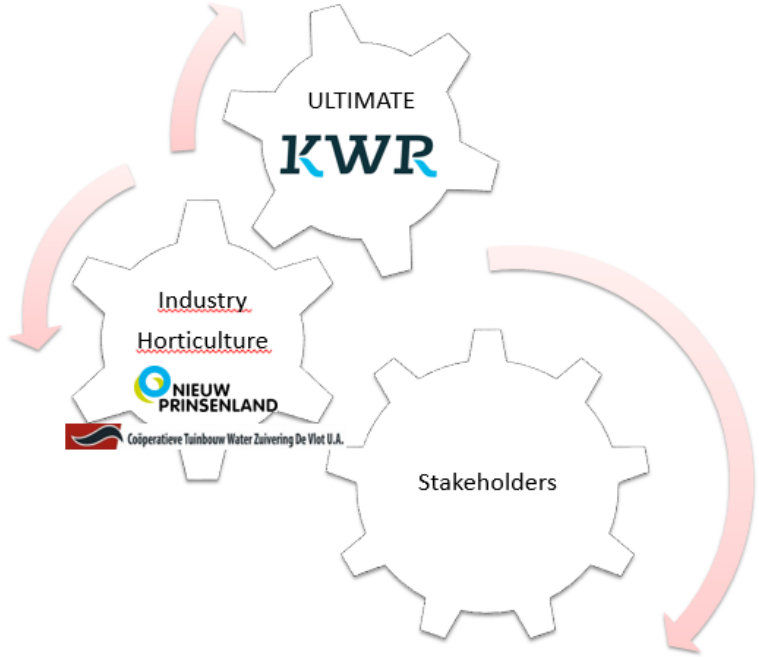
Horticulture – Industry symbiosis



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





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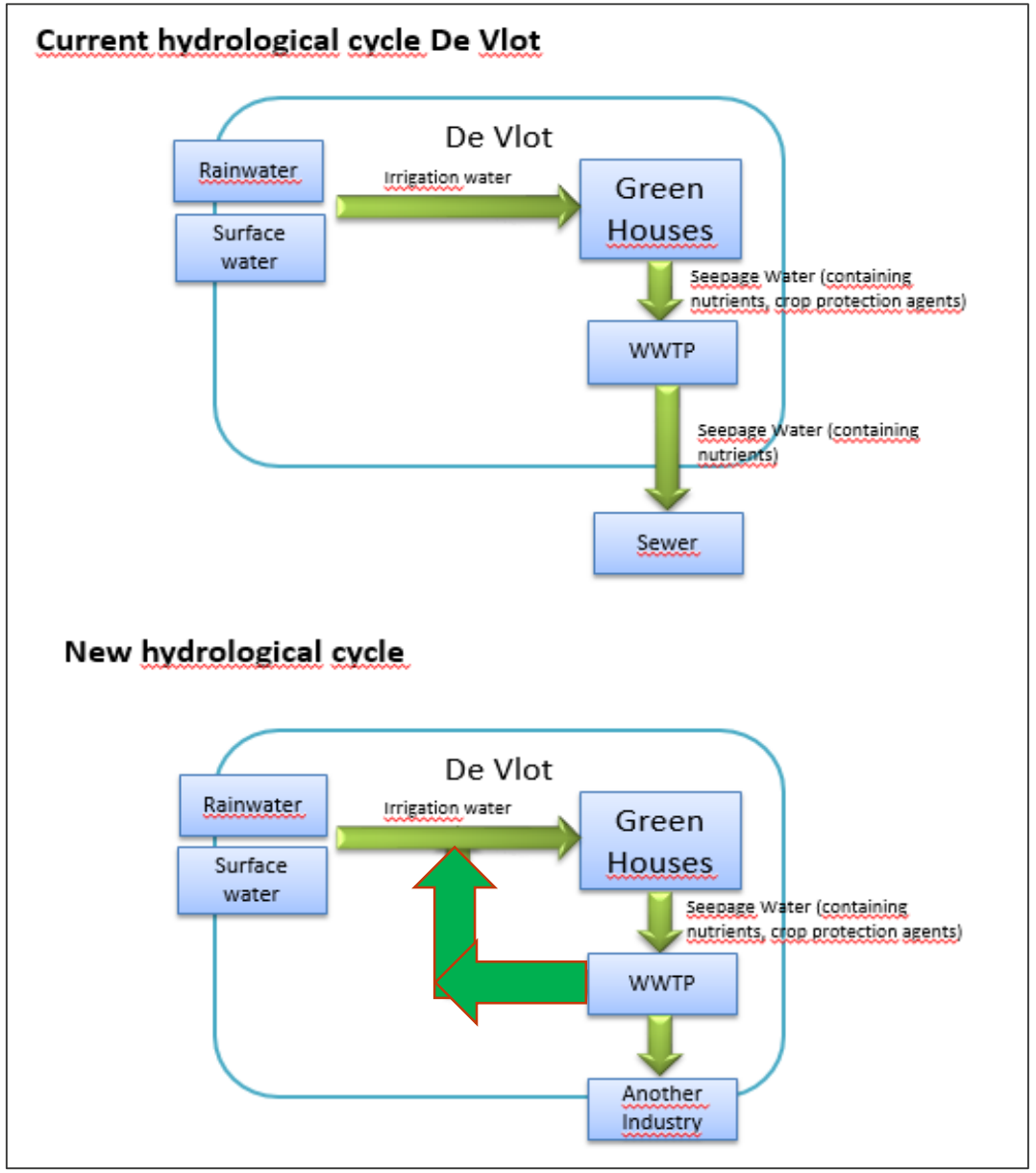
Fate of Nutrients

- 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



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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





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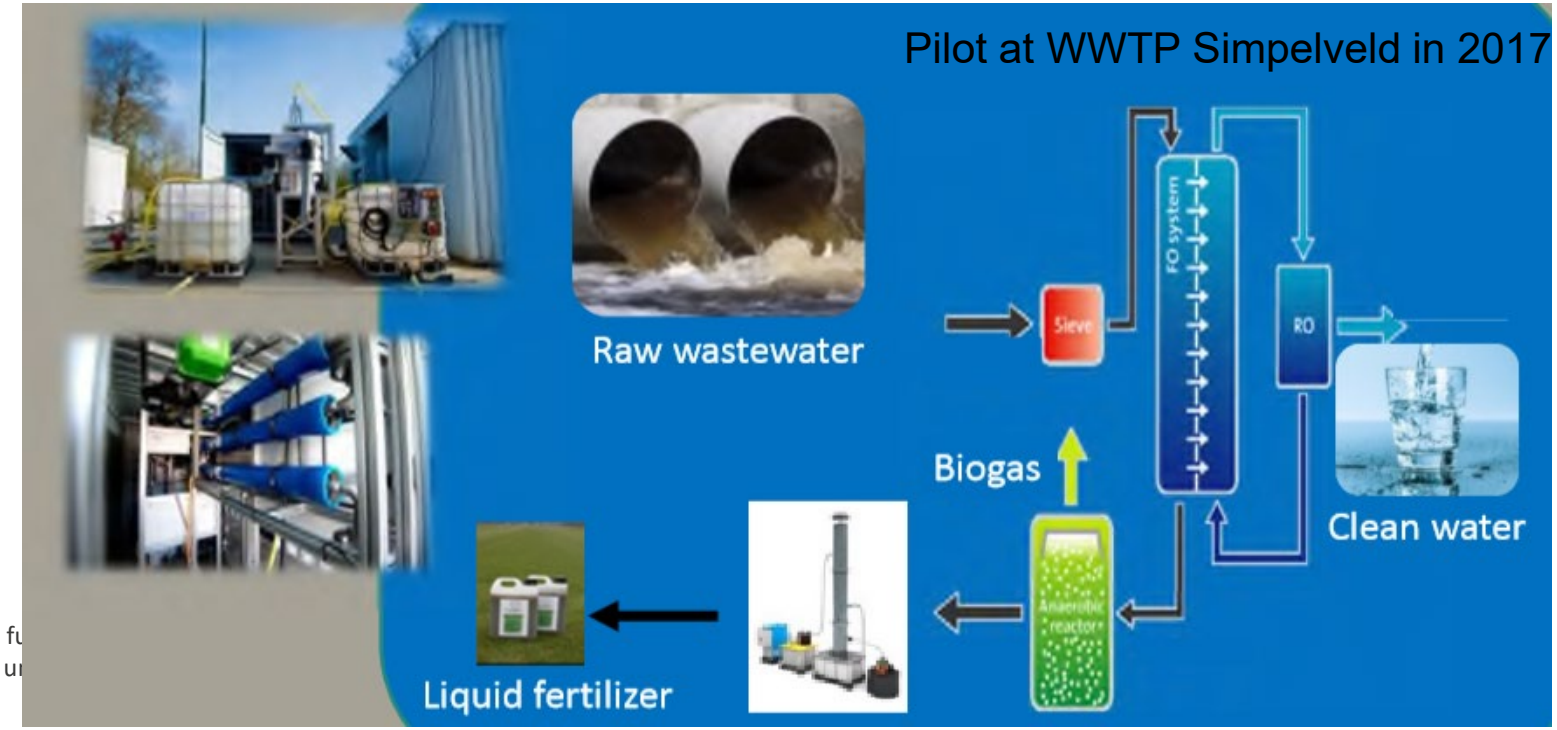
KWR and Nutrient Recovery

- 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

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WATER SMART INDUSTRIAL SYMBIOSIS

Thank You!

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WATER SMART INDUSTRIAL SYMBIOSIS

CS7 – Tain (Glenmorangie distillery)

Cranfield University

Aquabio



Meeting: December, 17th 2020

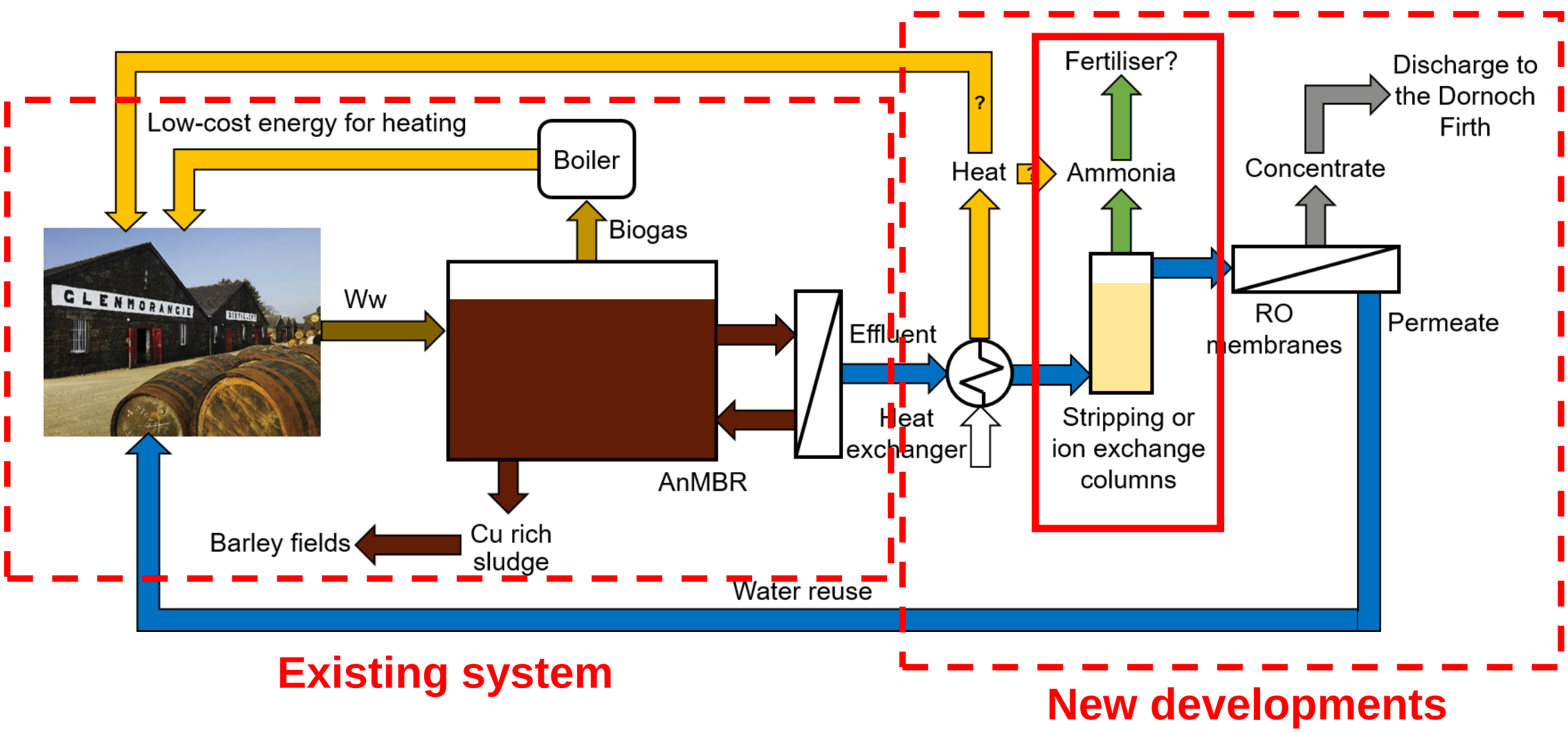
CS7


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



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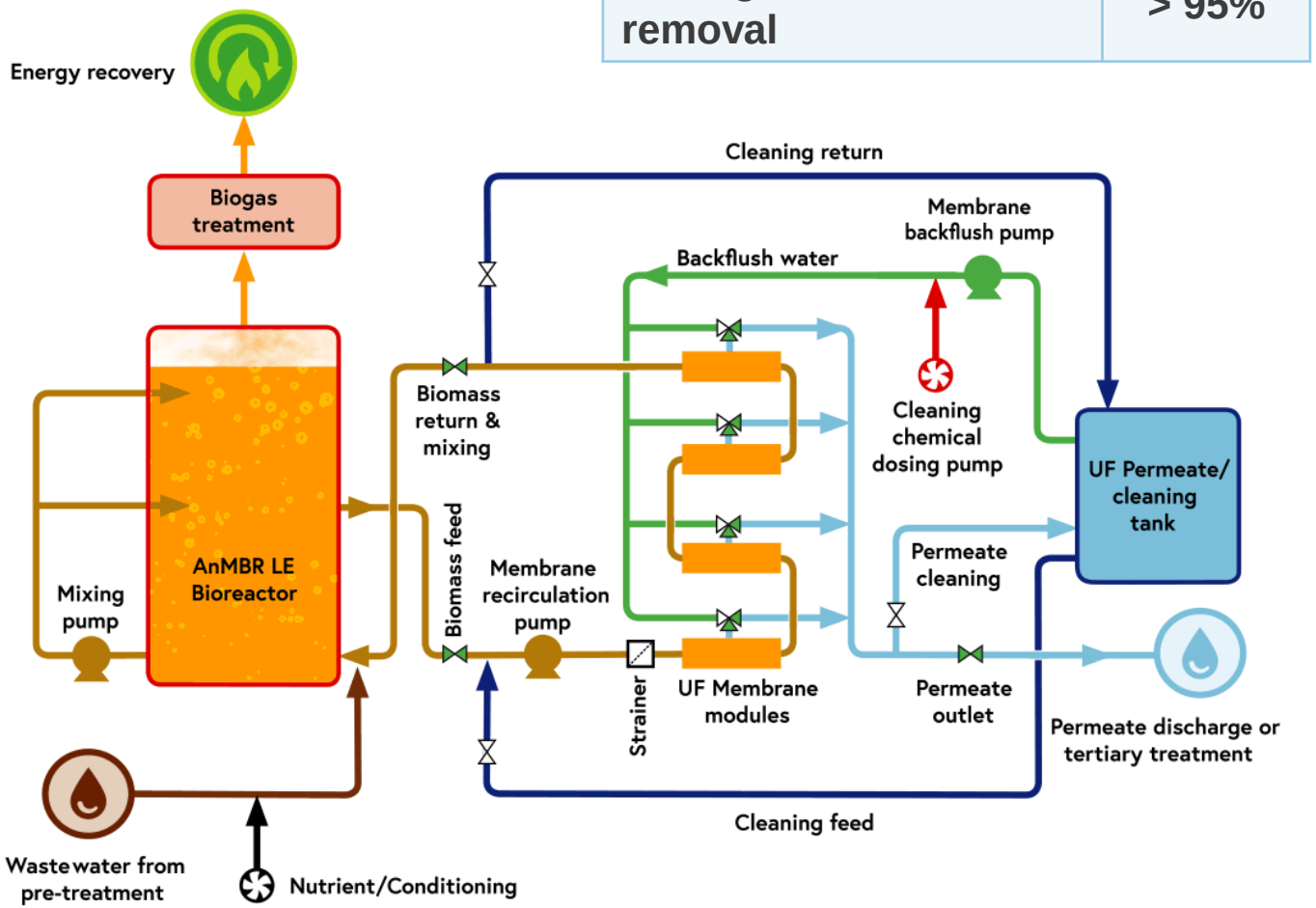
AnMBR LE™

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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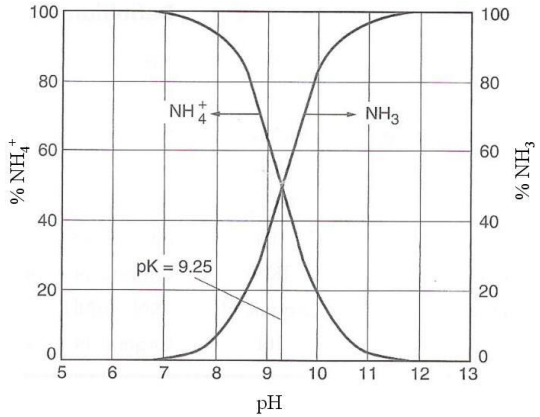
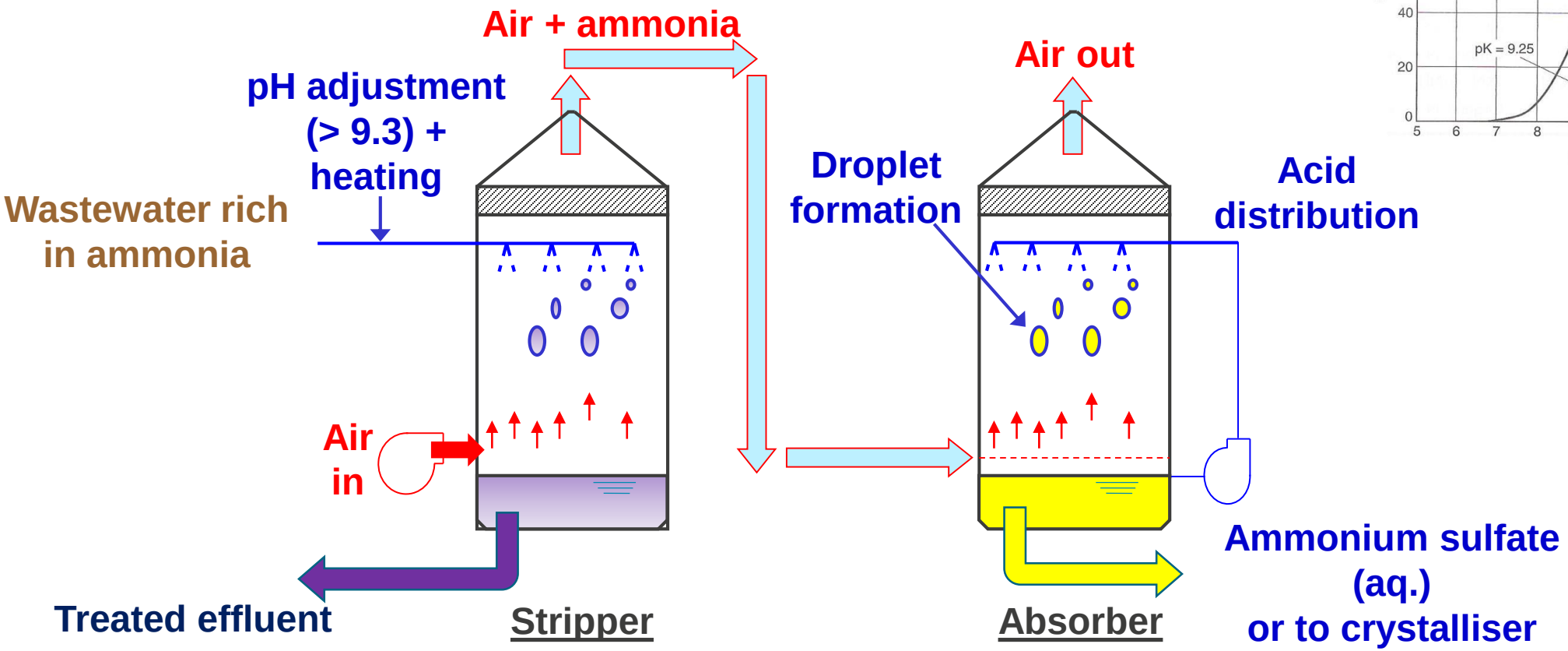
Stripping columns





Key attributes:

- **Established technology**
- **Large footprint**
- **Energy intensive**

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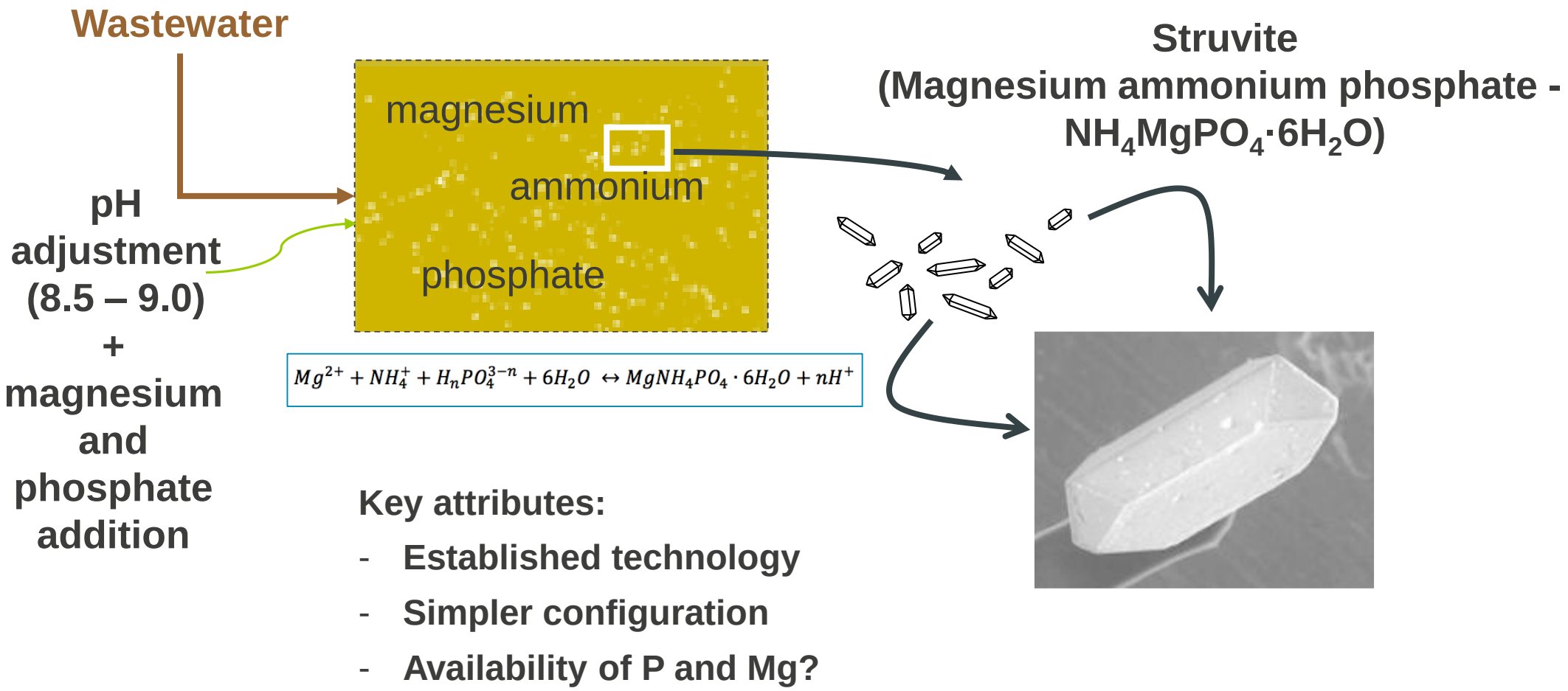
Precipitation - Struvite



Key attributes:

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

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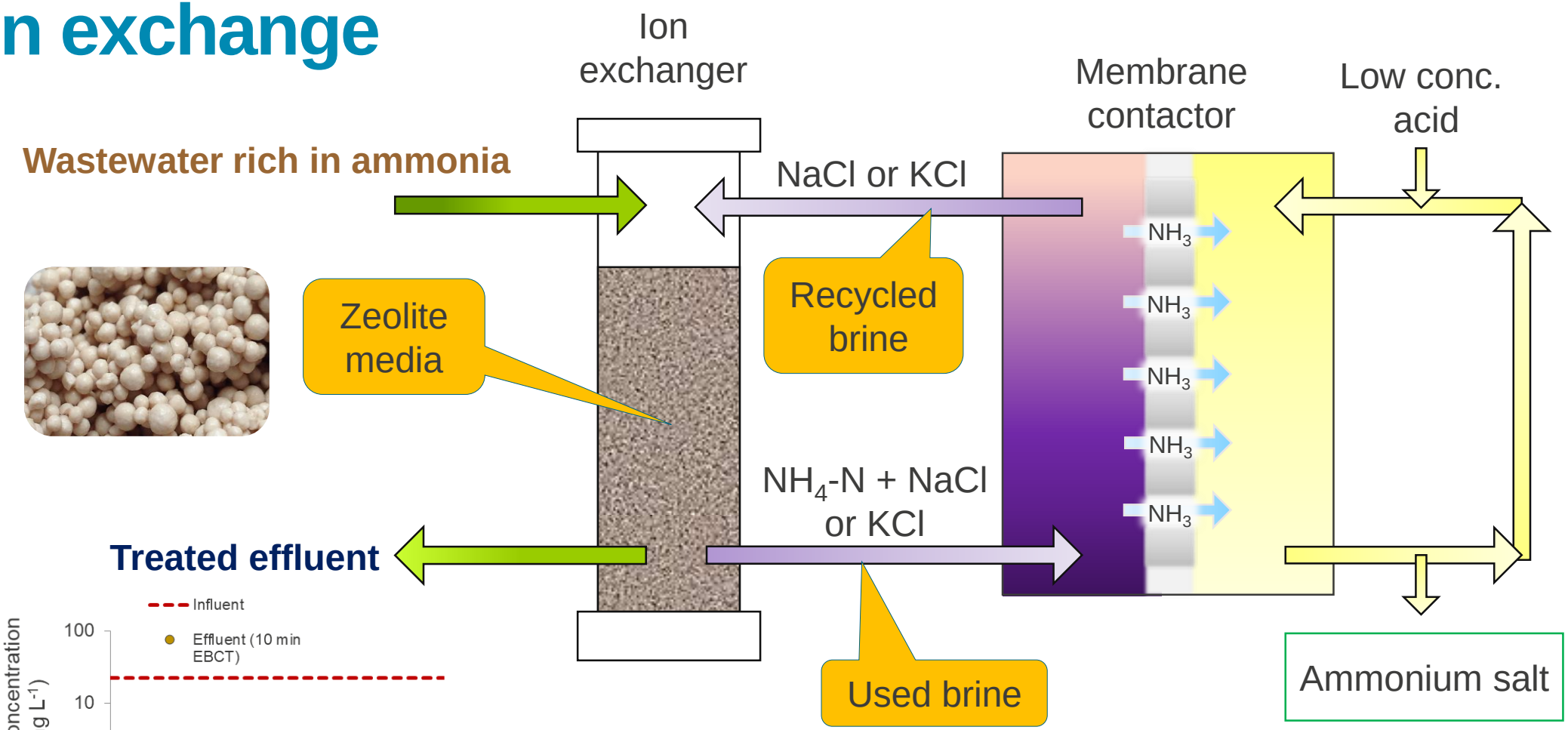
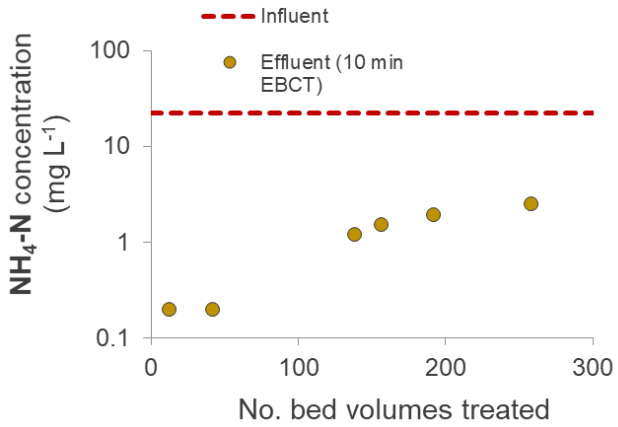
Ion exchange





Key attributes:

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

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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
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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

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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 within H2020 SMART-Plant project

Speaker: Sergio Ponsá – BETA Tech. Centre

sergio.ponsa@uvic.cat

Proud Partner of SMART Plant project

Beta
Biodiversitat, Ecologia, Tecnologia Ambiental i Alimentària

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WATER SMART INDUSTRIAL SYMBIOSIS

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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

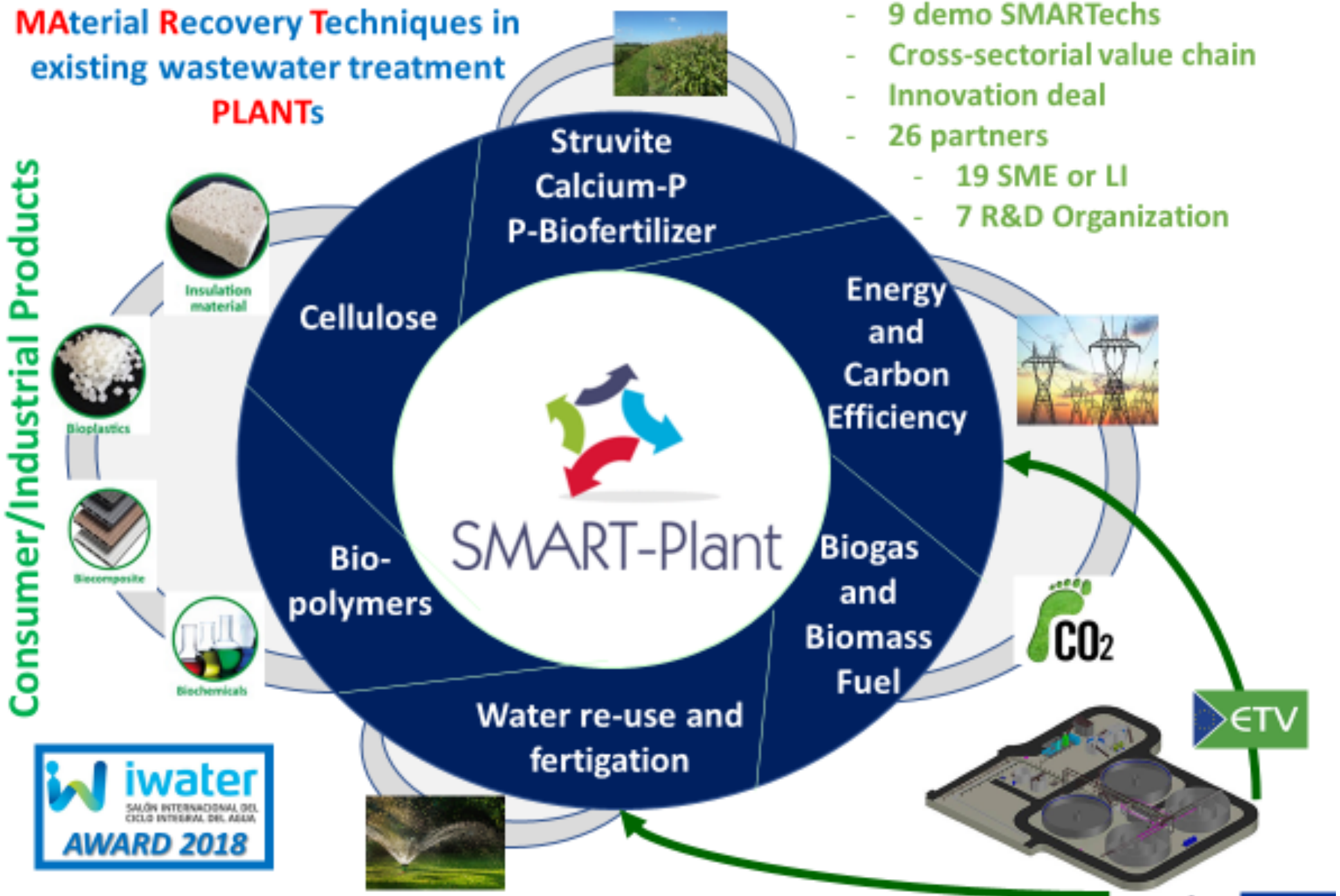
H2020-CE-SPIRE-07-2020.
Nutrient recovery and BBF and biostimulants production from food industries (WP Leader)

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

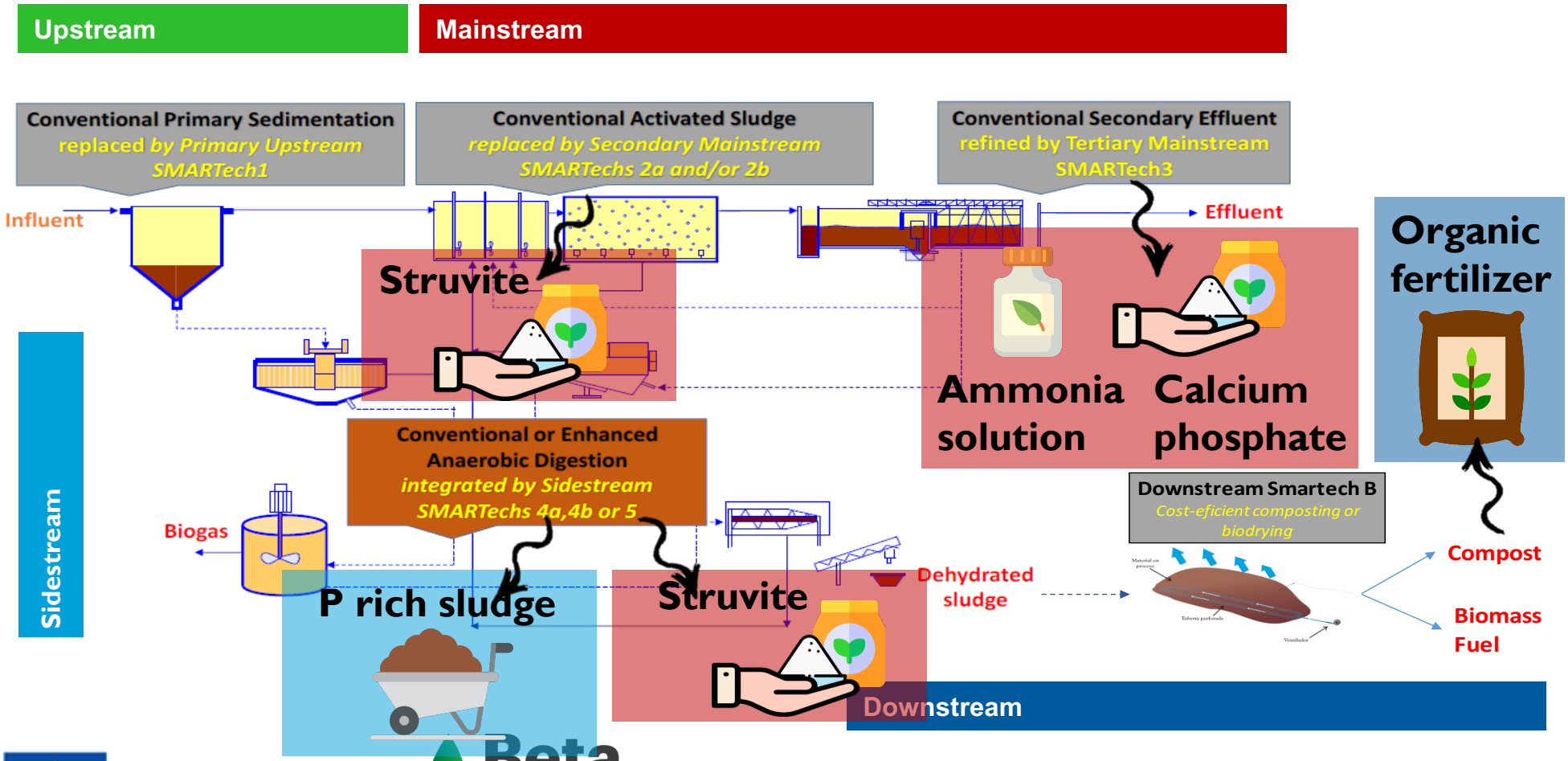
- Horizon2020 IA
- 9 demo SMARTechs
- Cross-sectorial value chain
- Innovation deal
- 26 partners
  - 19 SME or LI
  - 7 R&D Organization



iwater SALÓN INTERNACIONAL DEL CICLO INTEGRAL DEL AGUA **AWARD 2018**

www.smart-plant.eu Start: 01/Jun/2016 – End: 31/May/2020

Nutrient recovery within SMART Plant



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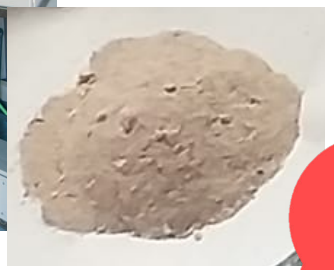
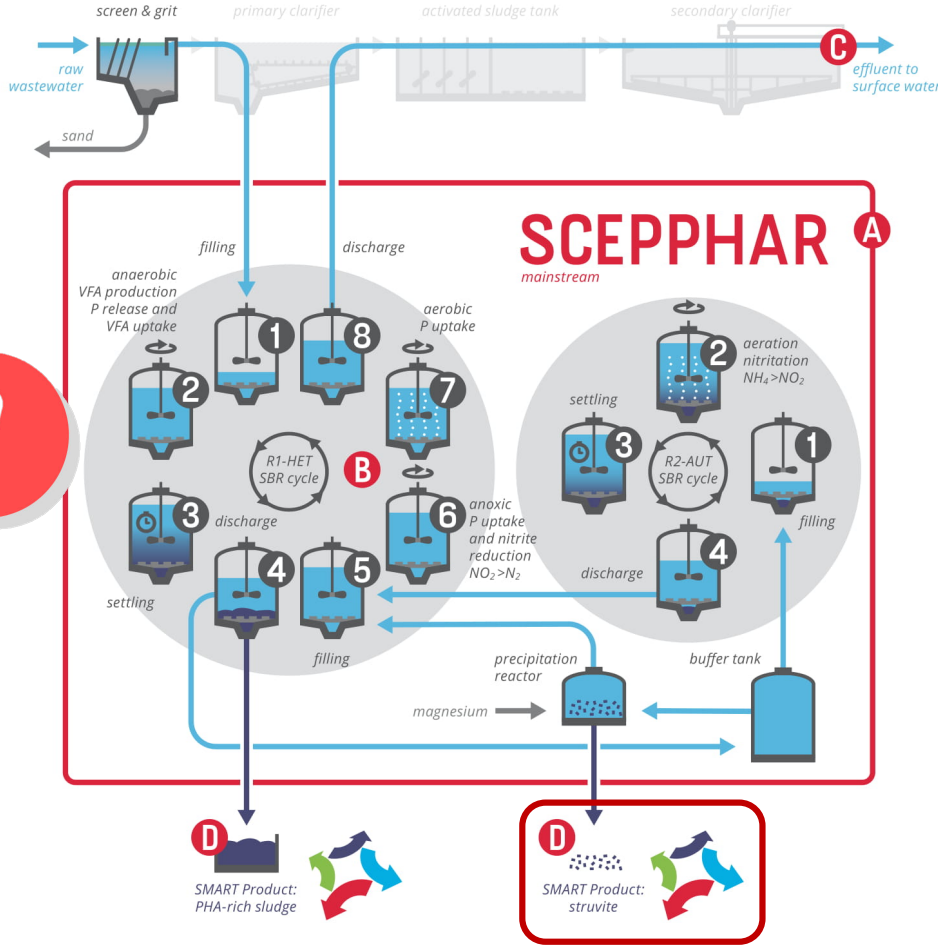
SMARTech 2b: mainstream SCEPPHAR







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

86% N removal
96% P removal
6.6g/m^3 struvite production

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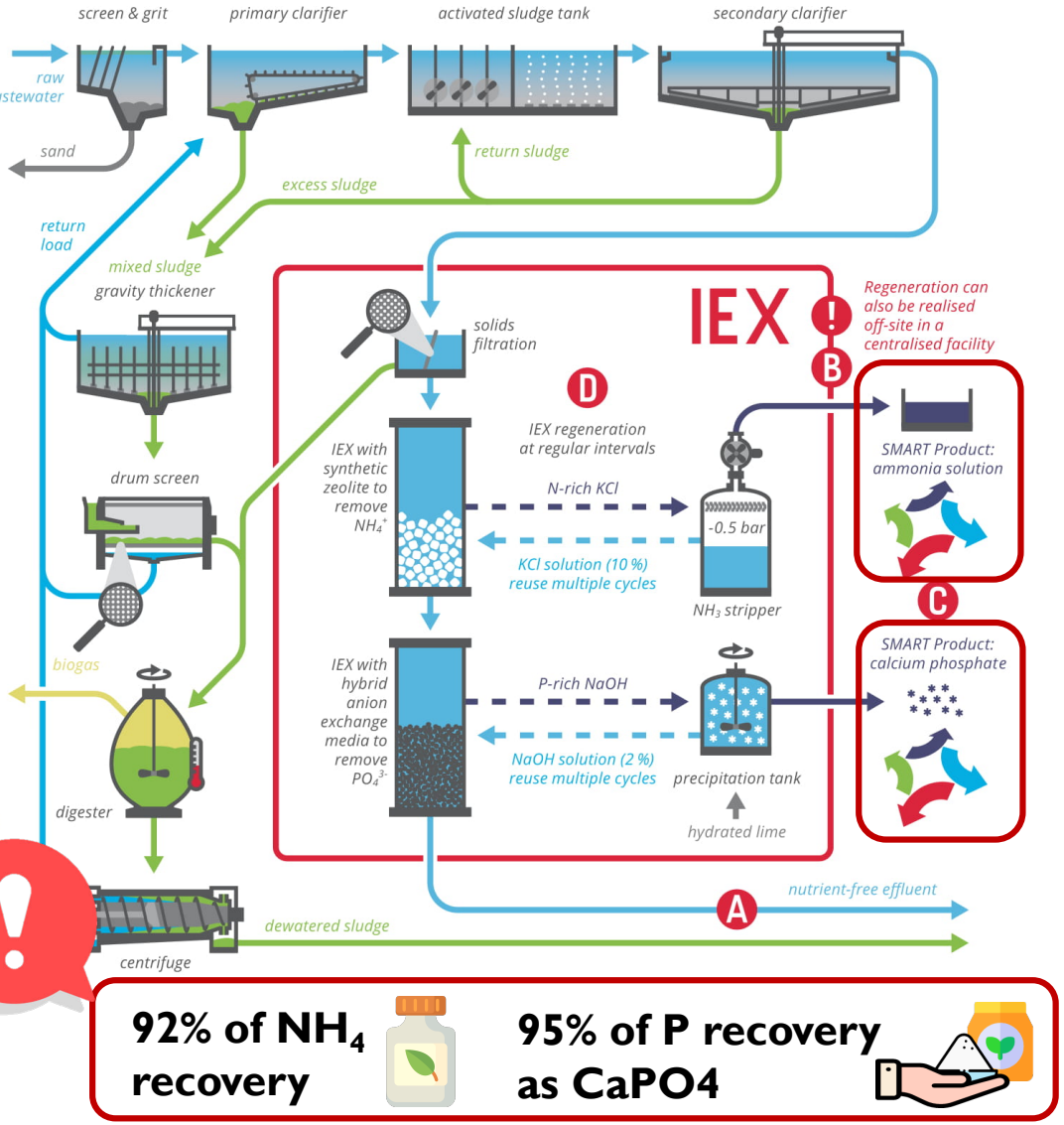
SMARTech 3: IEX







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 fertilizer industry
- **D** Multiple use and recovery of regenerants leading to an e feasibility of the IEX technolo wastewater industry

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SMARTech 4a: SCENA

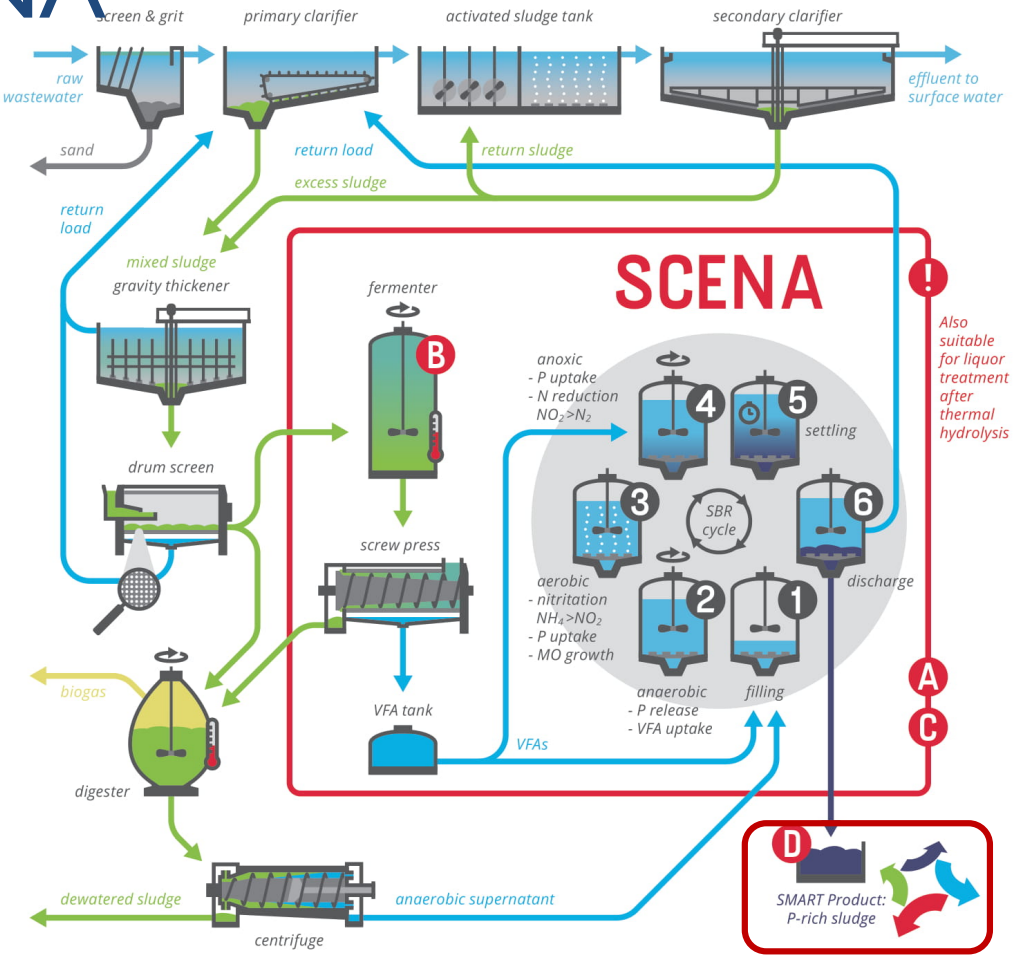


92% of P removal and recovery through P rich biomass. Dewatered SCENA sludge contains up to 5% (d.b) phosphorus



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



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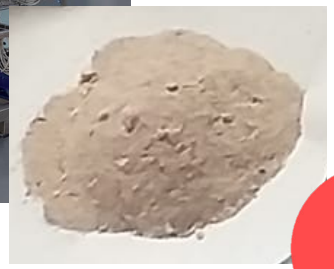
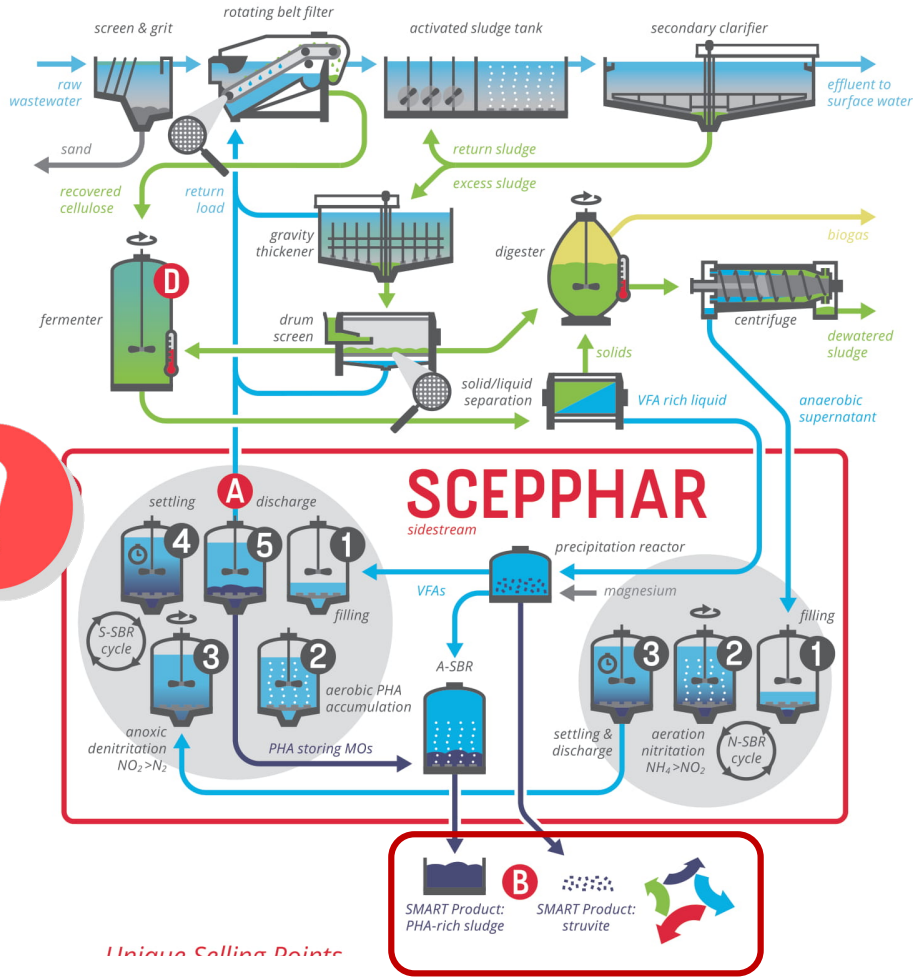
SMARTech 5: sidestream SCEPPHAR







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

Unique Selling Points

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Downstream SMARTechB

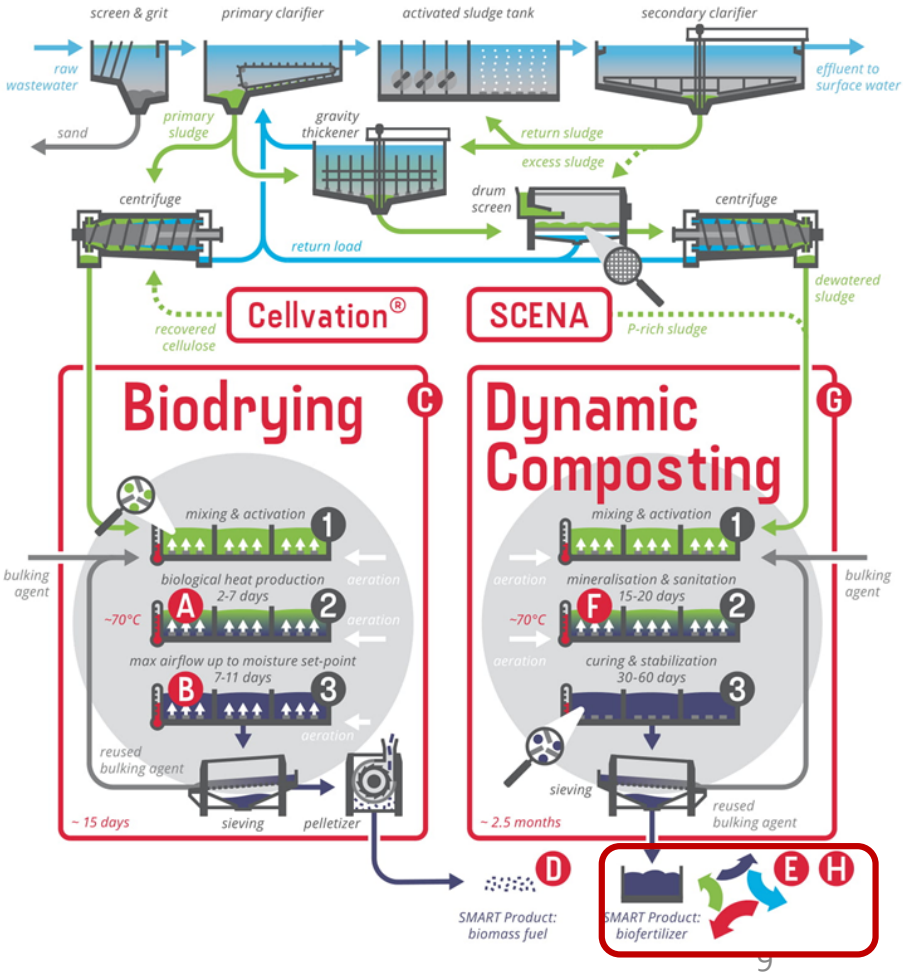




Unique Selling Points

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:
  - **Agronomic value**: agronomic test in pot and open field
- Safety of products:
  - Heavy metals
  - Polycyclic aromatic hydrocarbons (**PAH**)
  - **Cloroalkanes**
  - **Pesticides** (108 polluting molecules)
  - **PPCP** (including antibiotics, pesticides, and estrogens) (15 substances included in 2018 EU watch-list).





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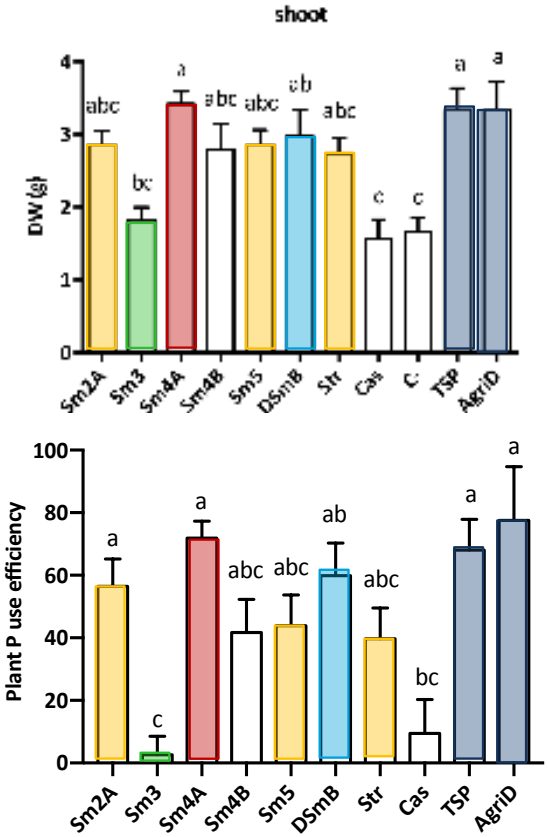
Agronomic value: agronomic test in pot



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

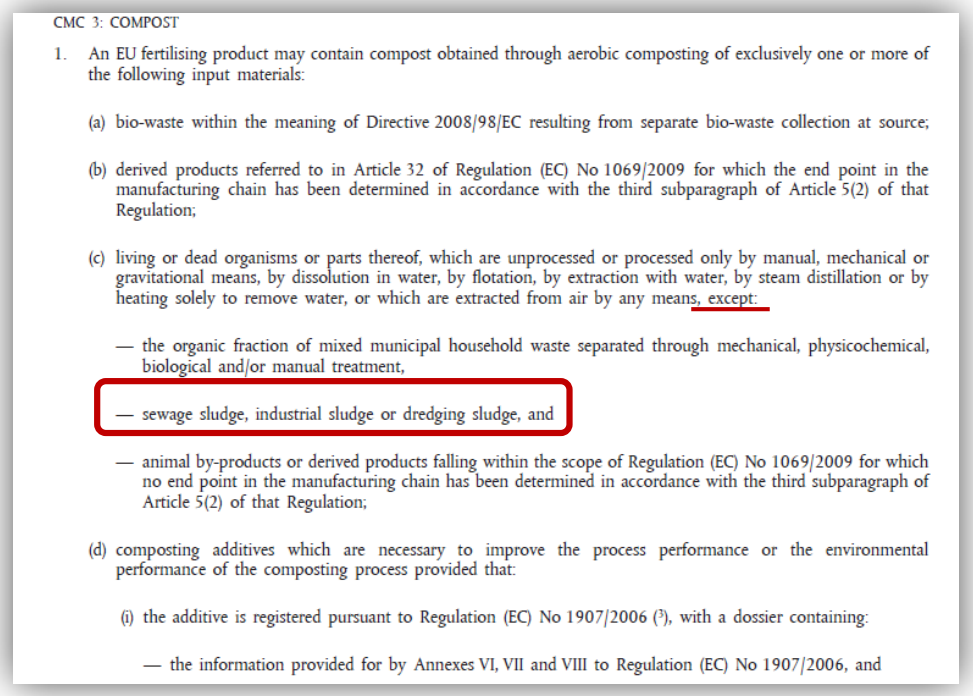
Safety of fertilising products: Heavy metals Regulation 2019/1009

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

SMART Product	SMARTech	Fertilising product	Categ
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**

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 (3), 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

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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)**

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

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 and biobased fertilizer recovery within H2020 SMART-Plant project



ANY QUESTIONS?



Speaker: Sergio Ponsá – BETA Tech. Center

sergio.ponsa@uvic.cat

Proud Partner of SMART Plant project

Beta
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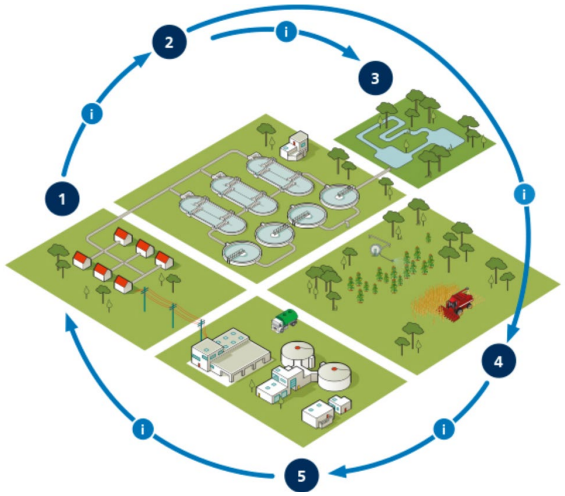
ULTIMATE
WATER SMART INDUSTRIAL SYMBIOSIS

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

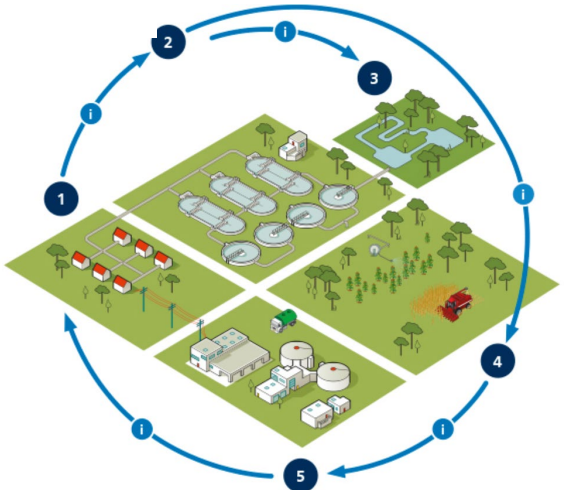
1. Objectives of the NextGen solutions

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



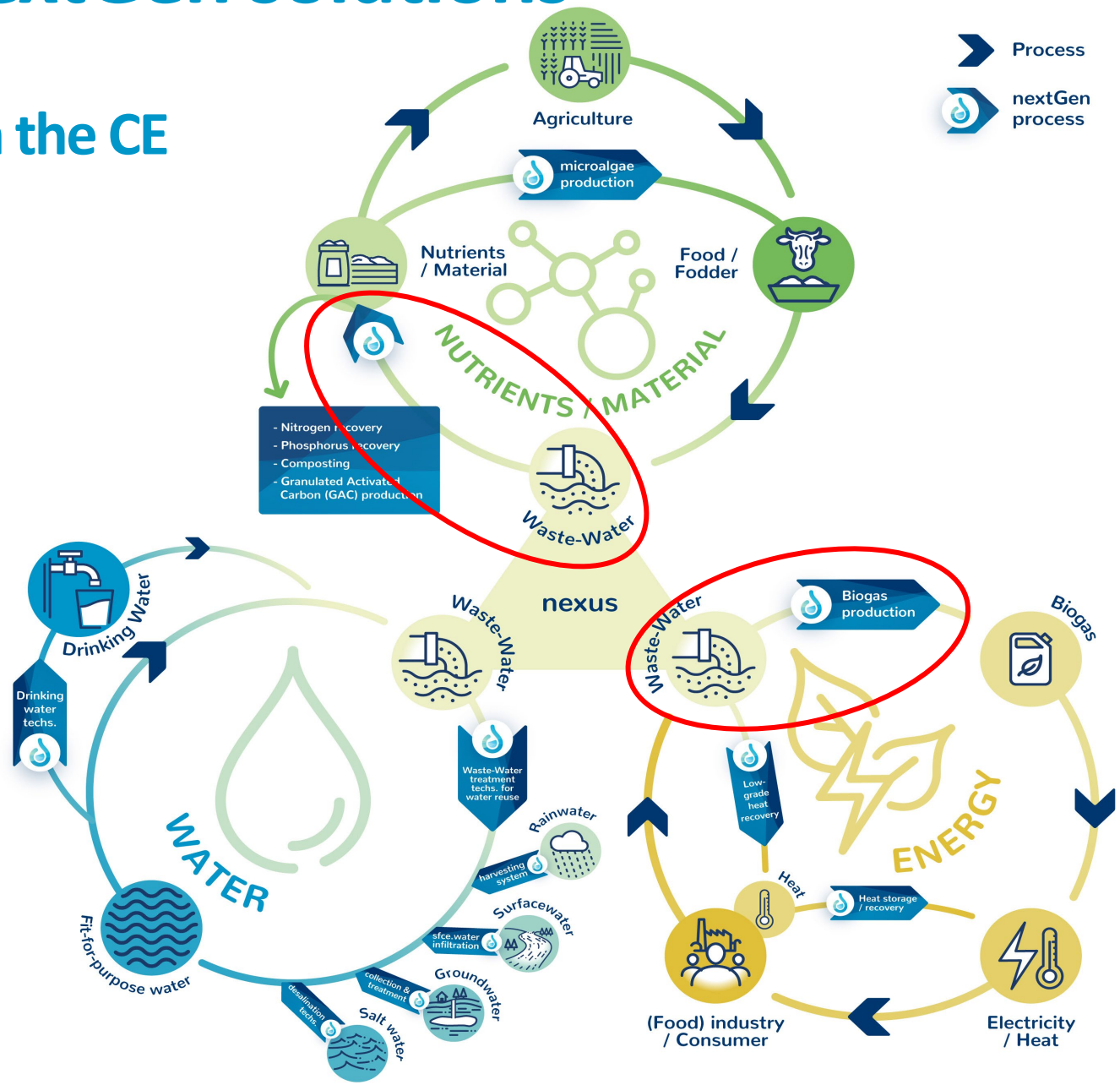


1. Objectives of the NextGen solutions

Positioning of demo case within the CE

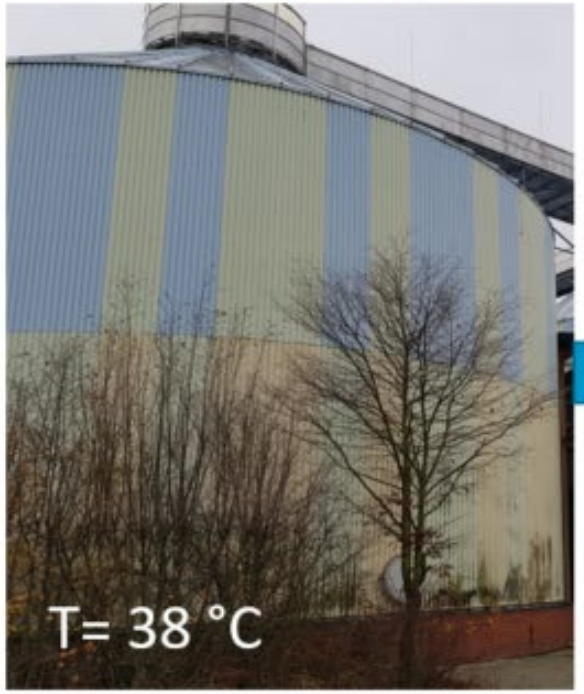
Technology Evidence Base (TEB).

Braunschweig



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

1st stage: 1 digester

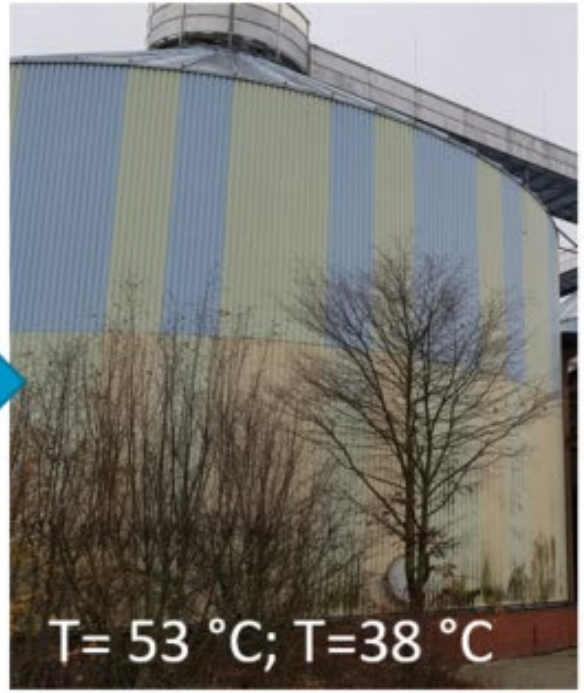


Thermal pressure hydrolysis (TPH)



T= 150 °C, p= 4.5 bar

2nd stage: 2 digesters



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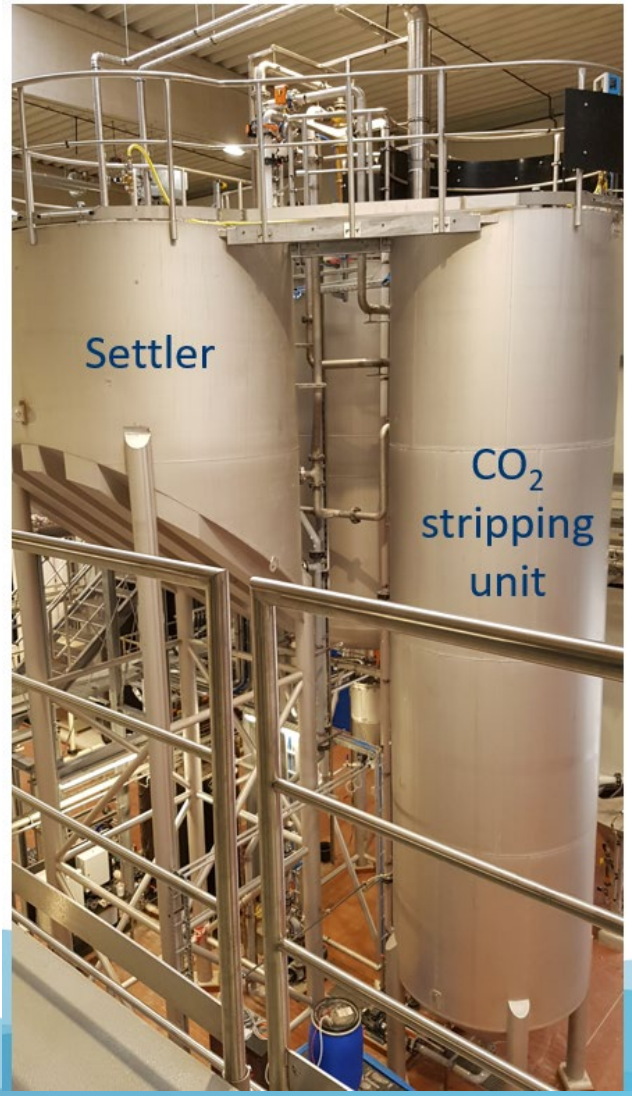
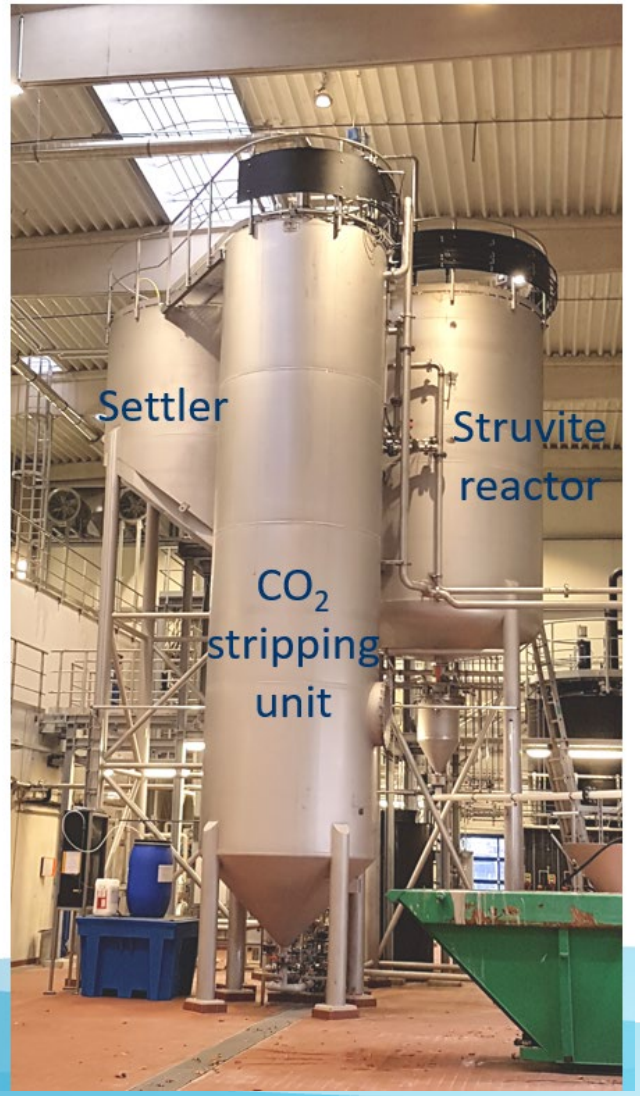
2. New NextGen solutions: struvite production







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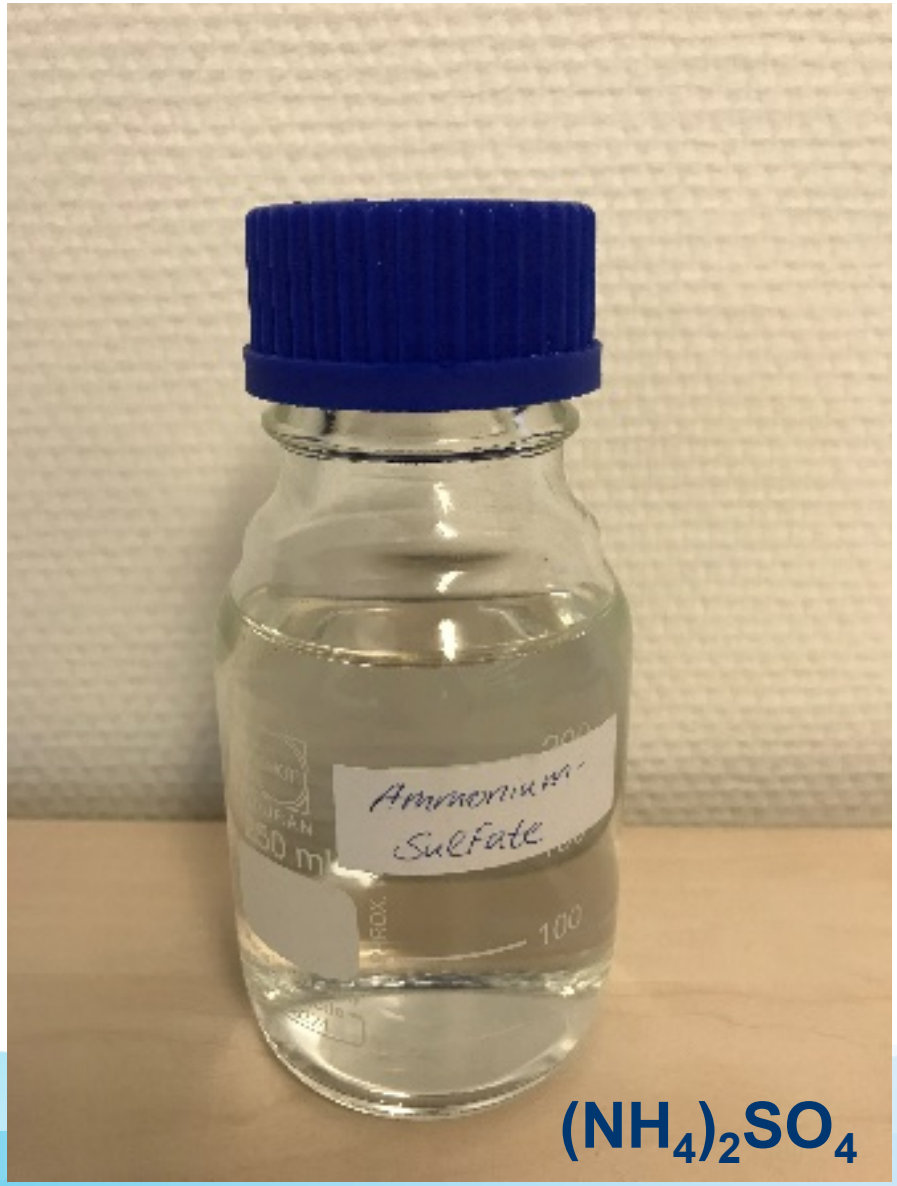
2. New NextGen solution: Ammonium sulphate production

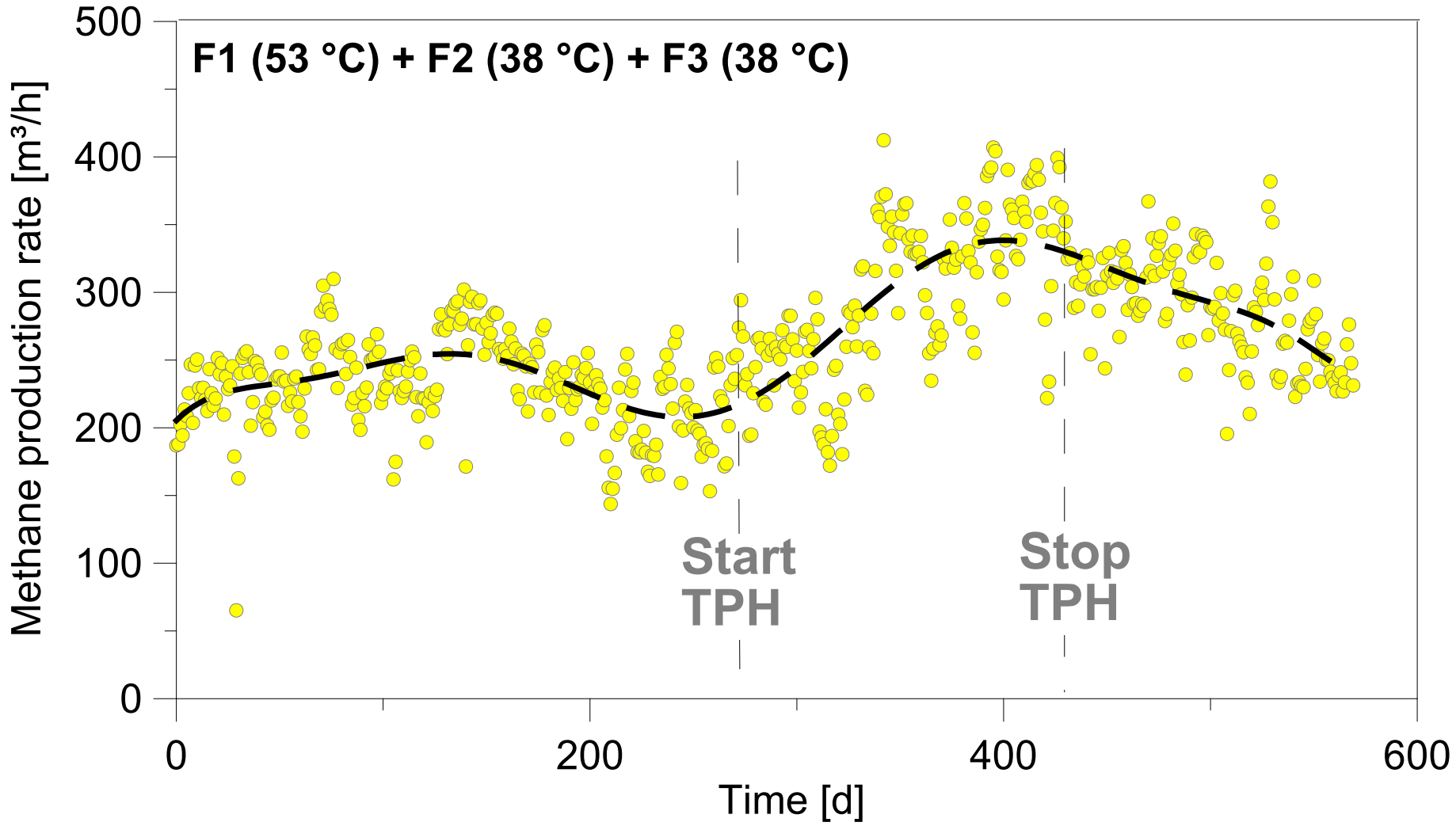






3. Results and key performance indicators (KPIs)

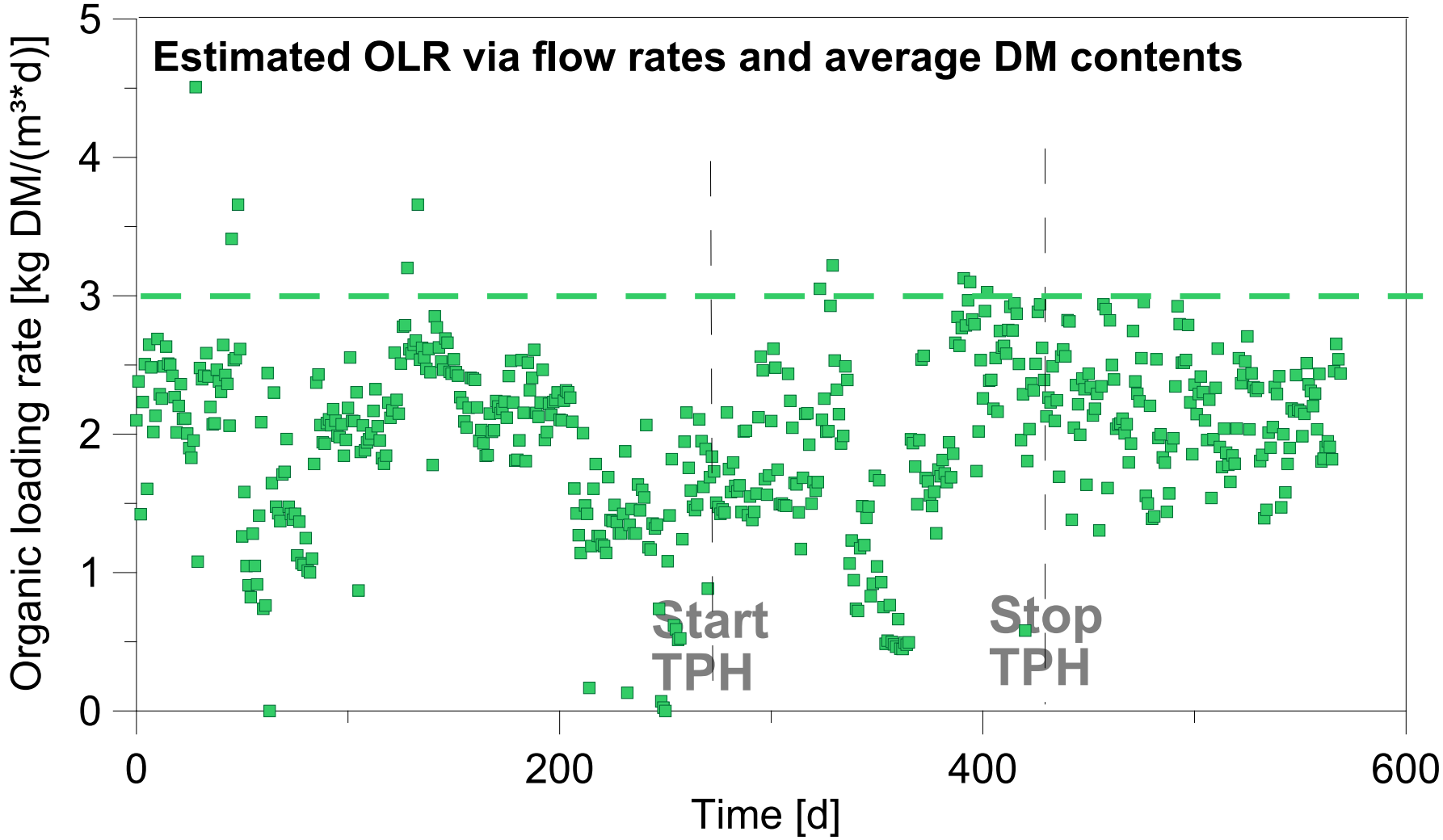
Up to 25% increase in methane production rate during TPH operation



3. Results and key performance indicators (KPIs)

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

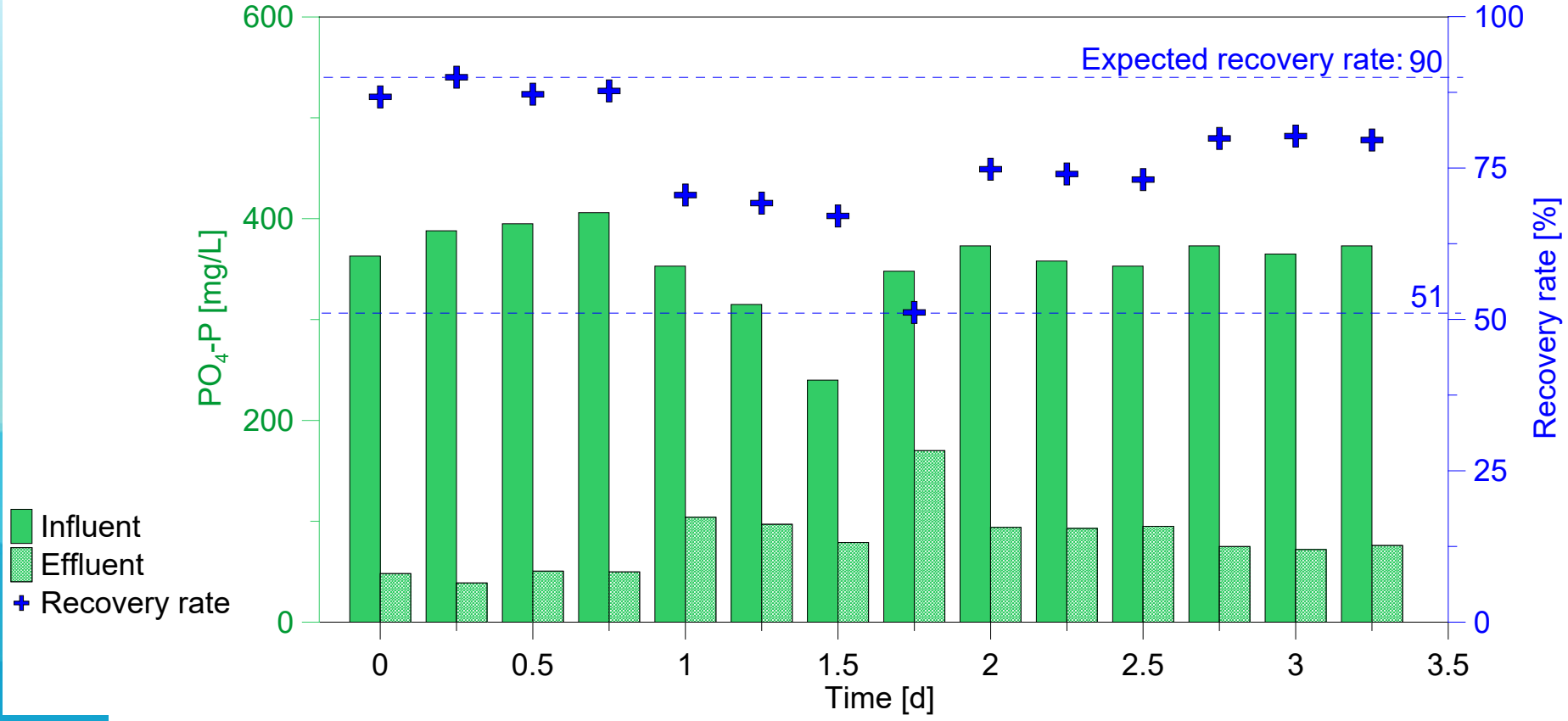
→ **Increase in methane production rate due to TPH**



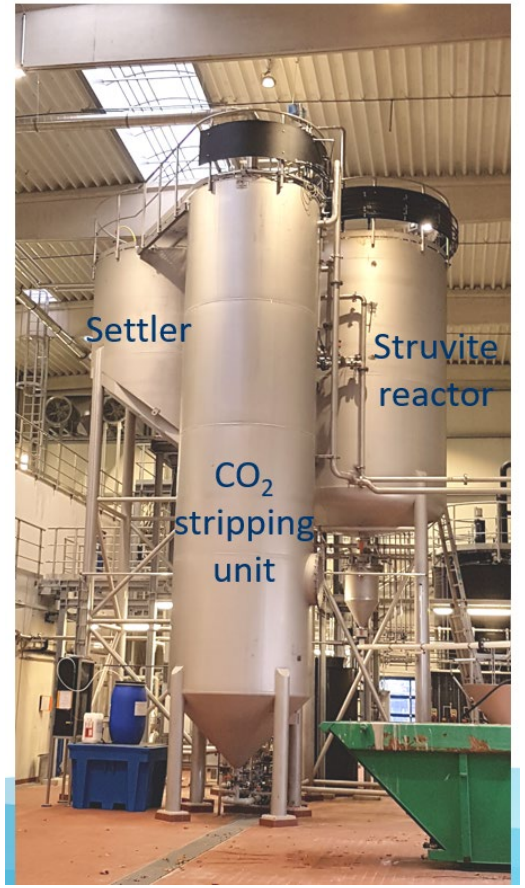
3. Results and key performance indicators (KPIs)

Full-scale nutrient recovery

GOAL: Phosphorus recovery





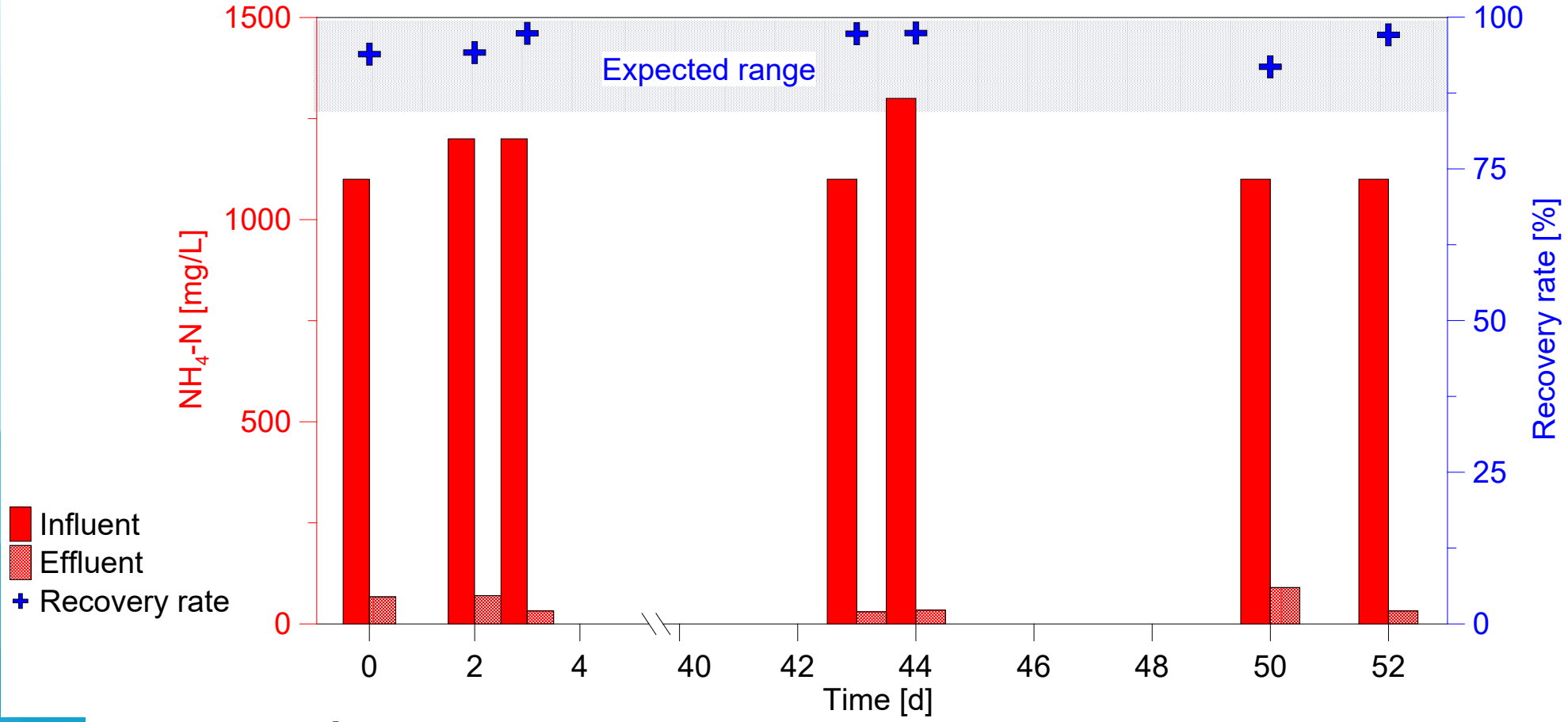


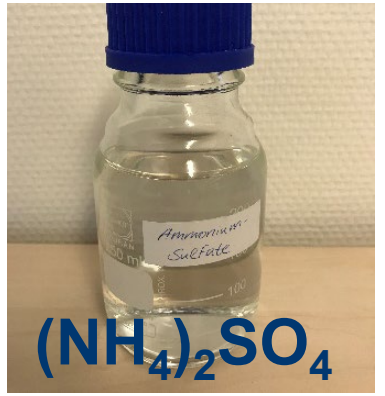
→ **Recovery rate is still too low: crystal size is too small**

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

nextGen

Thank you!

Run4Life project.
Current results and exploitation pathways

Nicolás Morales Pereira
Run4Life Project Manager

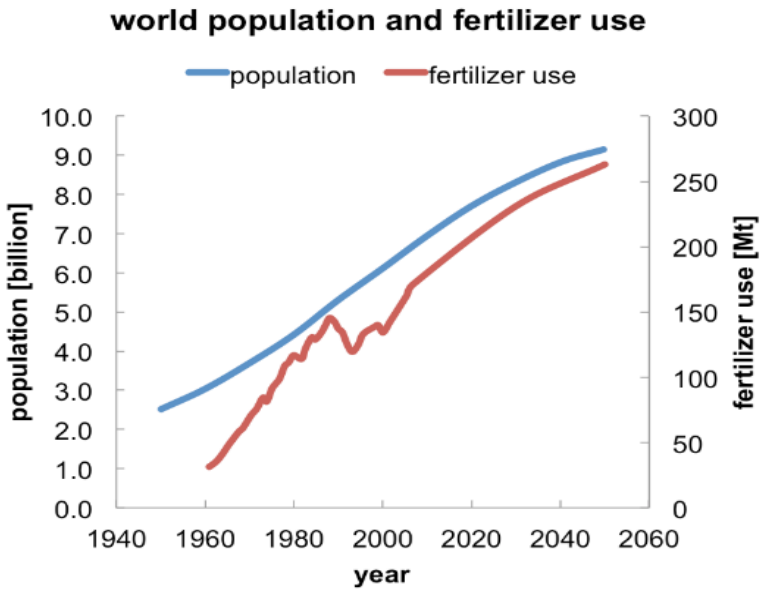
17th December 2020,
ULTIMATE Meeting on Nutrient Recovery

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

Nutrients in wastewater

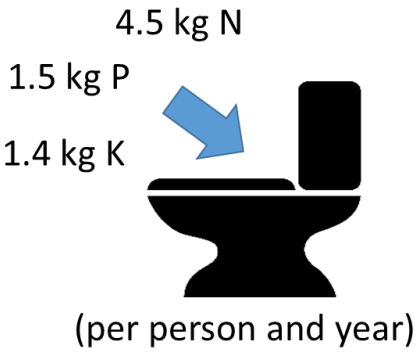
Context

- 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**



(per person and year)

Horizon 2020, GA 730285.

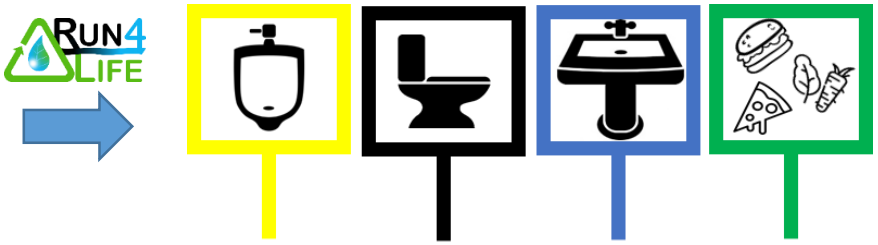
Run4Life change of concept

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



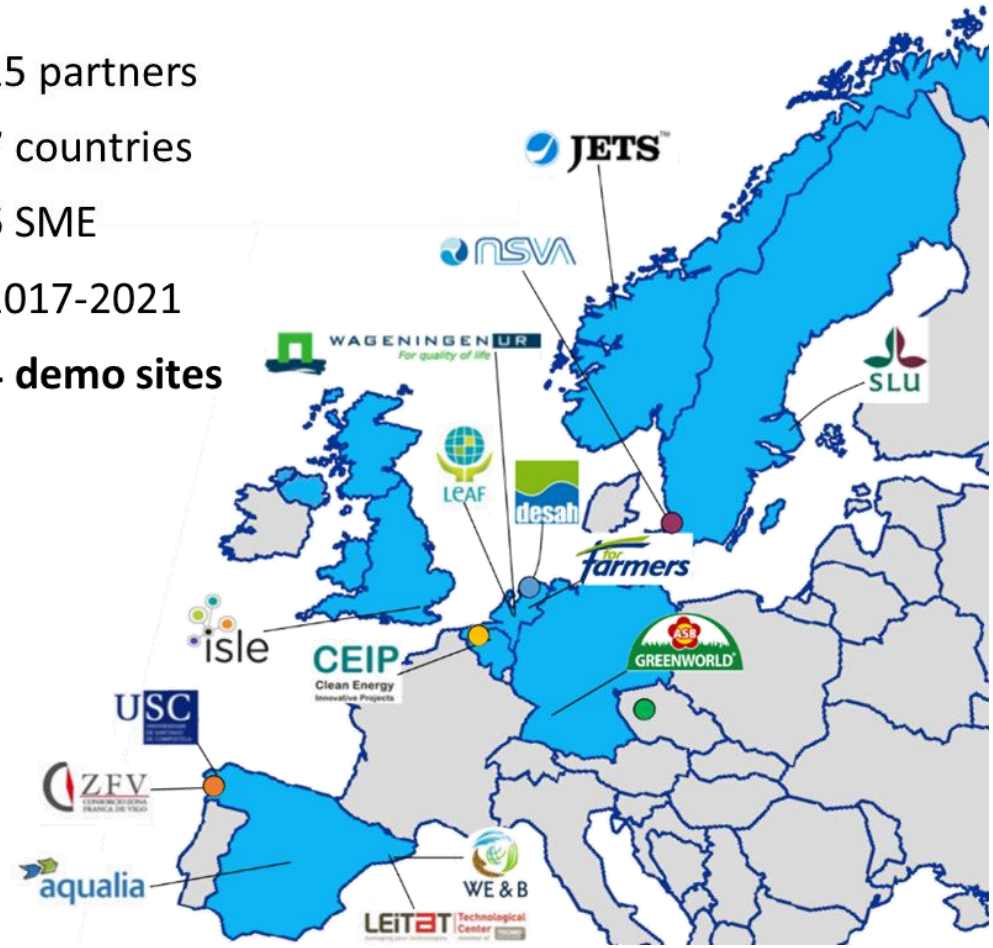




Horizon 2020, GA 730285.

Run4Life project. General data and demo sites

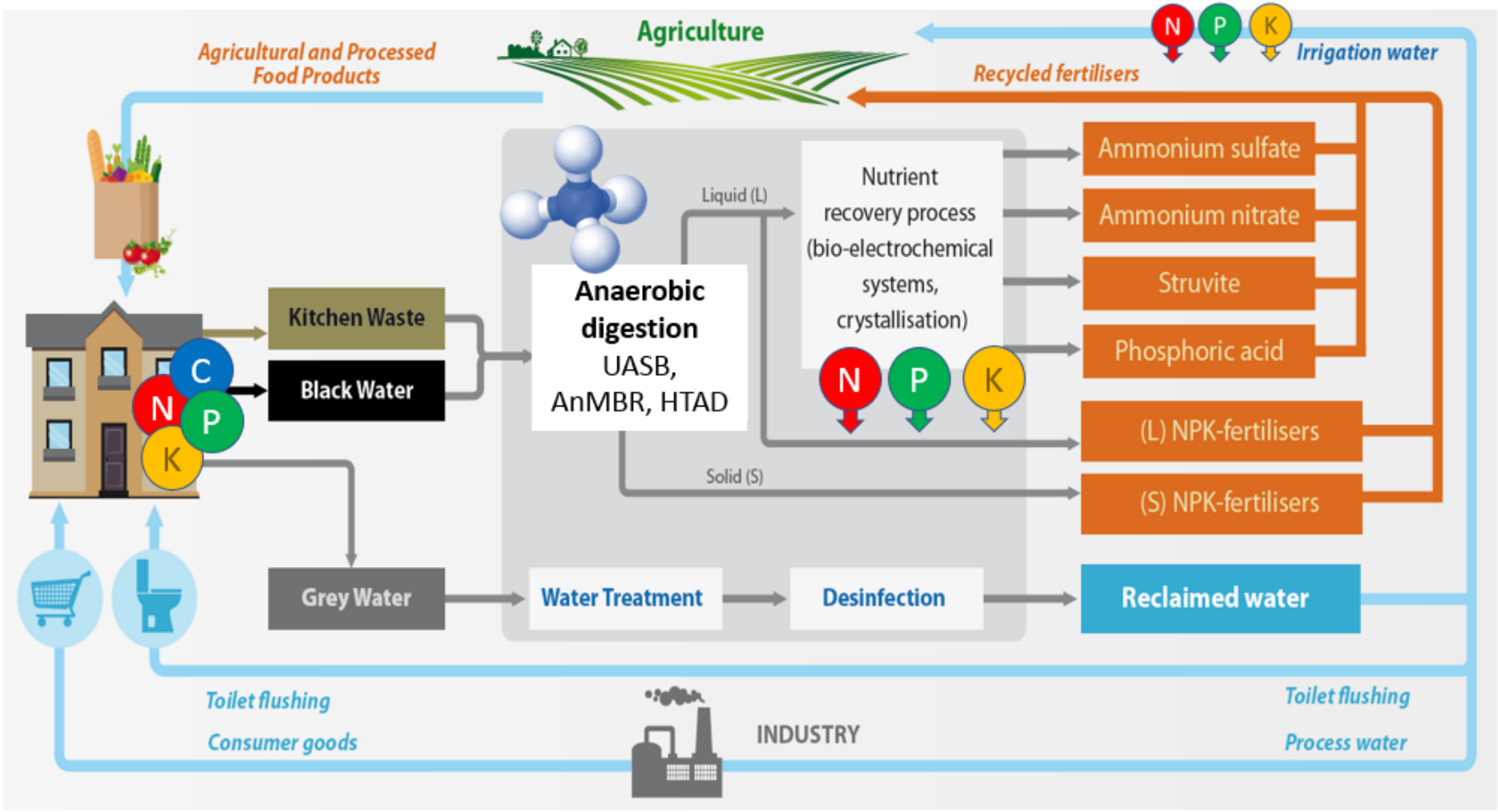
- 15 partners
- 7 countries
- 6 SME
- 2017-2021
- **4 demo sites**





Horizon 2020, GA 730285.

Run4Life General flowchart



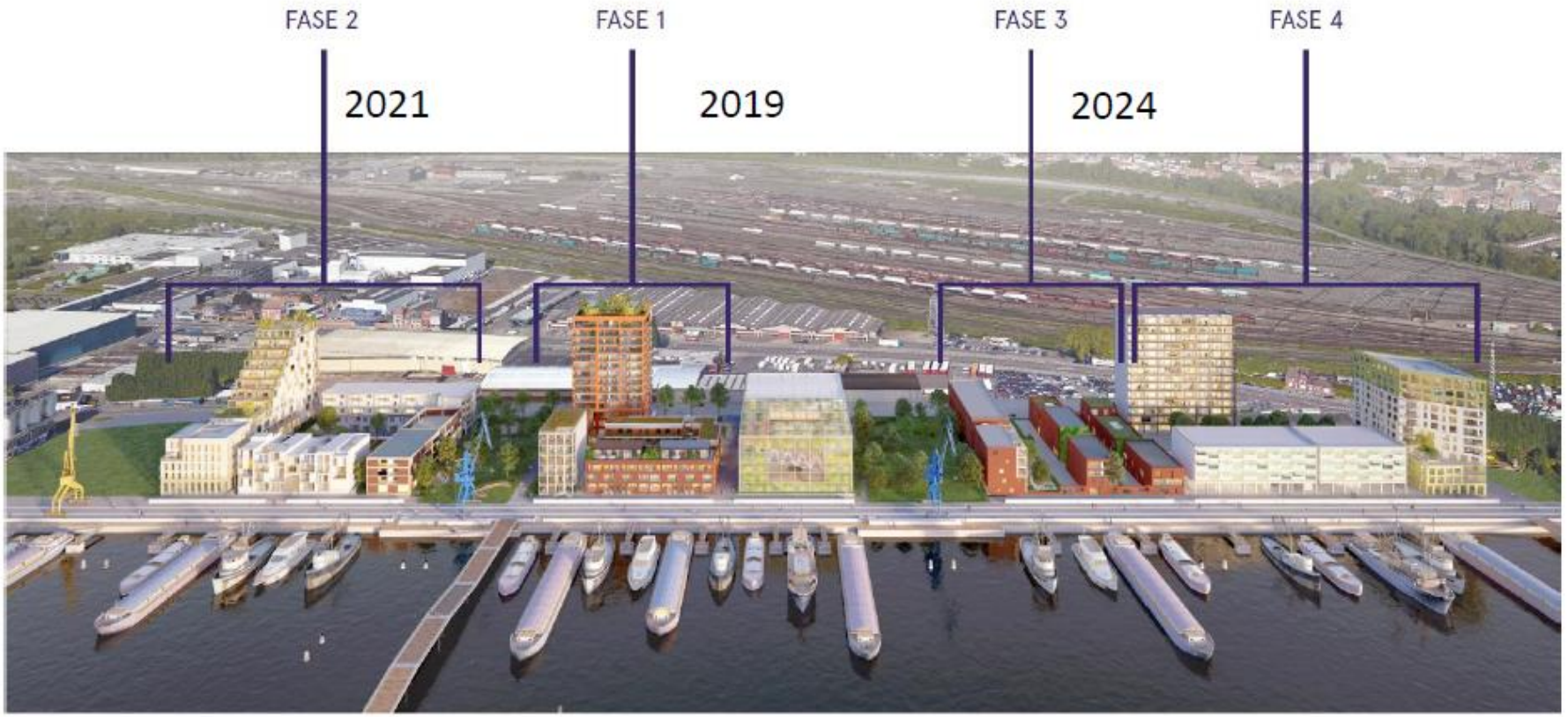
Horizon 2020, GA 730285.

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.)

Horizon 2020, GA 730285.

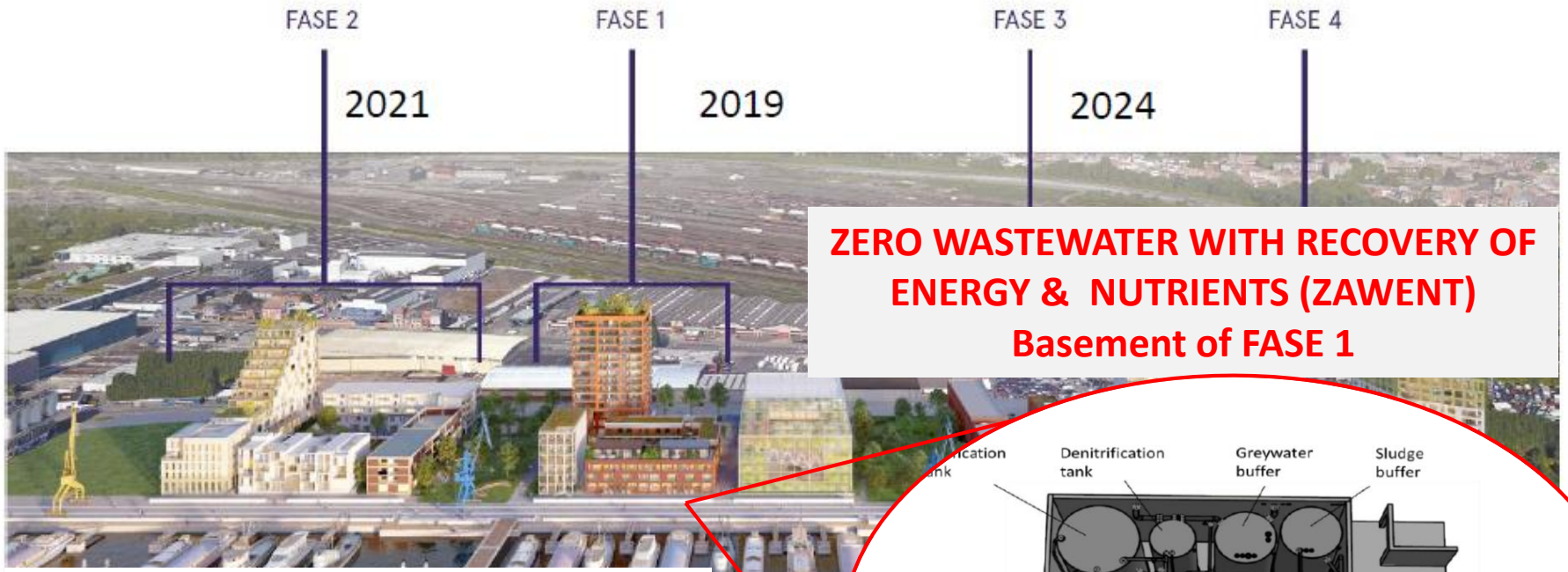
RUN4LIFE

Demo sites and technologies

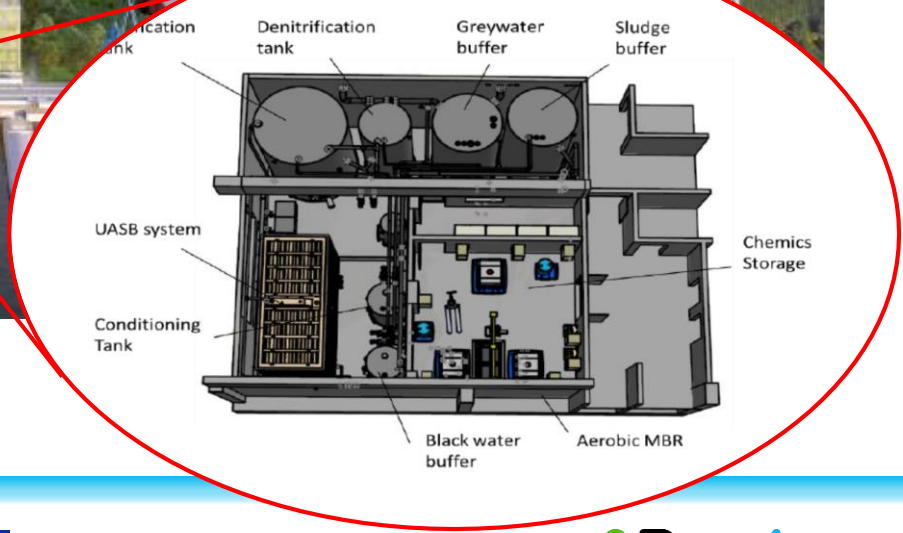
Nieuwe Dokken - Ghent, Belgium (1200 p.e.)

CEIP Clean Energy Innovative Projects

DuCoop



ZERO WASTEWATER WITH RECOVERY OF ENERGY & NUTRIENTS (ZAWENT)
Basement of FASE 1



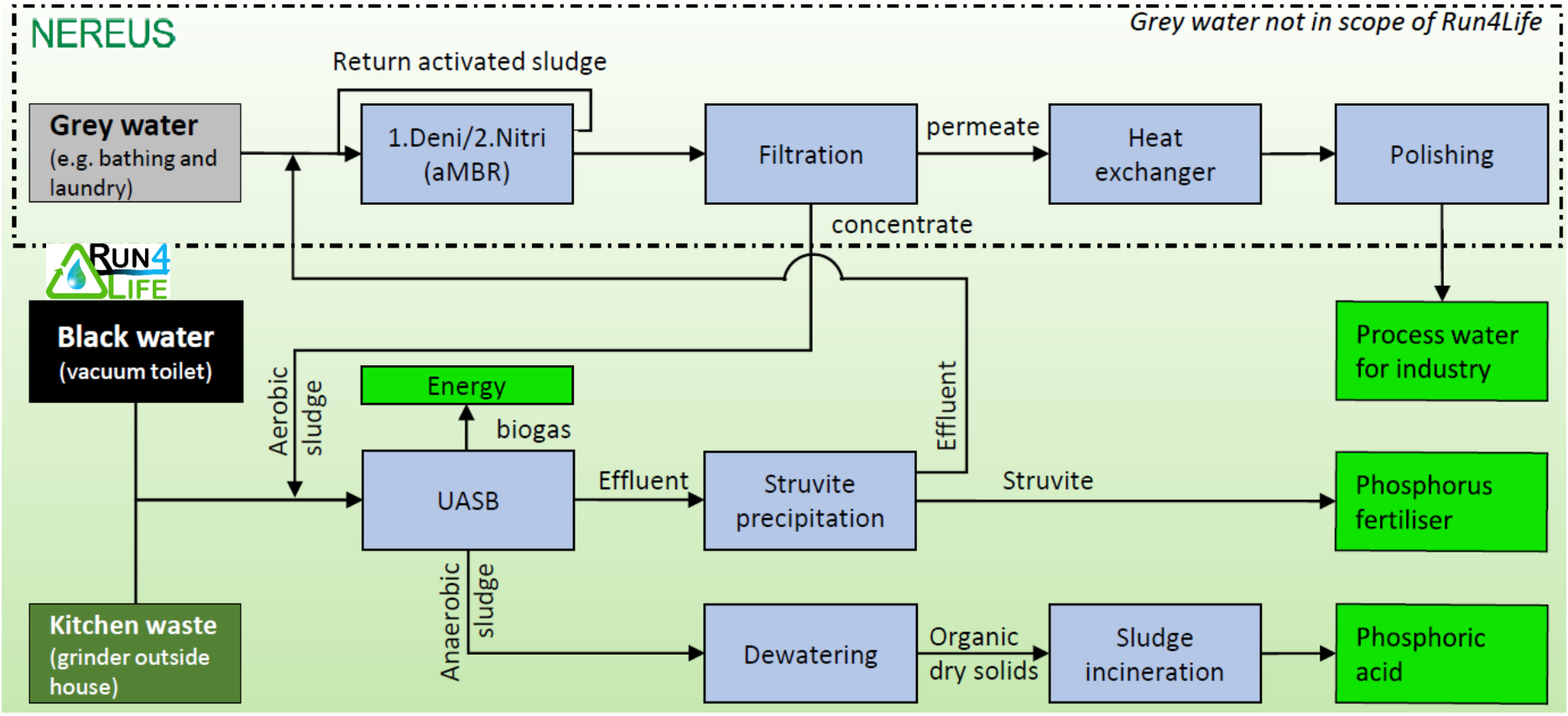
- 2500 MWh wasteheat
  - 2/3 process heat Christeyns
  - 1/3 from wastewater
- 30.000 m³ water
- 1.500kg green fertilizer

Horizon 2020, GA 730285.

RUN4LIFE

Demo sites and technologies

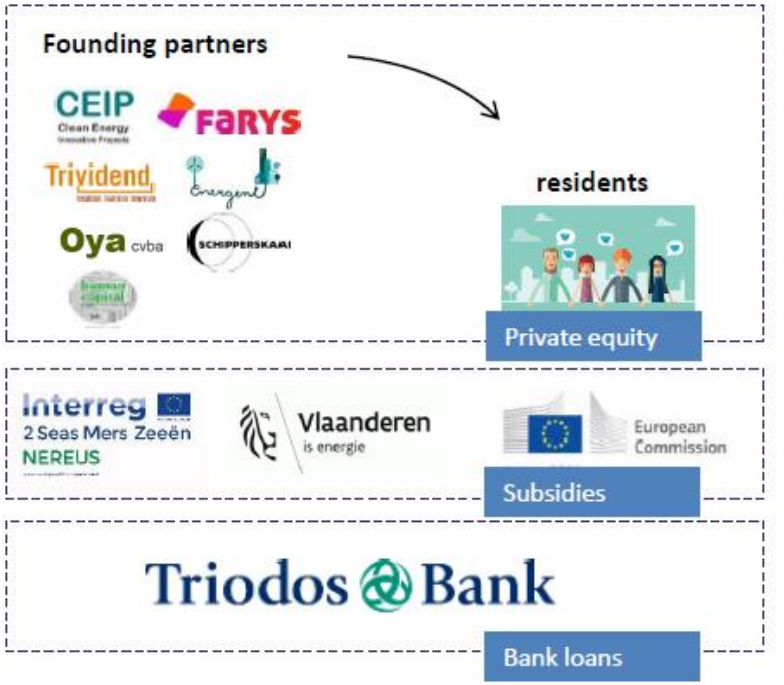
Nieuwe Dokken - Ghent, Belgium (1200 p.e.)

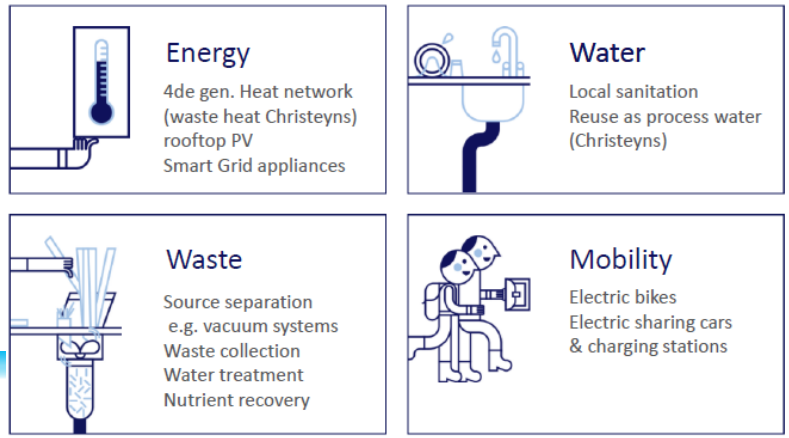


Horizon 2020, GA 730285.

Exploitation: Cooperative business model

Nieuwe Dokken - Ghent, Belgium (1200 p.e.)





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

Horizon 2020, GA 730285.

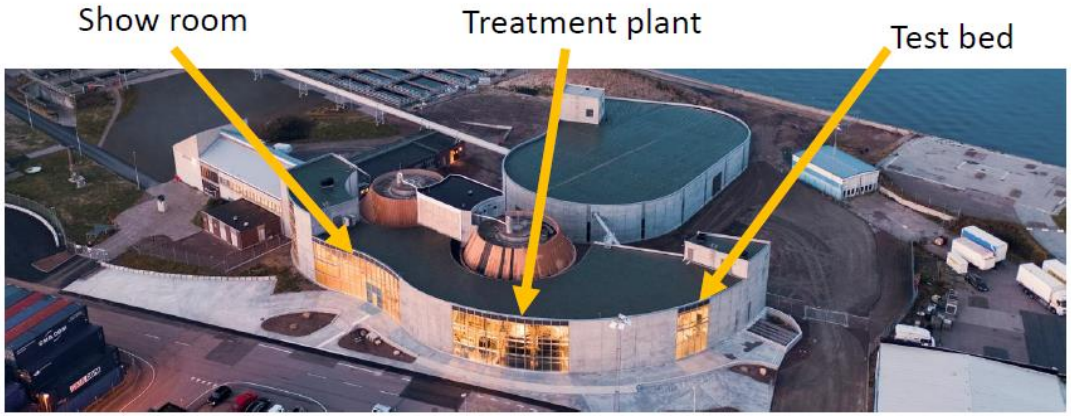
RUN4LIFE

Demo sites and technologies

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

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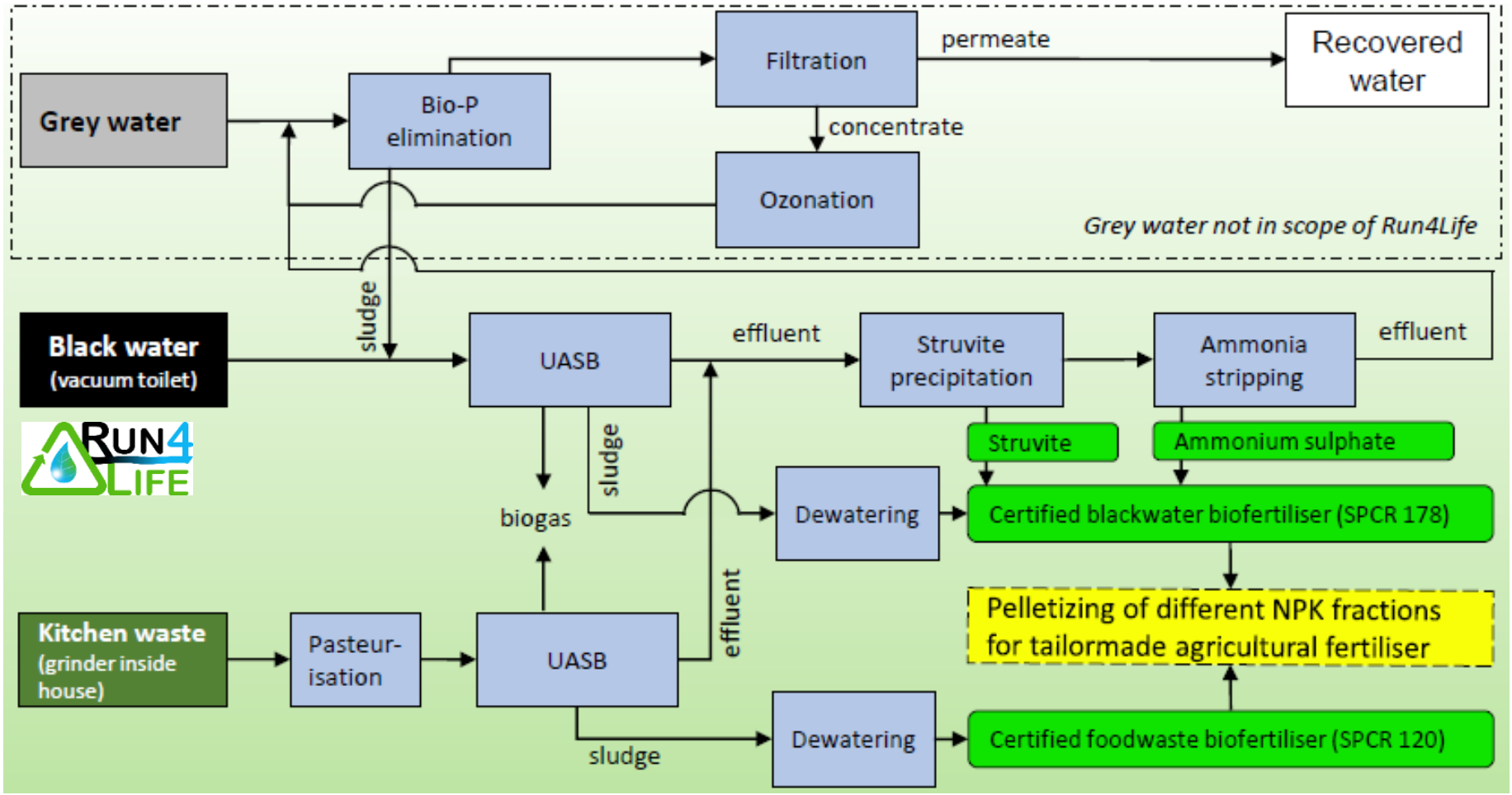
Demo sites and technologies

Oceanhamnen (H+) - Helsingborg, Sweden (1800 p.e.)



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Exploitation: Tailor made fertilizer

Oceanhamnen (H+) - Helsingborg, Sweden (1800 p.e.)

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**

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Demo sites and technologies

Lemmerweg - Sneek, the Netherlands (32 houses)





Black water
(ultra low flush vacuum toilet)

biogas

HTAD

NPK liquid fertiliser

NPK solid fertiliser

Agricultural fertiliser

Horizon 2020, GA 730285.

Demo sites and technologies

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

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Demo sites and technologies

Lemmerweg - Sneek, the Netherlands (32 houses)

Innovations: (H)TAD

One step for 3 processes (innovation)

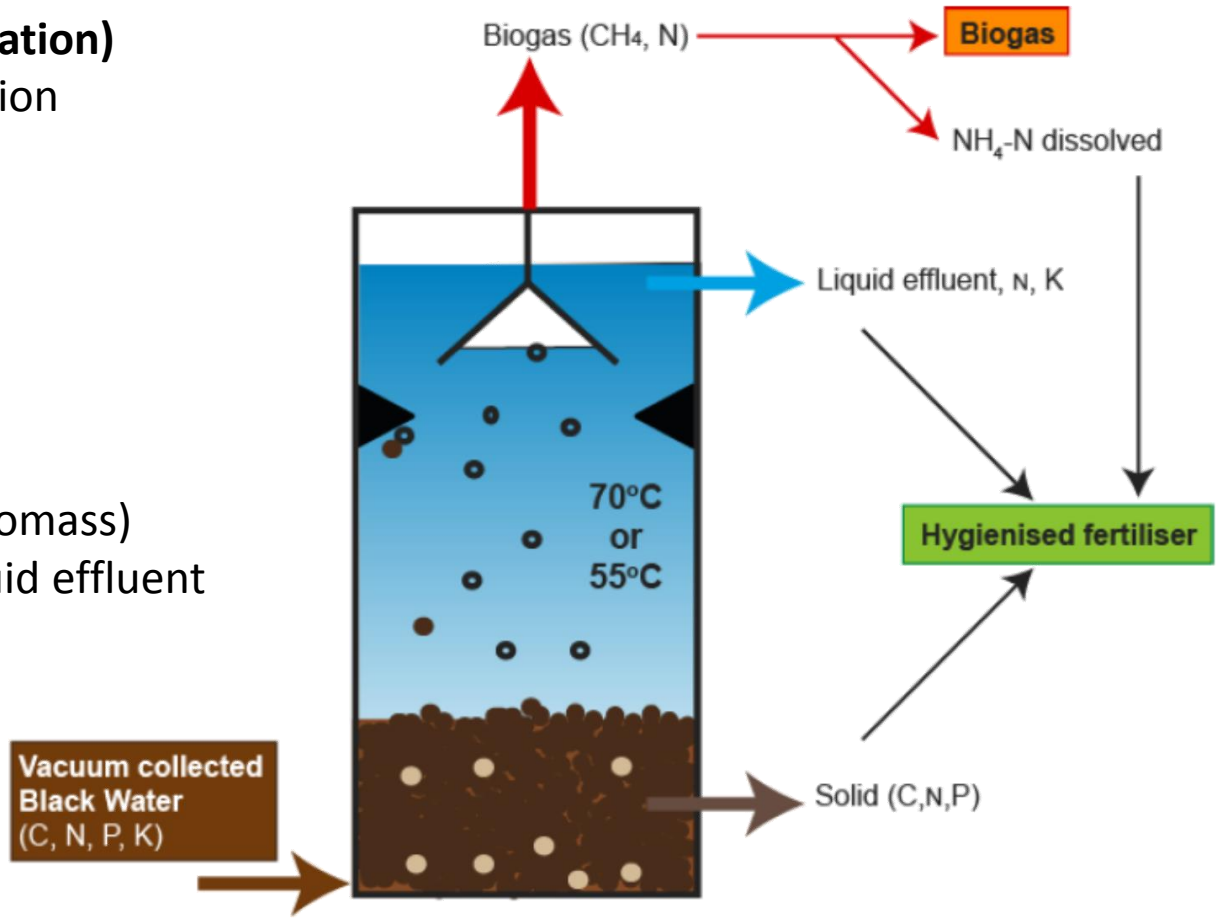
- Treatment and biogas production
- Fertiliser production
- Hygienisation

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



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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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Demo sites and technologies

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

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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)



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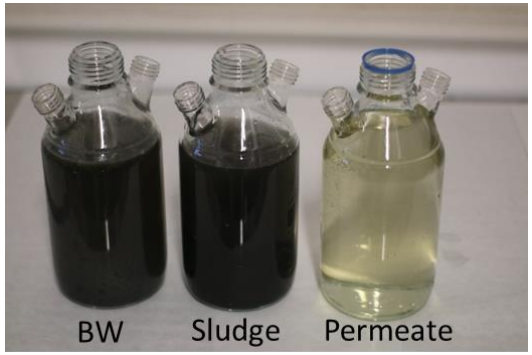
Demo sites and technologies

Porto do Molle Business Centre - Vigo, Spain (250 people)



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

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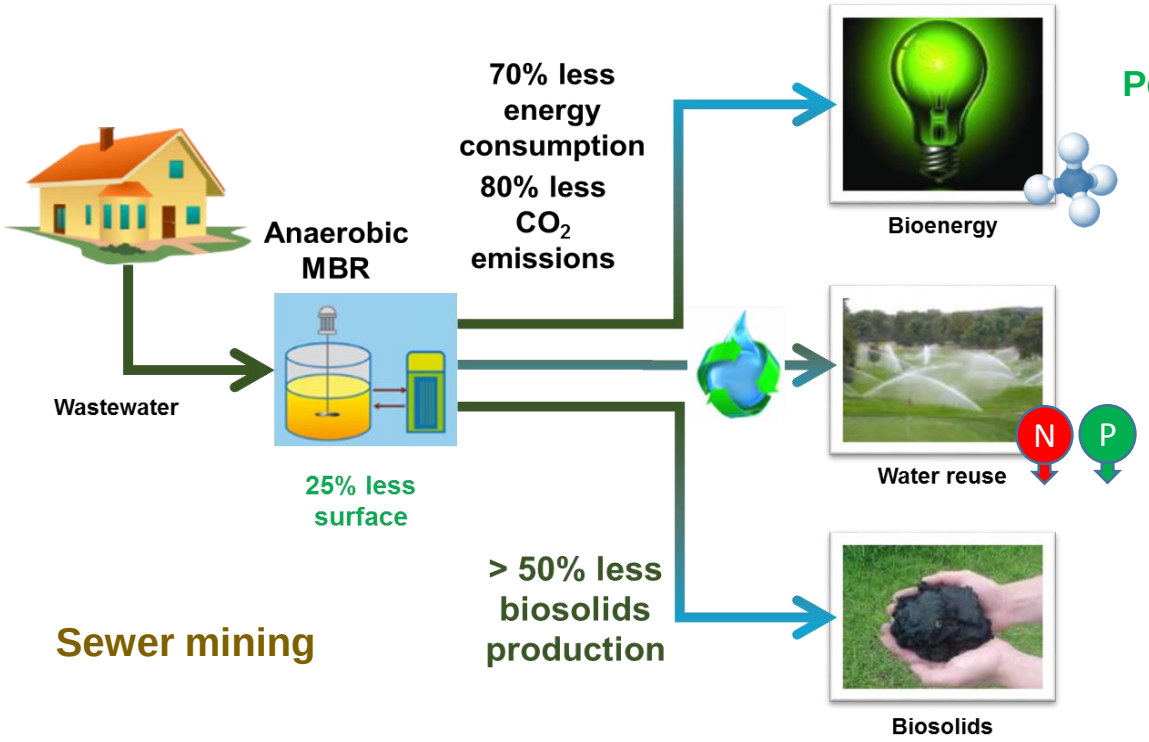
Exploitation

Anaerobic Membrane Bioreactor AnMBR



Potential Net Energy production of > 0.1 kWh/m³

Sewer mining

Disinfected Nutrient Rich Water for Irrigation



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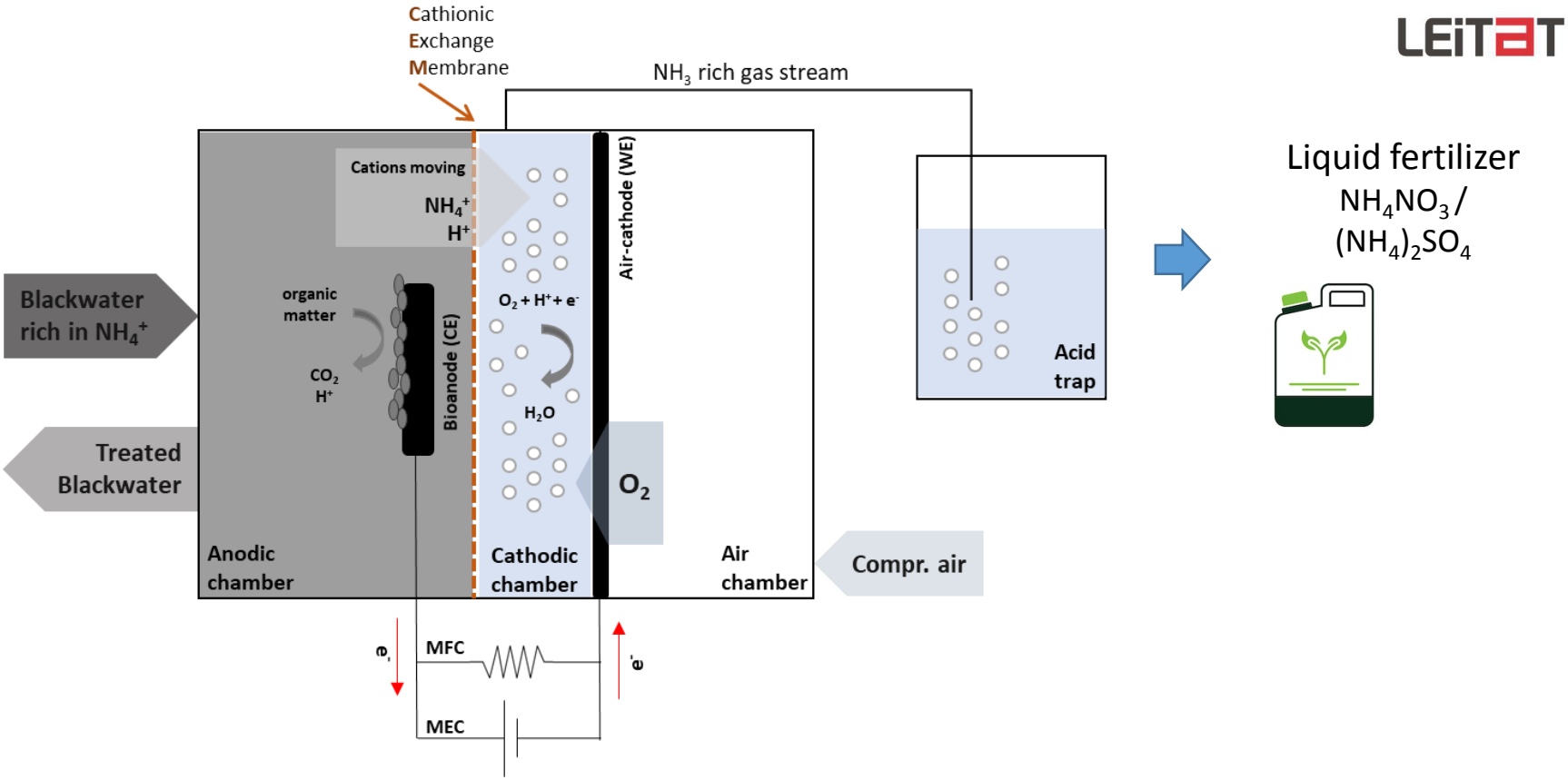
Demo sites and technologies

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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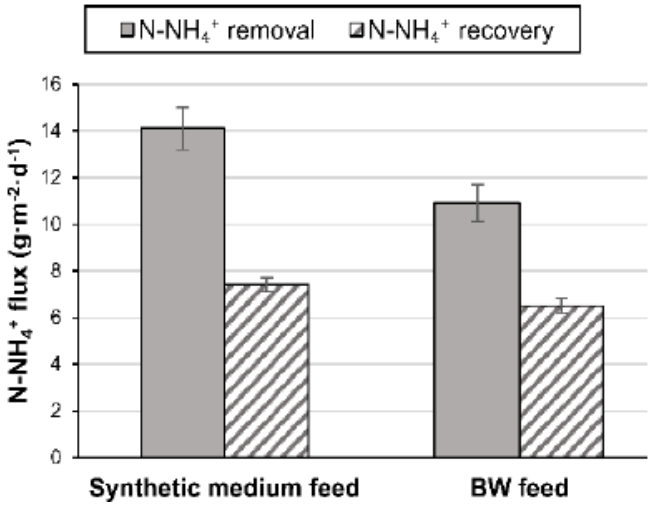
Demo sites and technologies

Innovations: Nitrogen recovery with BioElectrochemical Systems (BES)





≈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

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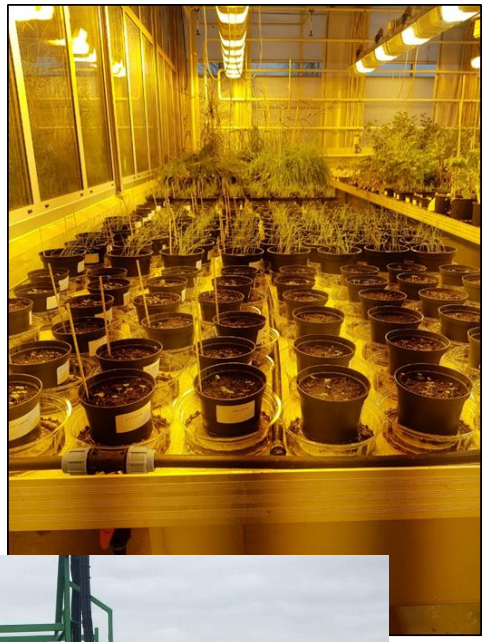
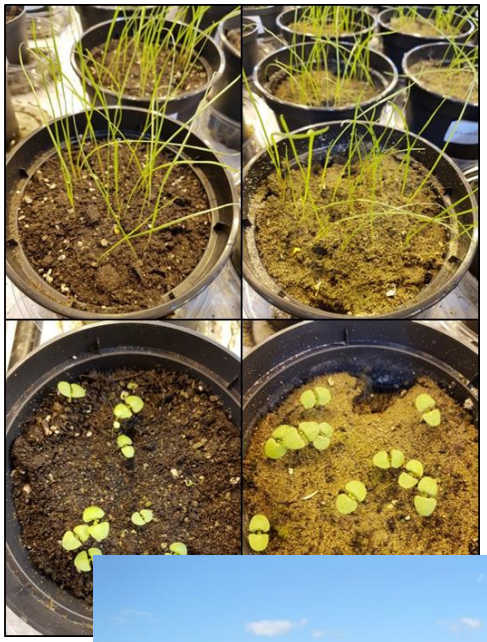
Pot and field fertilizer tests









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ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

Online seminar
Material recovery and safe reuse

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



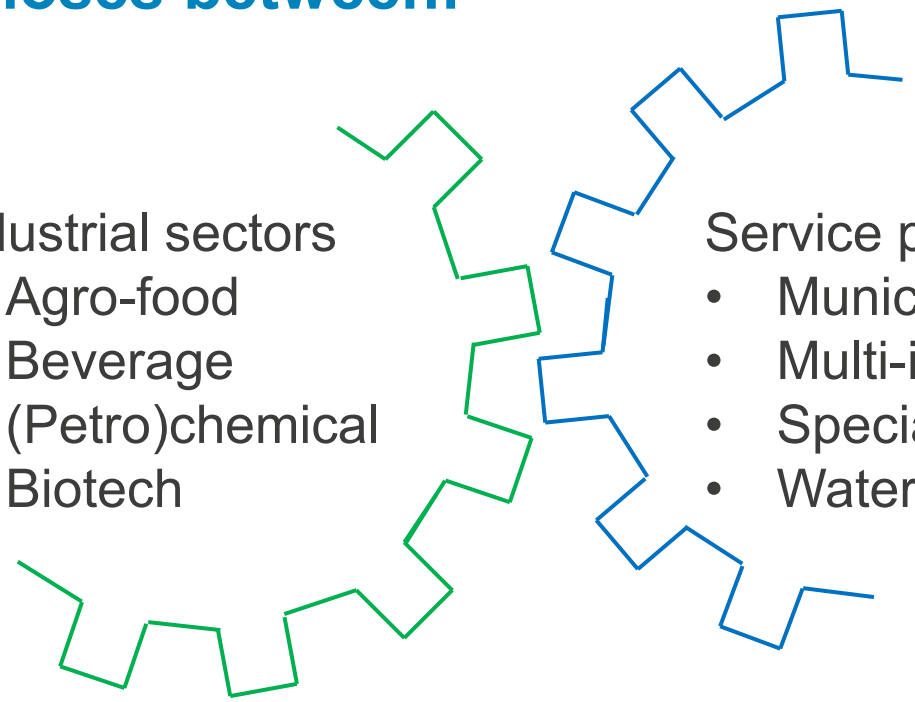
June, 23rd 2021

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

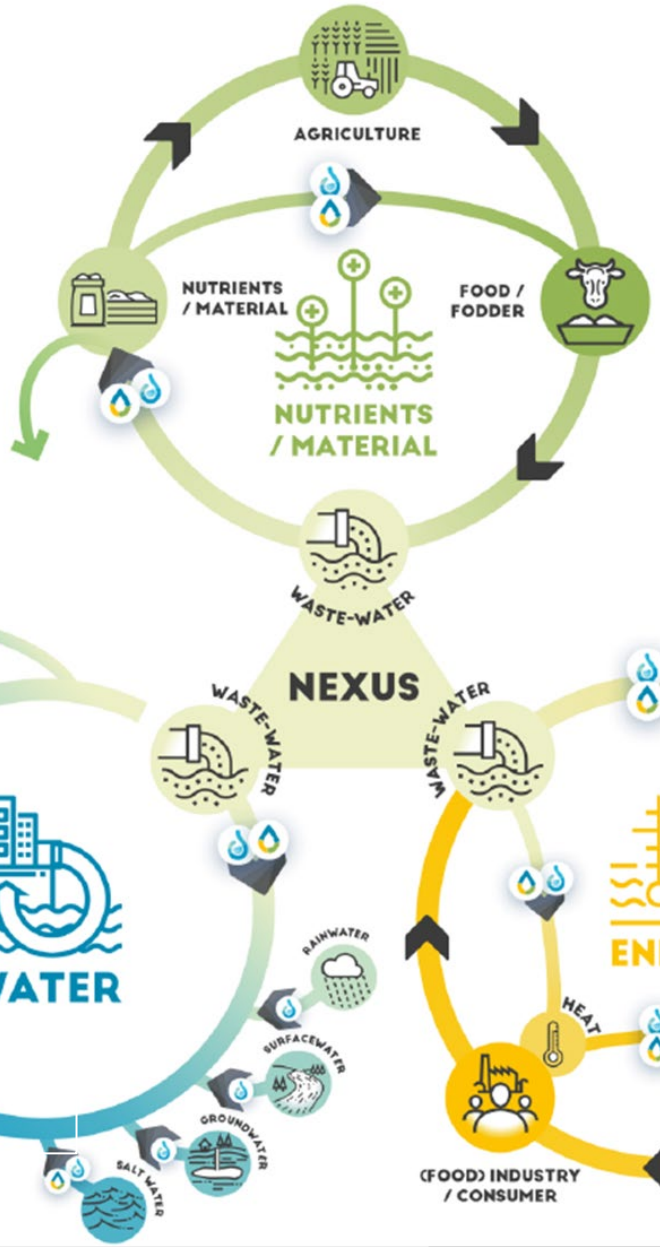
27 Partners

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



KOMPETENZZENTRUM Wasser Berlin

A. Kleyböcker

- Biogas technologies
- Heat Recovery
- Digitalization

Coordinator: KWR

9 Case Studies

27 Partners

37 Technologies



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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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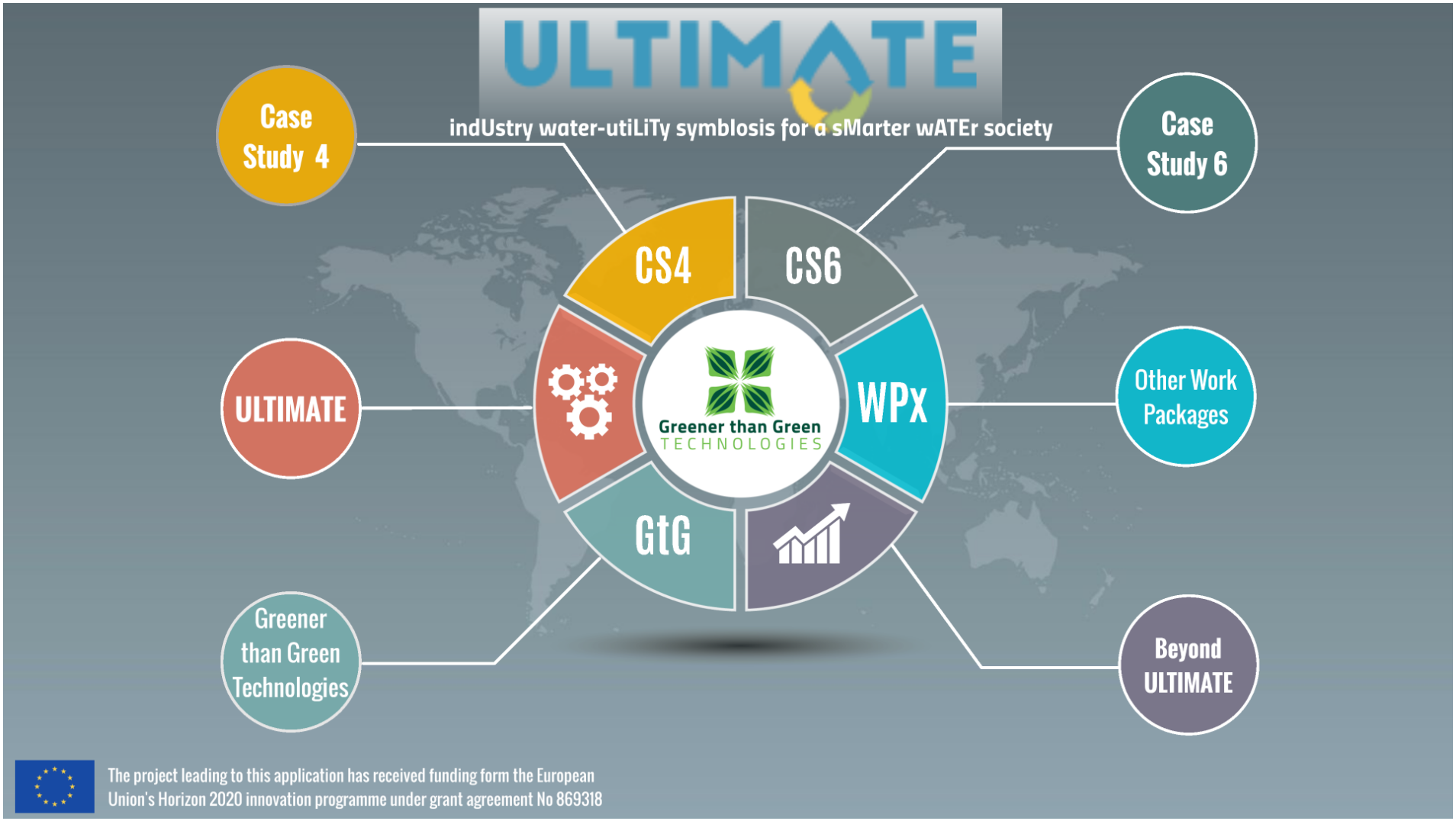
ULTIMATE
indUstry water-utiLiTy symbIosis for a sMarter wATEr society
Case Study 4
Case Study 6
CS4
CS6
ULTIMATE
Greener than Green TECHNOLOGIES
WPx
Other Work Packages
GtG
Greener than Green Technologies
Beyond ULTIMATE
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Greener than Green Technologies 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

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The team



Christophoros Christophoridis
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Chemist, BSc MSc



Haris Magonis
Environmental Engineer
MEng MSc



Charalampos- Philip Iossifidis
Chemist, BSc MSc MBA



Dimitri Iossifidis
Chemist, BSc MSc PhD



Eri Bizani
Chemist, BSc MSc PhD

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Case Study 4

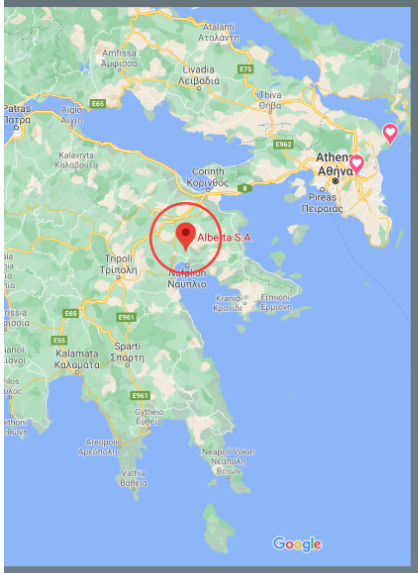
- Fruit processing industry

- 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

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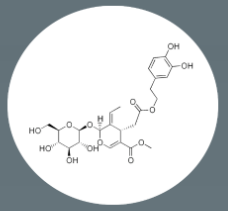
Case Study 4 Goals

- 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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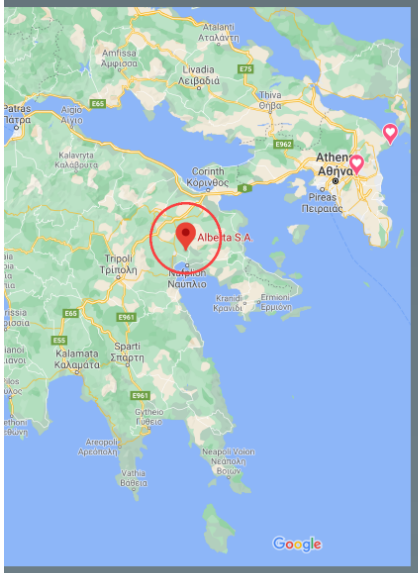

Goals

The Unit

Value-added compound extraction

AOP

SBP

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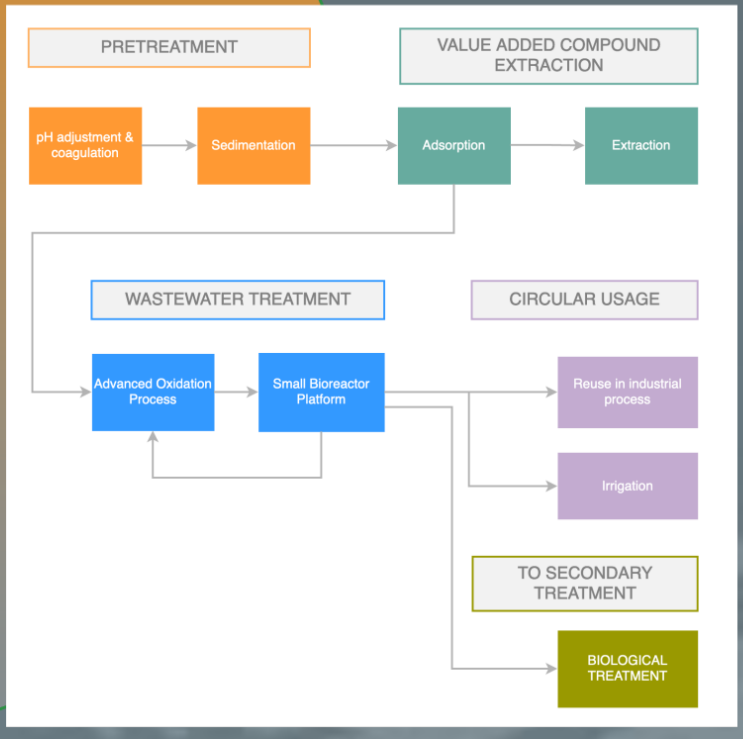
Unit Design



Cross-section

P&ID



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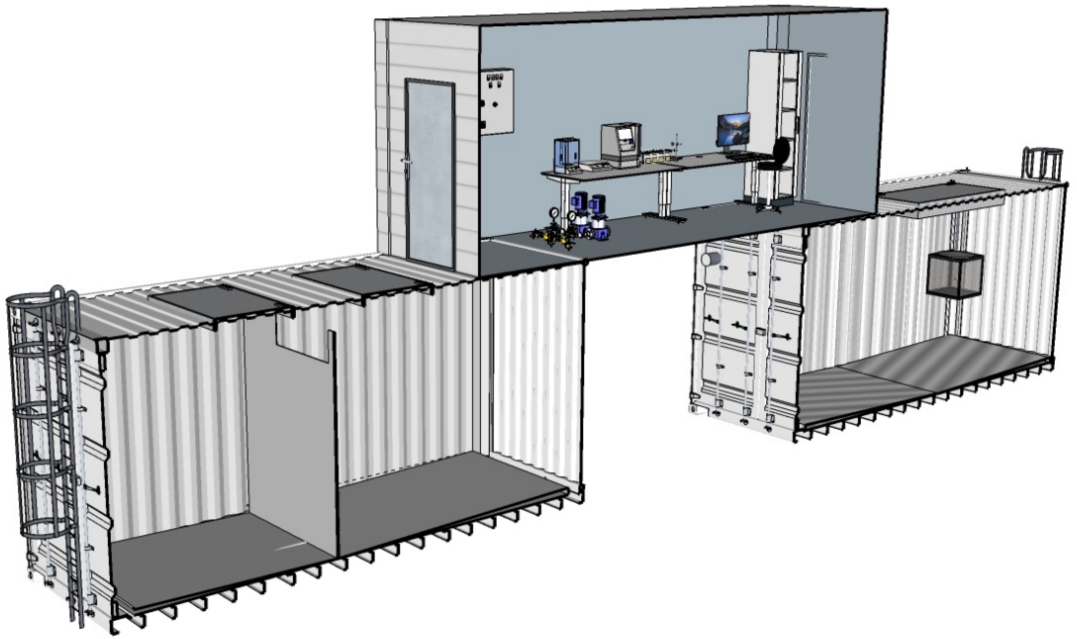
Unit Cross-section



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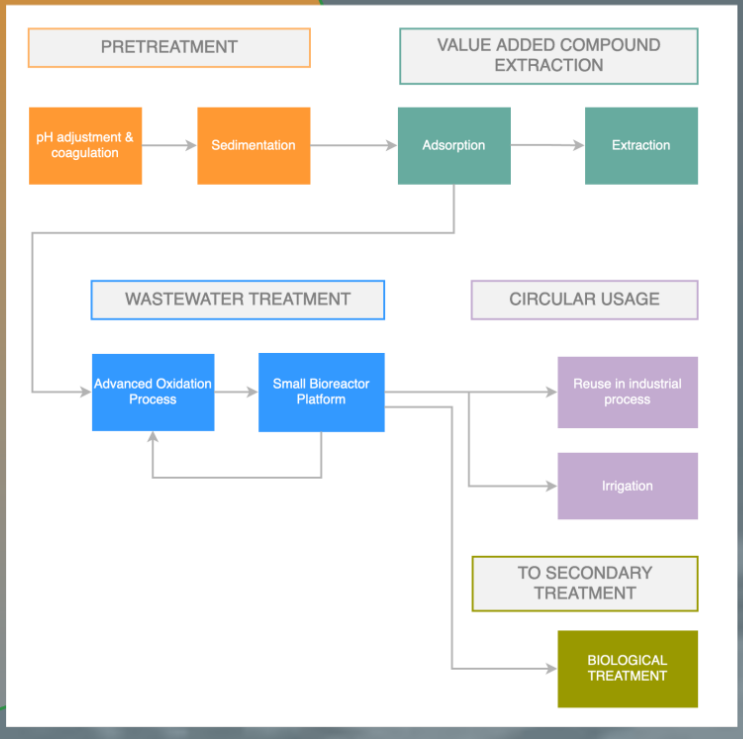
Unit Design



Cross-section

P&ID



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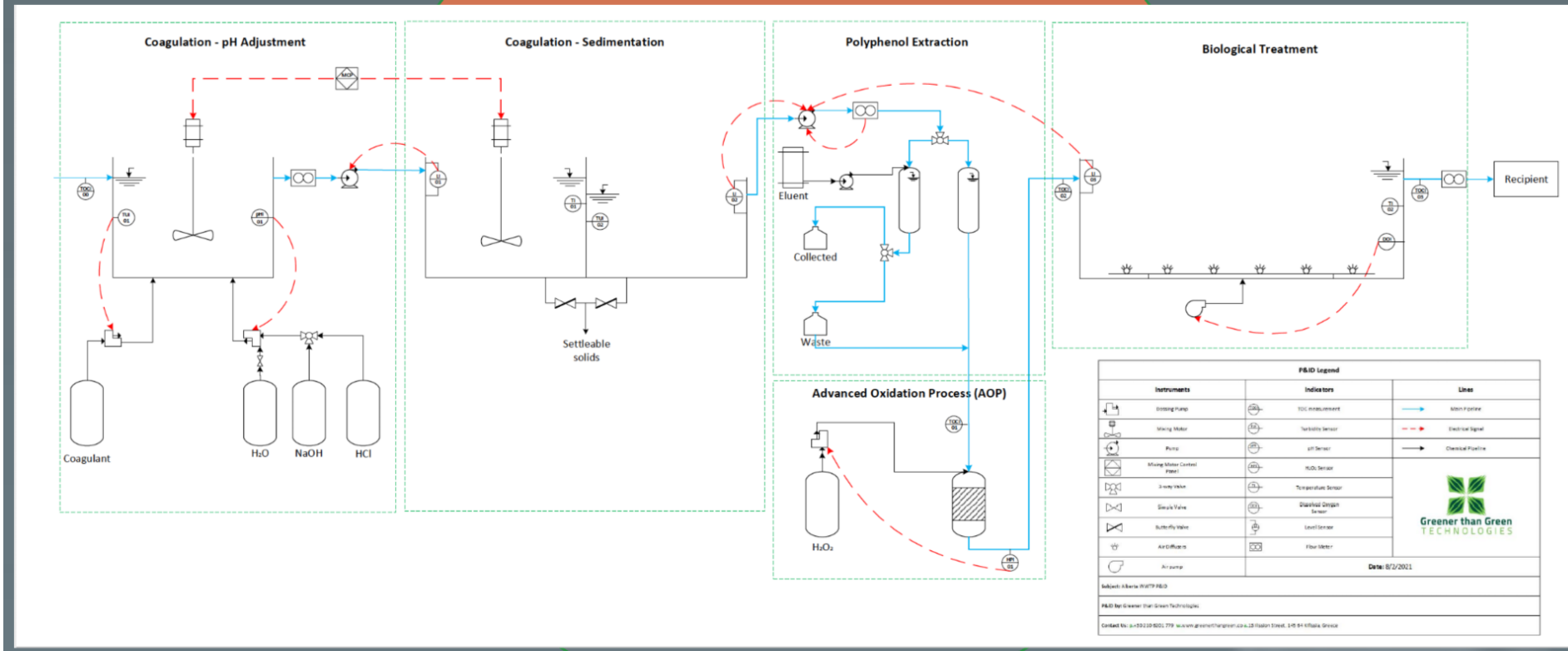
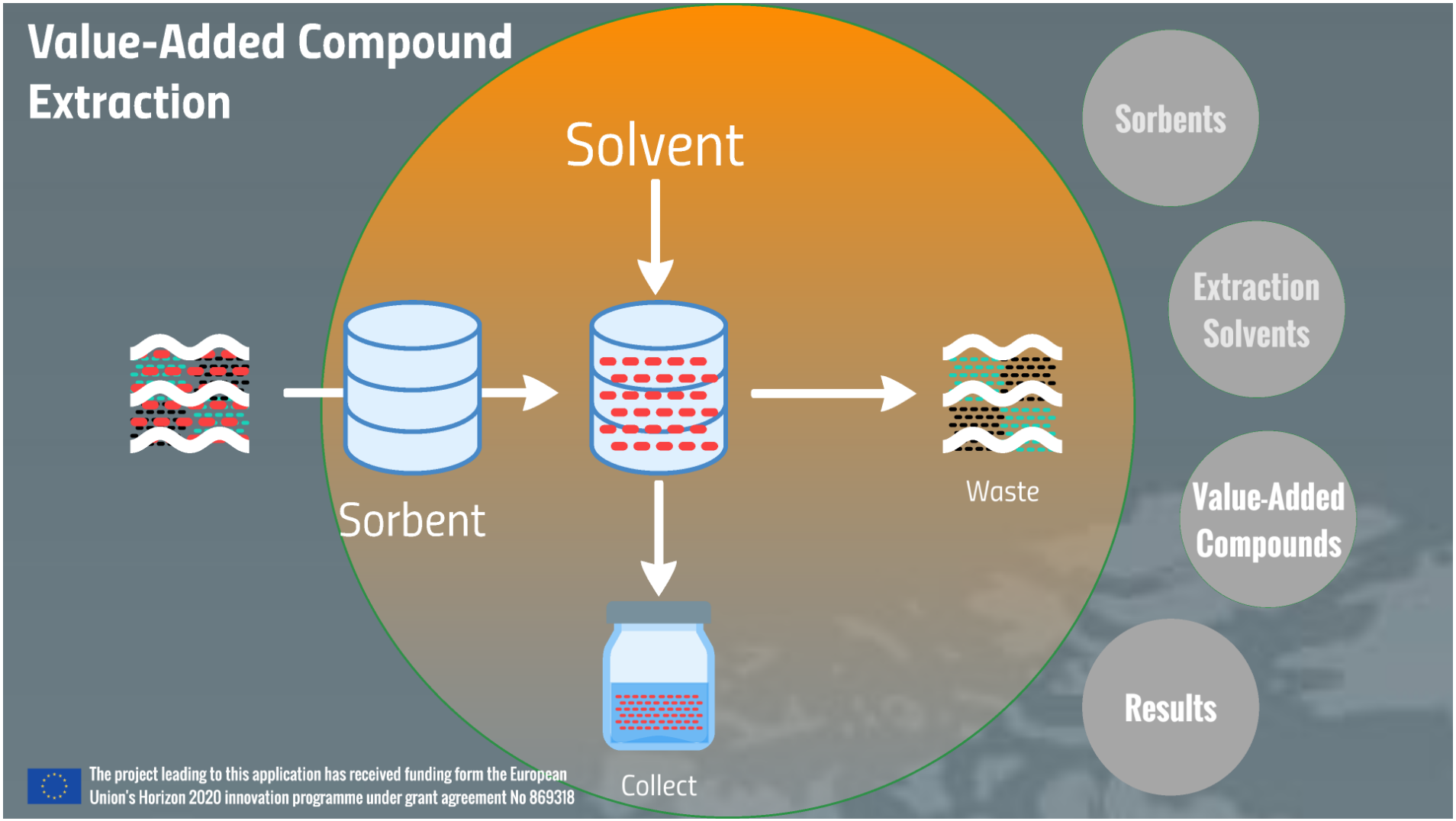
Unit P&ID

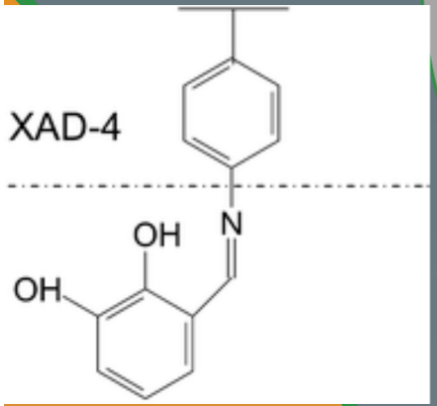

Coagulation - pH Adjustment
Coagulant
H₂O
NaOH
HCl
Coagulation - Sedimentation
Settleable solids
Polyphenol Extraction
Eluent
Collected
Waste
Advanced Oxidation Process (AOP)
H₂O₂
Biological Treatment
Recipient
P&ID Legend
Instruments
Indicators
Lines
Greener than Green
TECHNOLOGIES
Date: 8/2/2021

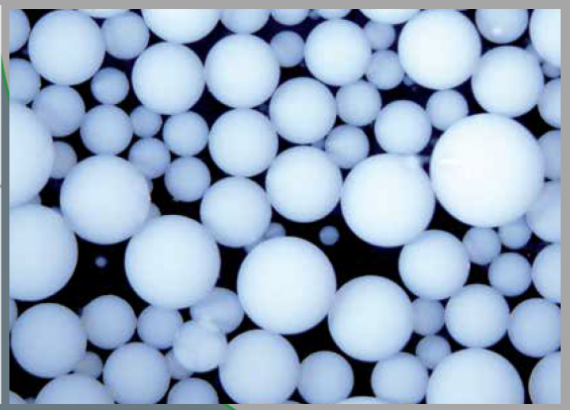

Value-Added Compound Extraction
Solvent
Sorbent
Waste
Collect
Sorbents
Extraction Solvents
Value-Added Compounds
Results
The project leading to this application has received funding form the European Union's Horizon 2020 innovation programme under grant agreement No 869318

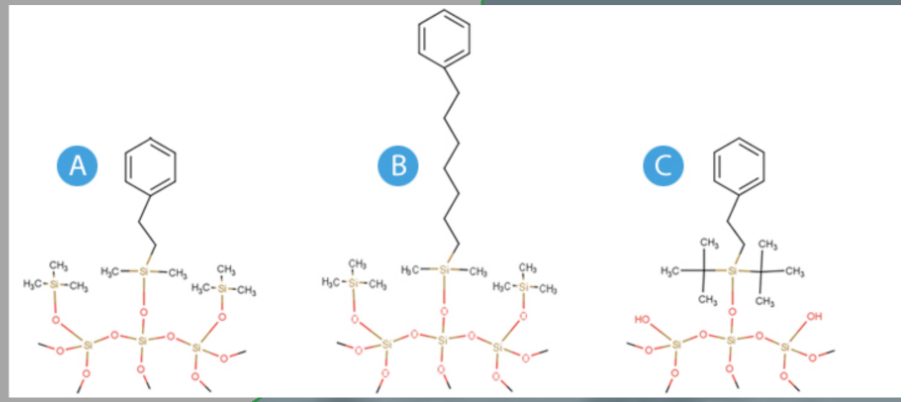
Sorbents

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

?



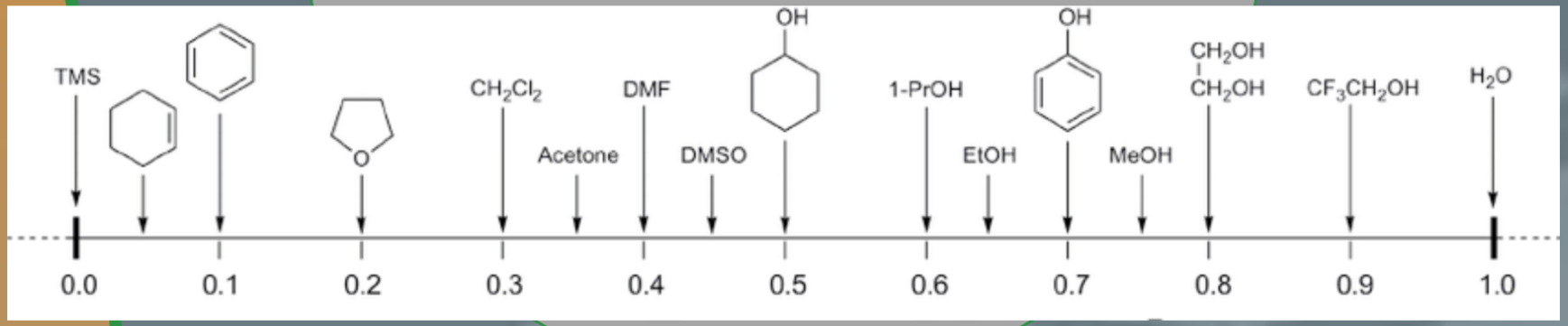




Extraction Solvents

Water - cheap, inefficient, non-toxic
Methanol - high cost, increased toxicity
Ethanol - very high cost, lower toxicity

Subcritical Water Extraction



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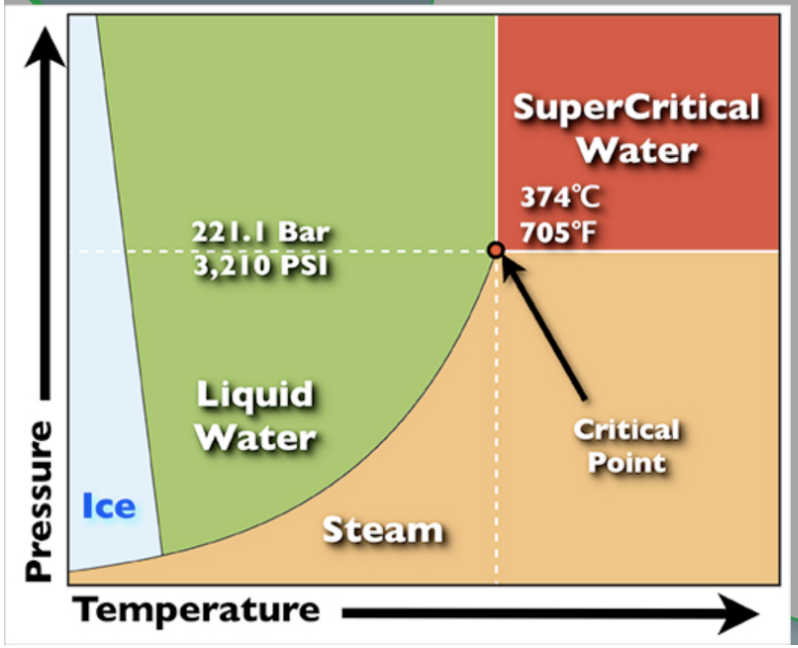
SubCritical Water Extraction (SCWE)

- 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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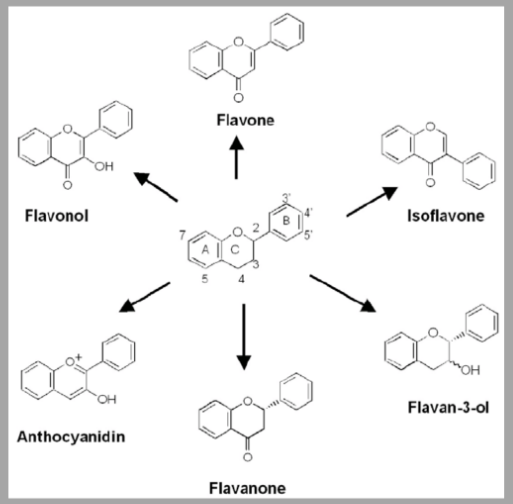
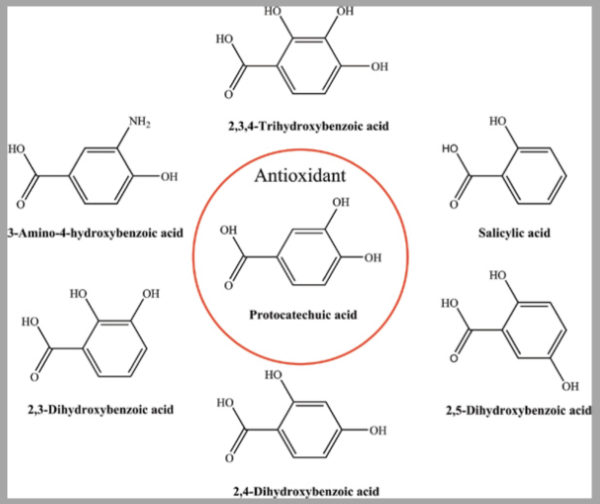
Structure of polyphenols

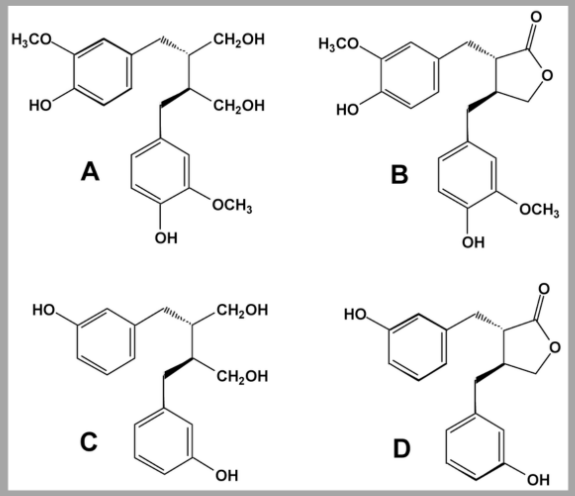
Flavonoids



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

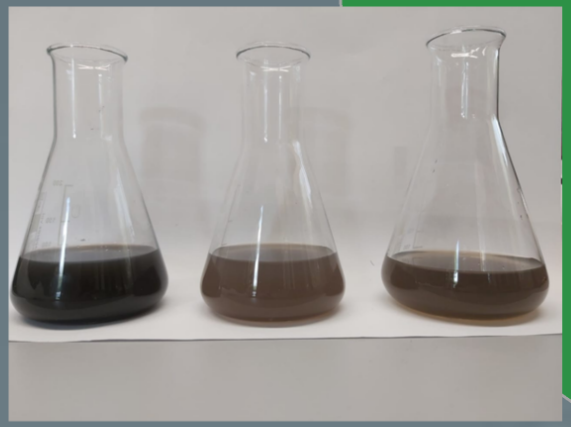
Recovery

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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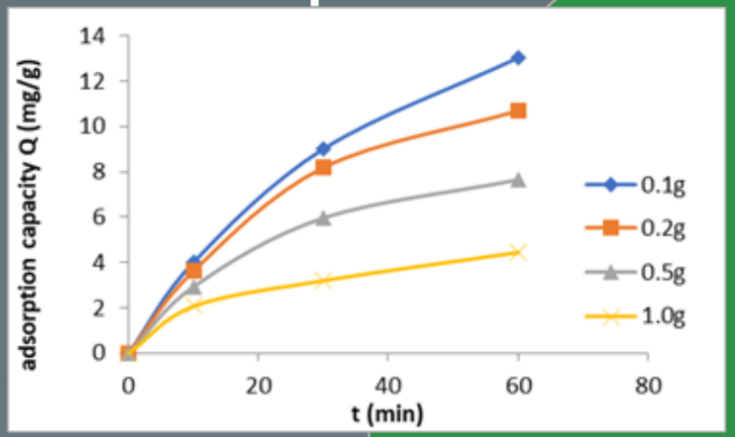
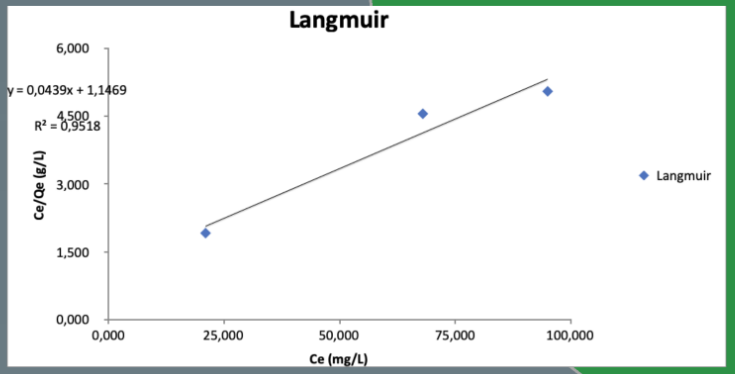
Static Adsorption Results





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)

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

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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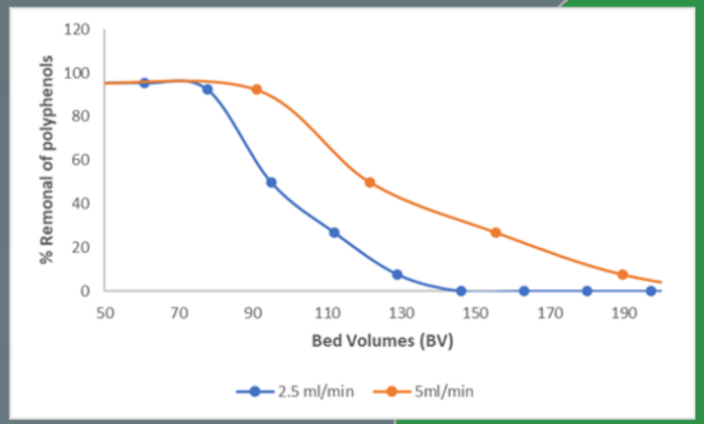
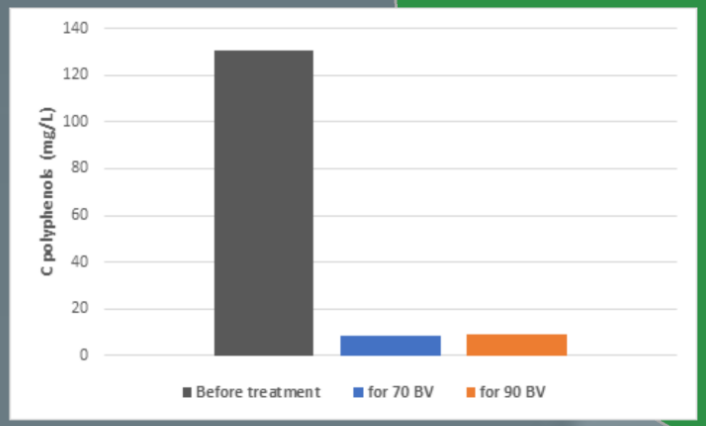
Dynamic Adsorption Results





- 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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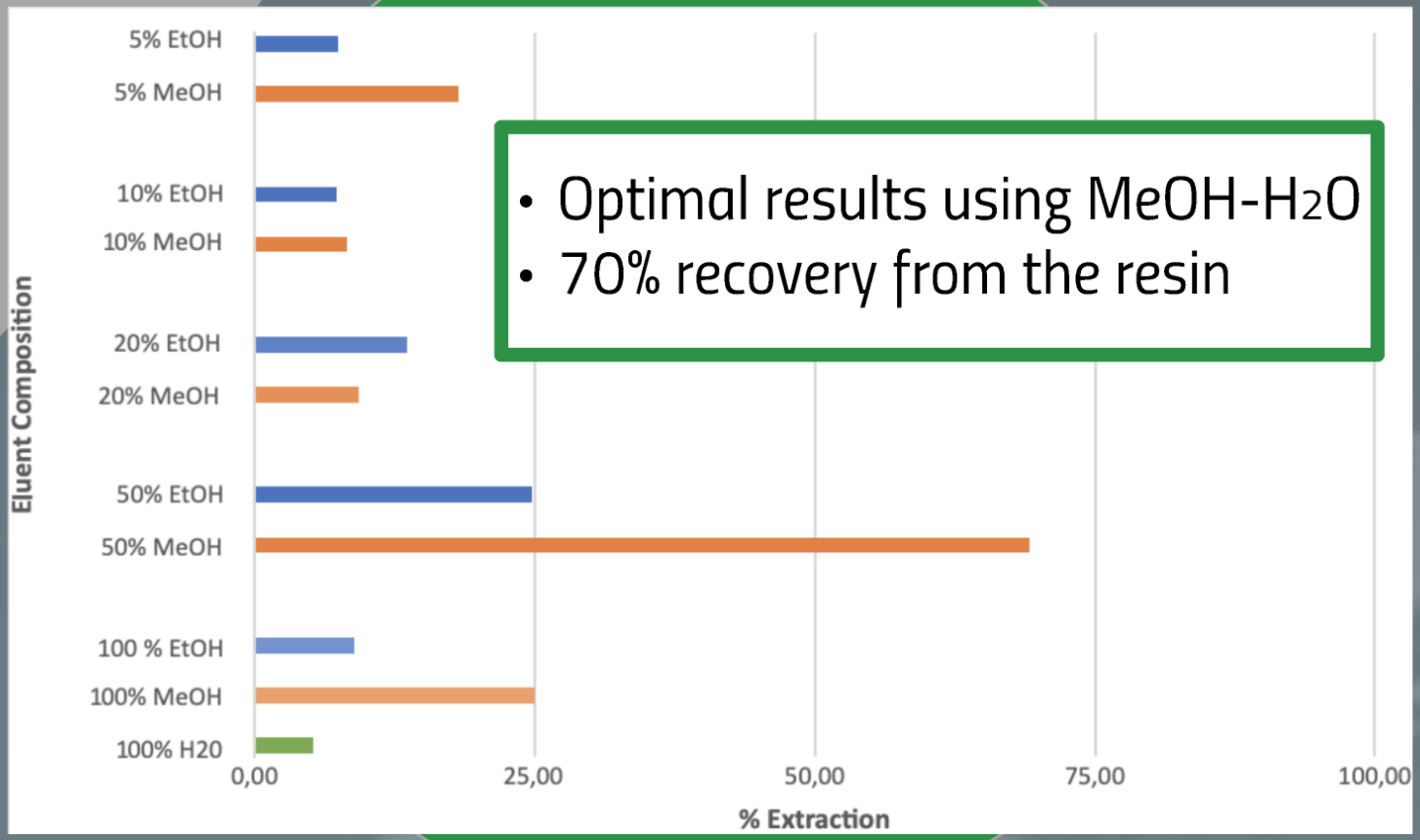
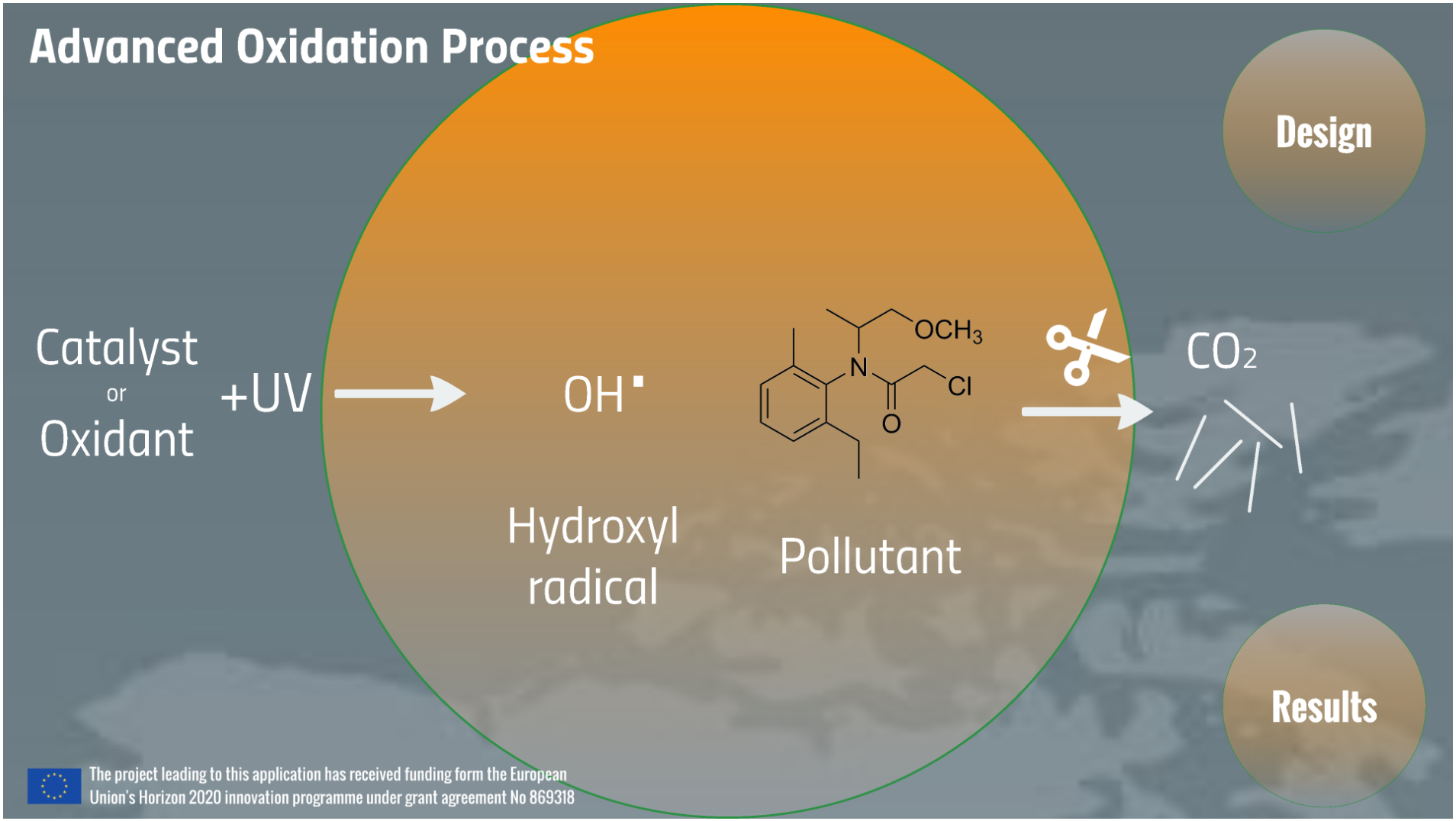
Recovery



- Optimal results using MeOH-H_2O
- 70% recovery from the resin

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

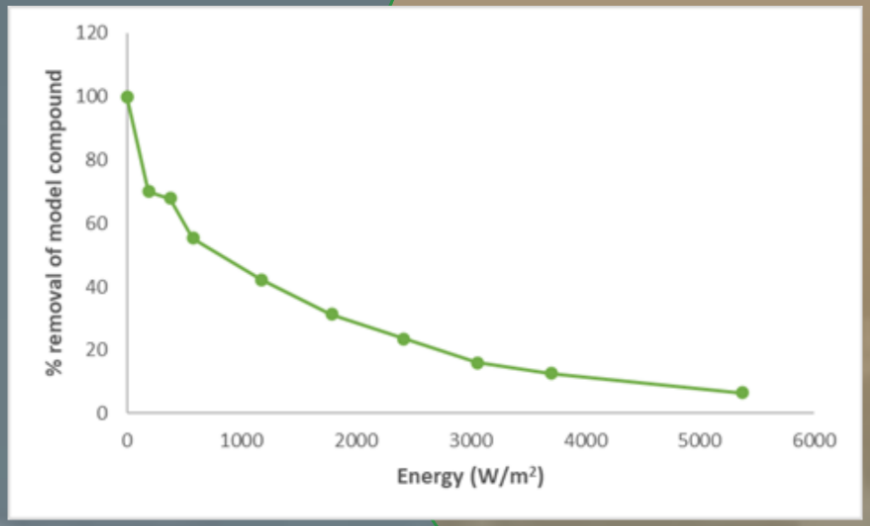

Advanced Oxidation Process
Design
Catalyst
or
Oxidant
+UV
OH·
Hydroxyl radical
OCH3
N
Cl
O
Pollutant
CO2
Results
The project leading to this application has received funding form the European Union's Horizon 2020 innovation programme under grant agreement No 869318

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

BioCastle
Nature open-code inspired



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

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

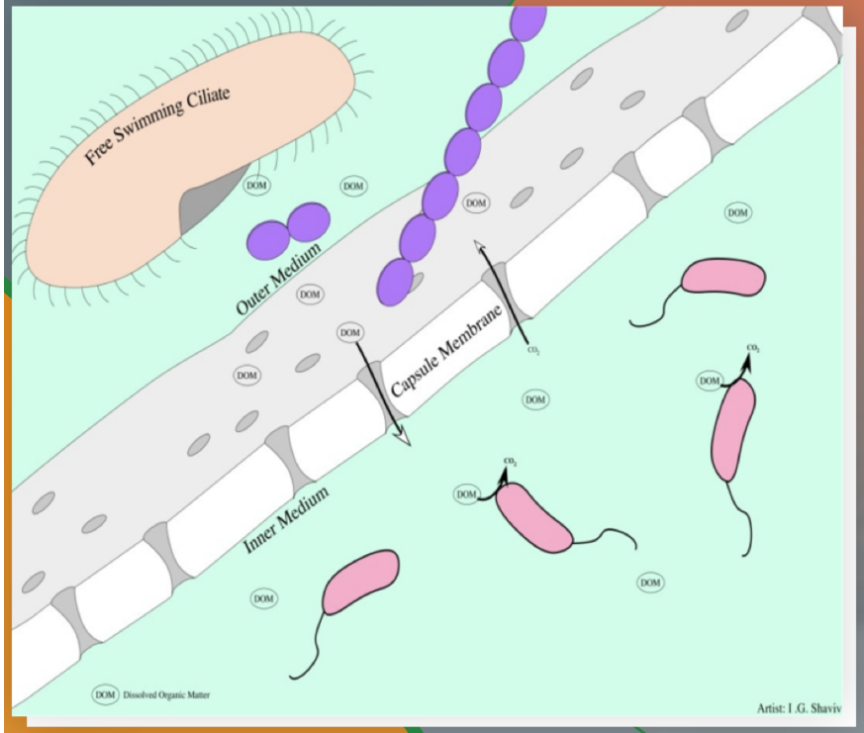
Applications

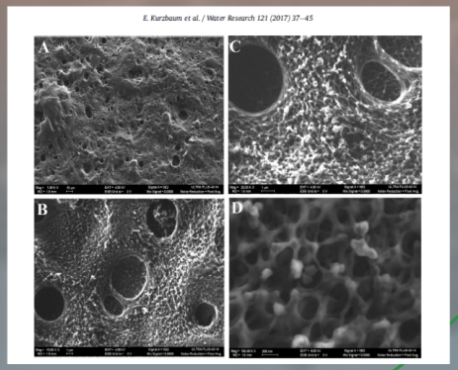
ULTIMATE

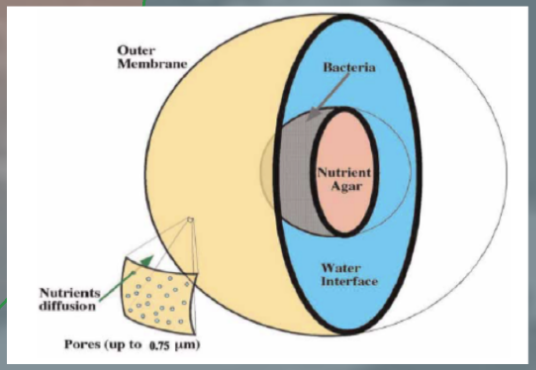
The project leading to this application has received funding form the European Union's Horizon 2020 innovation programme under grant agreement No 869318

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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Small Bioreactor Platform

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Controlling the type of bacteria needed
Defining the space they grow
Controlling the amount of biomass

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

Benefits

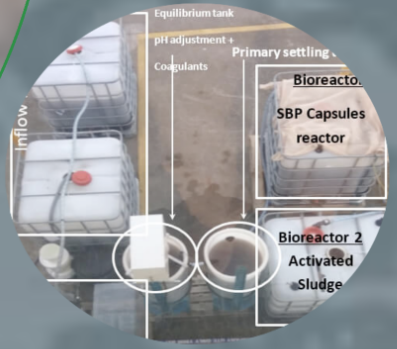
SBP technology addresses certain biological treatment problems:

- 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





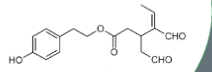
The project leading to this application has received funding form the European Union's Horizon 2020 innovation programme under grant agreement No 869318

Polyphenol Extraction

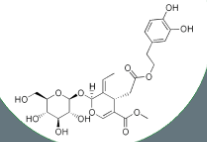
"Let food be thy medicine and medicine be thy food"
Hippocrates 460-377 BC

- 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

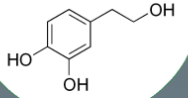
Oleocanthal



Oleuropein



3-Hydroxy tyrosol

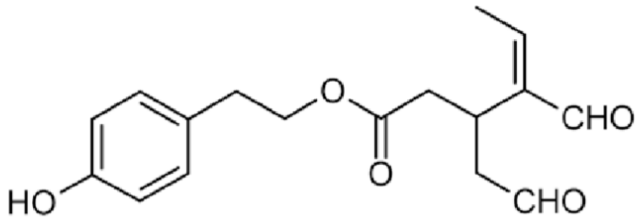


Sorbents

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

Oleocanthal

Market value:
€1620/g

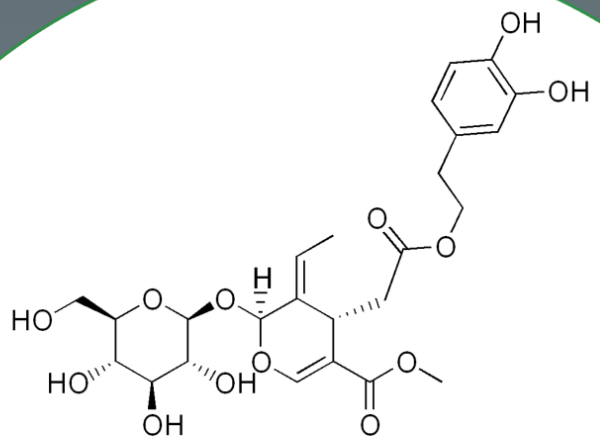


Properties:

- Antioxidant
- Anti-inflammatory
- Anti-cancer
- Reduce risk of AD
- Reduce risk of heart disease

Oleuropein

Market value:
€7.240/g

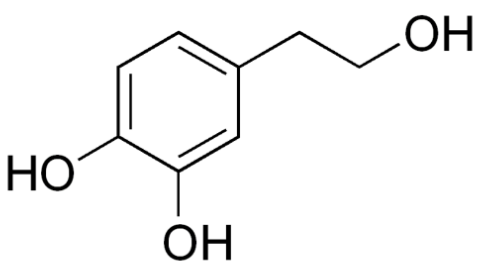


Properties:

- Antioxidant
- Anti-inflammatory
- Anti-cancer
- Protects skin & eyes
- Protection against pathogens

3-Hydroxy tyrosol

Market value:
€7.240/g

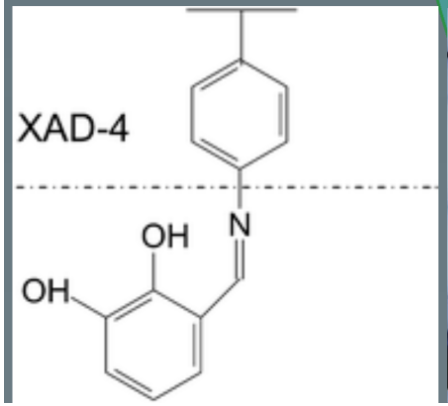


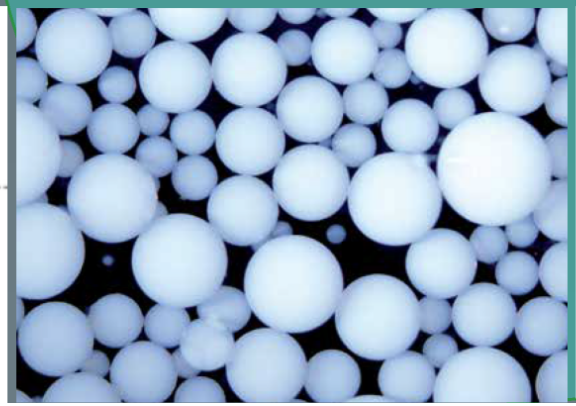
Properties:

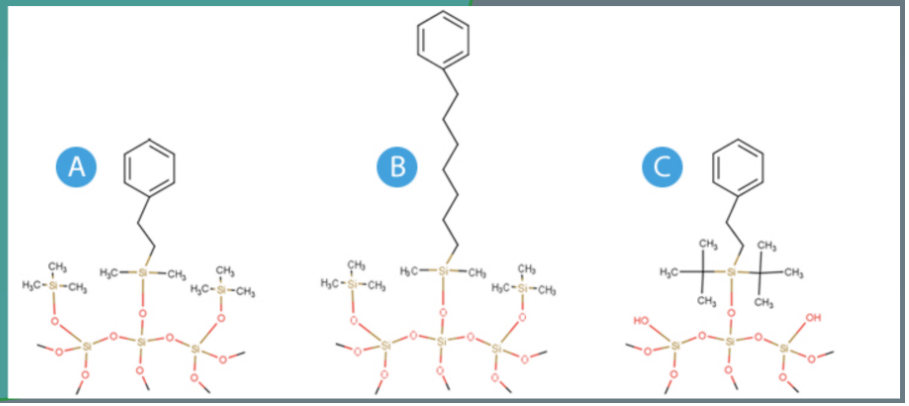
- Antioxidant
- Anti-inflammatory
- Anti-cancer
- Protects skin & eyes
- Protection from pathogens

Sorbents

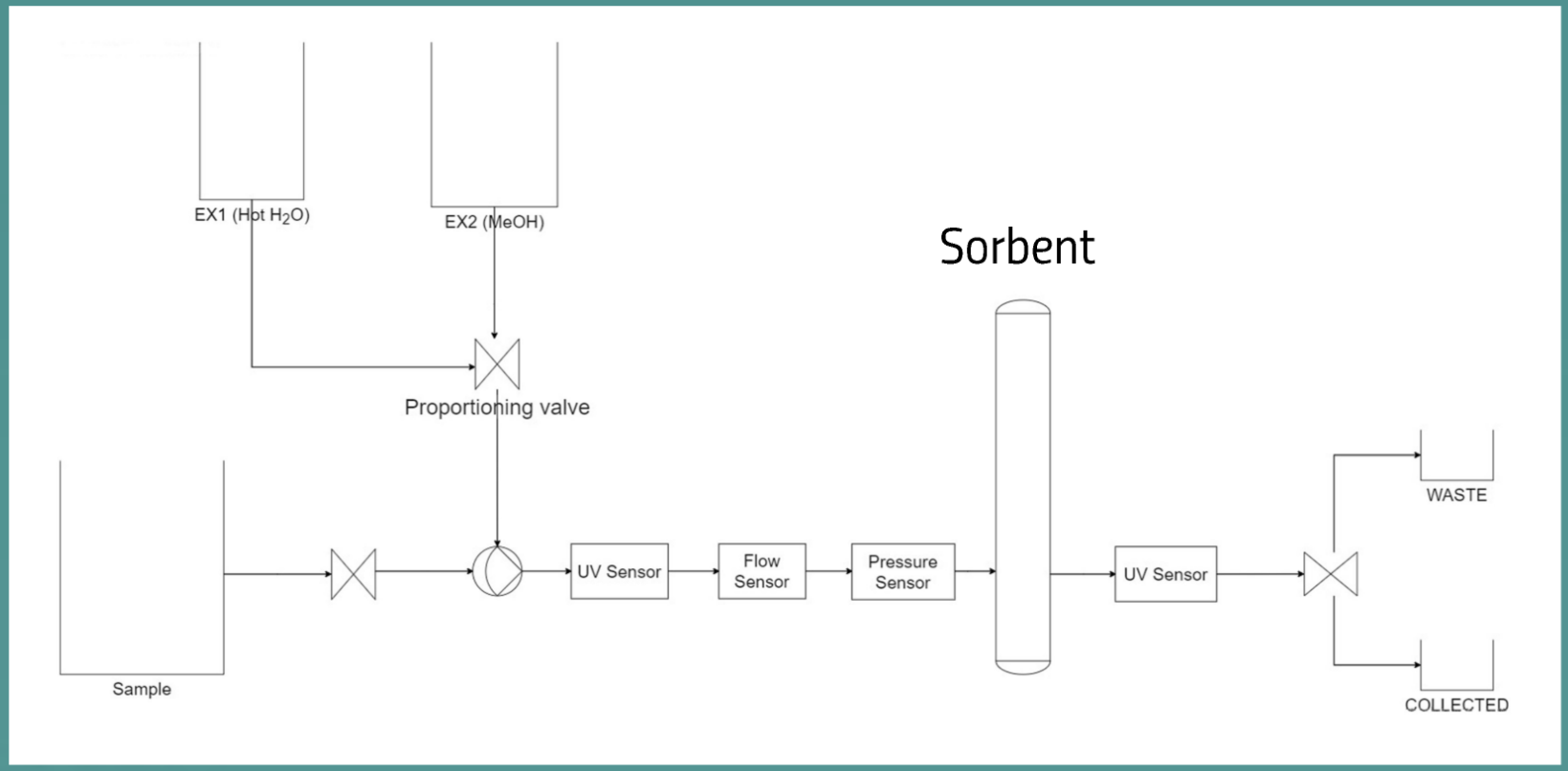
Adsorbent	Material	Structure	Particle size (µm)	Surface Area (m^2/g)	Pore Size (Å)
AmberLite™ FPX66	Resin	Aromatic	700	800	150
AmberLite™ XAD-4	Resin	Aromatic	640	750	100
Phenyl-Hexyl	Silica	Aromatic	15	400	100







Design



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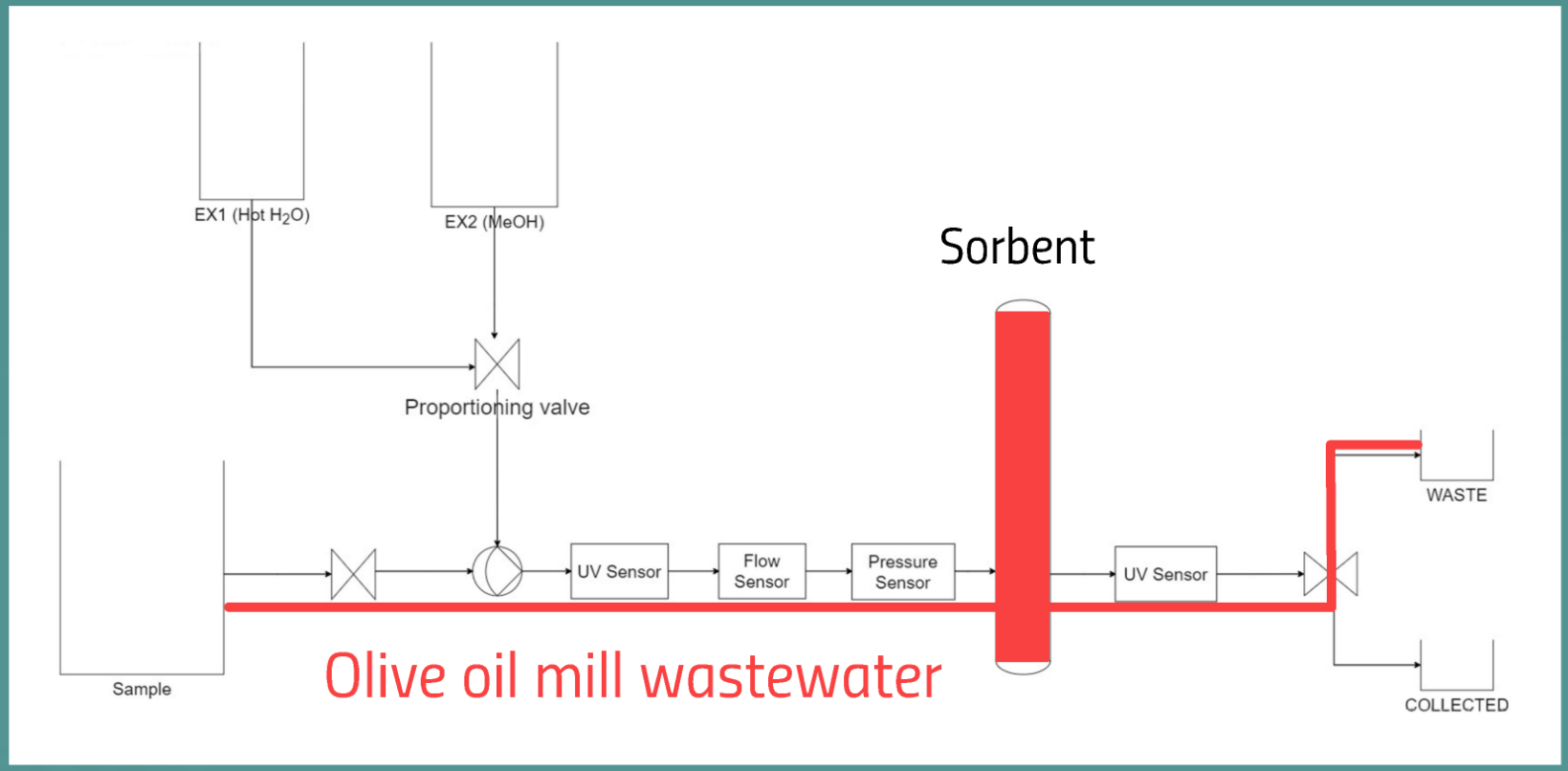

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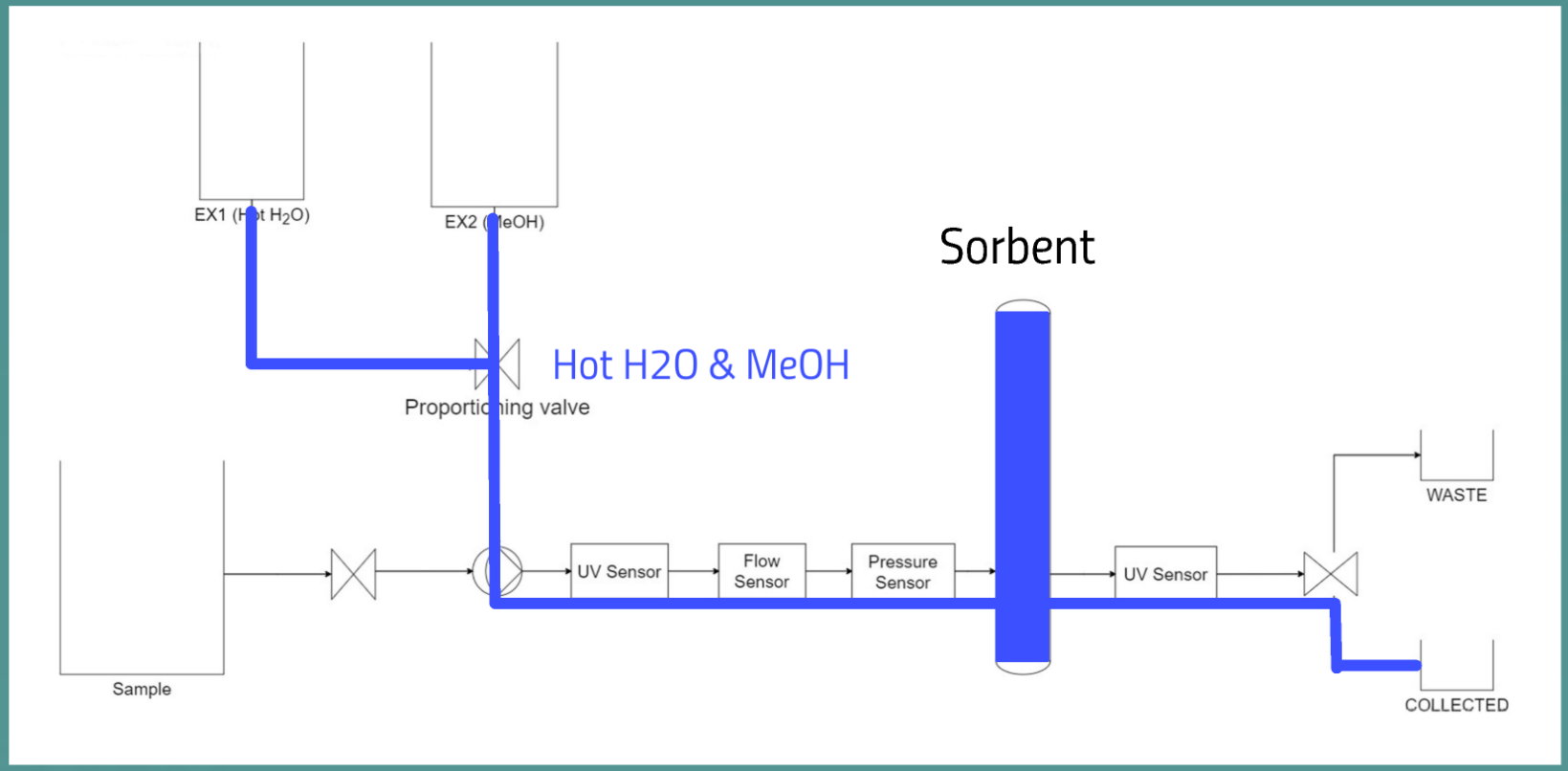
Extraction



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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

9 DEMOSITES

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

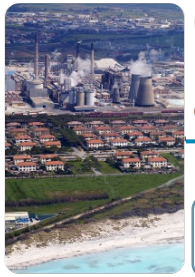
- 1- Tarragona (ES)
- 2- Nieuw Prinsenland (NL)
- 3- Rosignano (IT)
- 4- Nafplio (EL)
- 5- Lleida (ES), Ostrava (CZ)
- 6- Karmiel, Shafdan (IL)
- 7- Tain (UK)
- 8- Saint-Maurice l'Exil (FR)
- 9- Kalundborg (DK)





Cecina municipality

Unpredicted Saltwater intrusion



Unpredicted Saltwater intrusion

Rosignano municipality

Cecina WWTP





Rosignano WWTP

Aretusa WWTP



High values of salinity, hardness and COD

Groundwater

Solvay industry

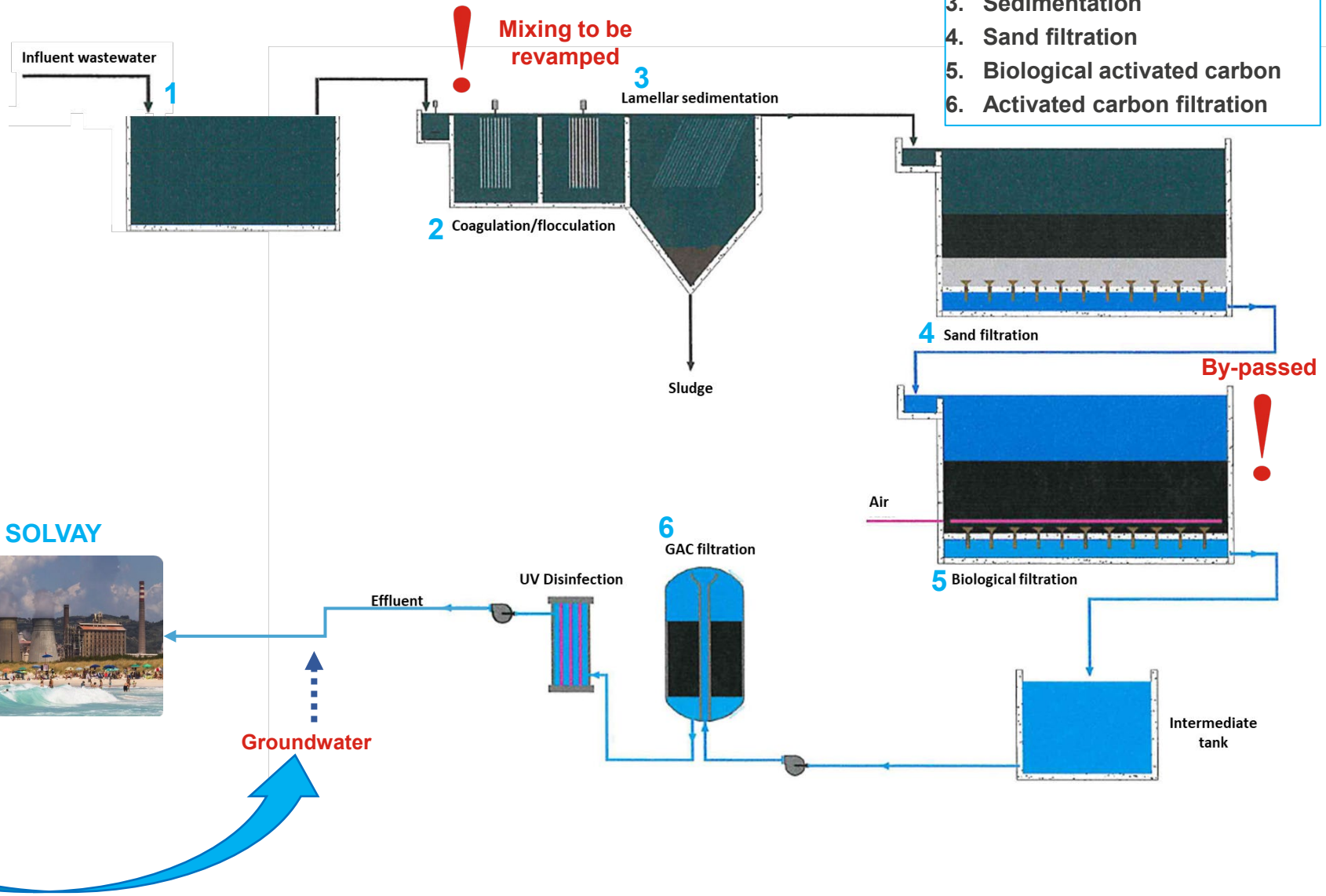


ARETUSA WWRP

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

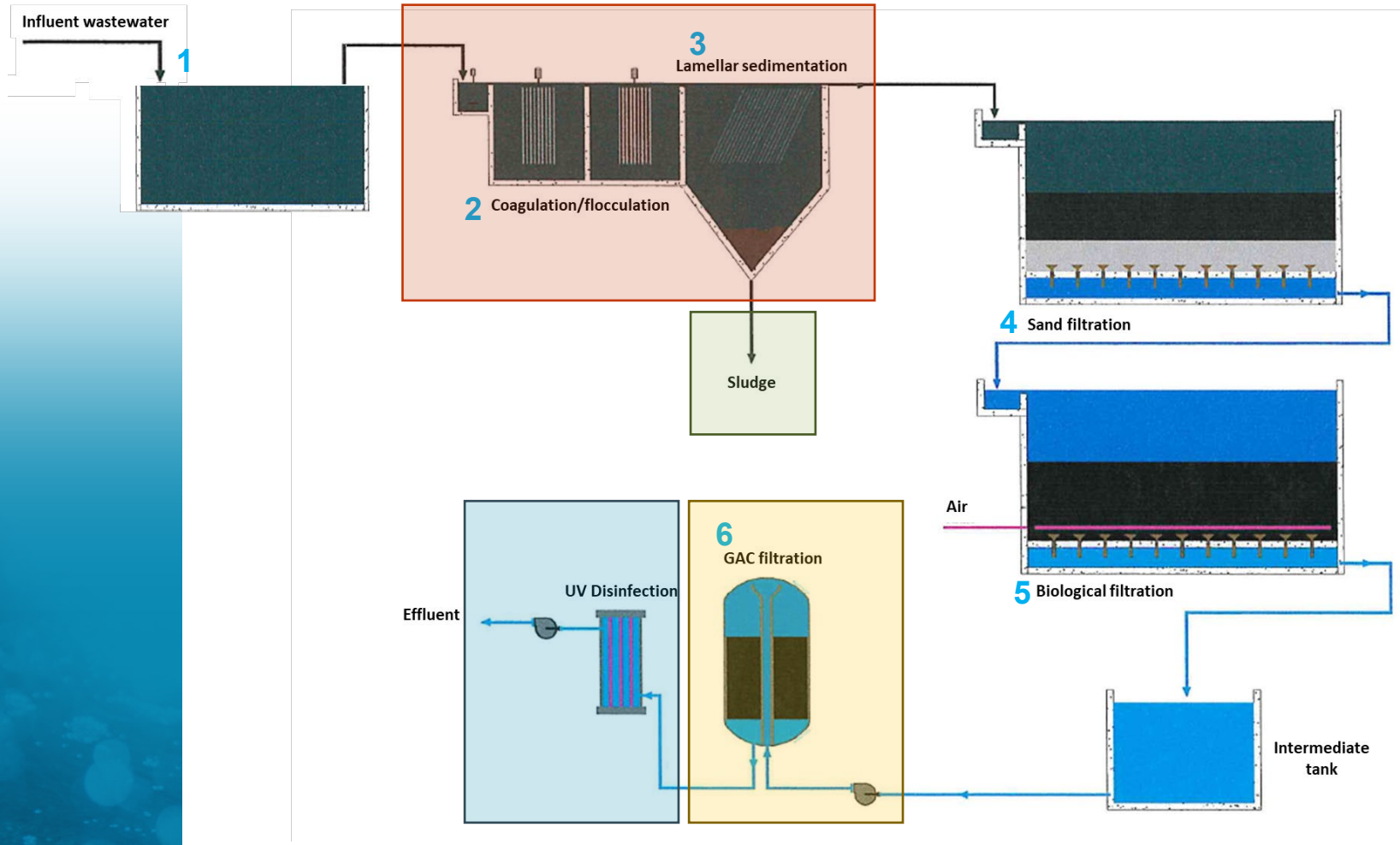


When needed (internally agreed) water quality standard are not reached

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

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

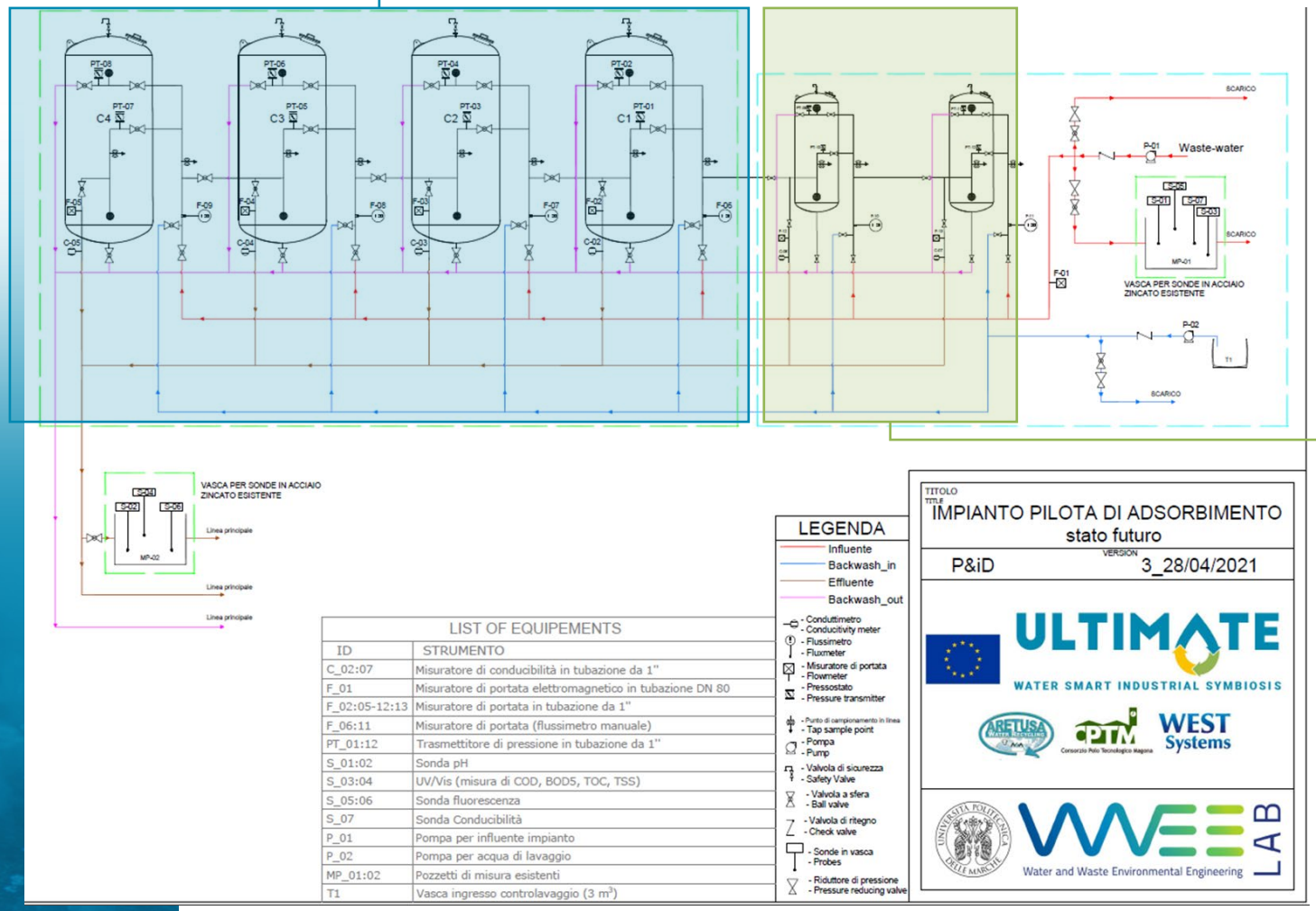
4. Preliminary assessment of possible applications: absorbents/coagulants in wastewater treatmnent, geotechnical, geo-environmental and building sectors

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

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

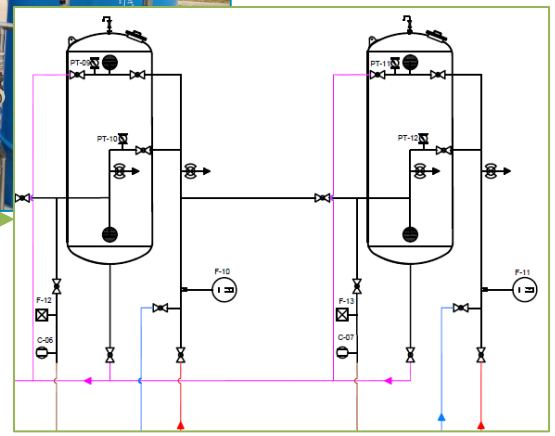
A pilot scale adsorption system will be tested with alternative GAC.



LIST OF EQUIPEMENTS

ID	STRUMENTO
C_02:07	Misuratore di conducibilità in tubazione da 1"
F_01	Misuratore di portata elettromagnetico in tubazione DN 80
F_02:05-12:13	Misuratore di portata in tubazione da 1"
F_06:11	Misuratore di portata (flussimetro manuale)
PT_01:12	Trasmettitore di pressione in tubazione da 1"
S_01:02	Sonda pH
S_03:04	UV/Vis (misura di COD, BOD5, TOC, TSS)
S_05:06	Sonda fluorescenza
S_07	Sonda Conducibilità
P_01	Pompa per influente impianto
P_02	Pompa per acqua di lavaggio
MP_01:02	Pozzetti di misura esistenti
T1	Vasca ingresso controlavaggio (3 m³)





	Bigger columns	Smaller columns
Numbers	4	2
Volume (m3)	0.6	0.11
Diameter (m)	0.8	0.32
Material (kg)	325	60

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

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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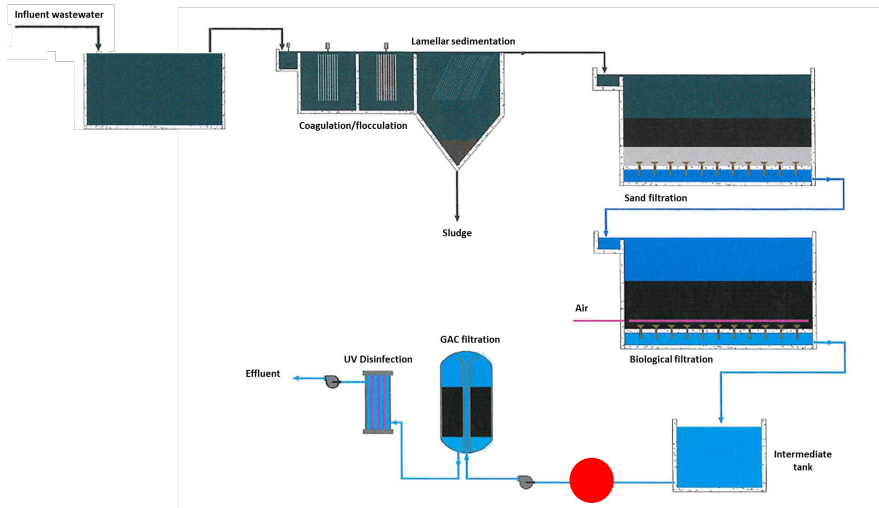
Characterization of the water sample collected in May 2021

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



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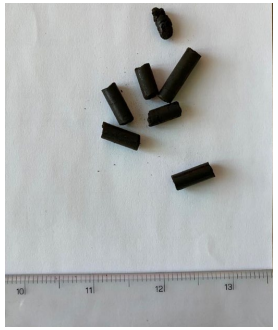
Industrial by-product

- Bentonite OC by-product “Scarto centrifuga”

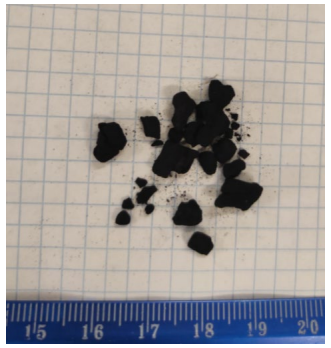


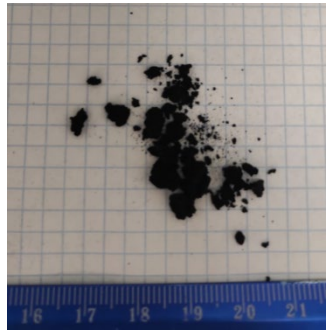
- Hydro-char from municipal sewage sludge



Hydrochar activated with different processes







- Granulated Limestone rocks only partially calcinated



- Na2CO3 “Soda Solvay® Light” >> out of specification



- NaHCO3 >> out of quality standard

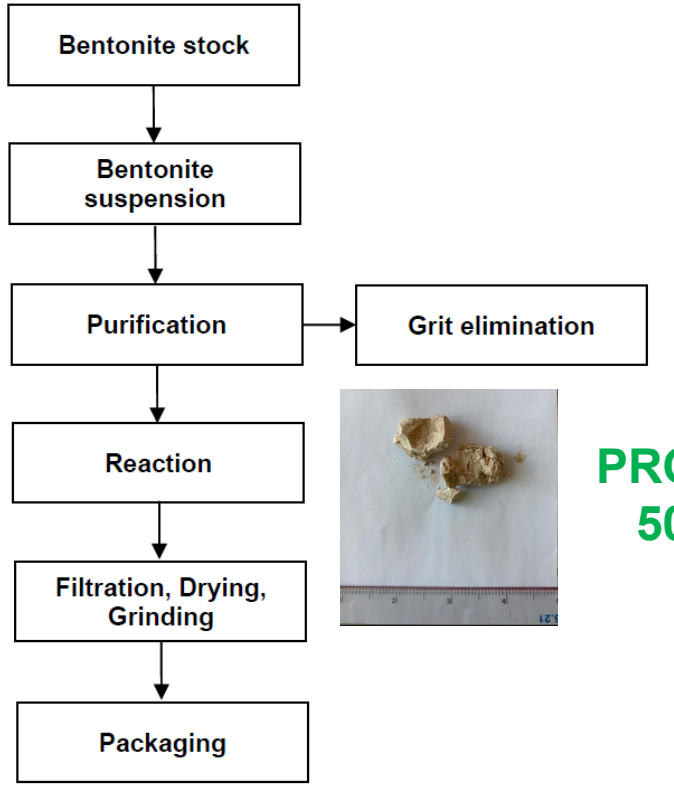


The project leading to this application has received funding from the Europ
Horizon 2020 research and innovation programme under grant agreement

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.**



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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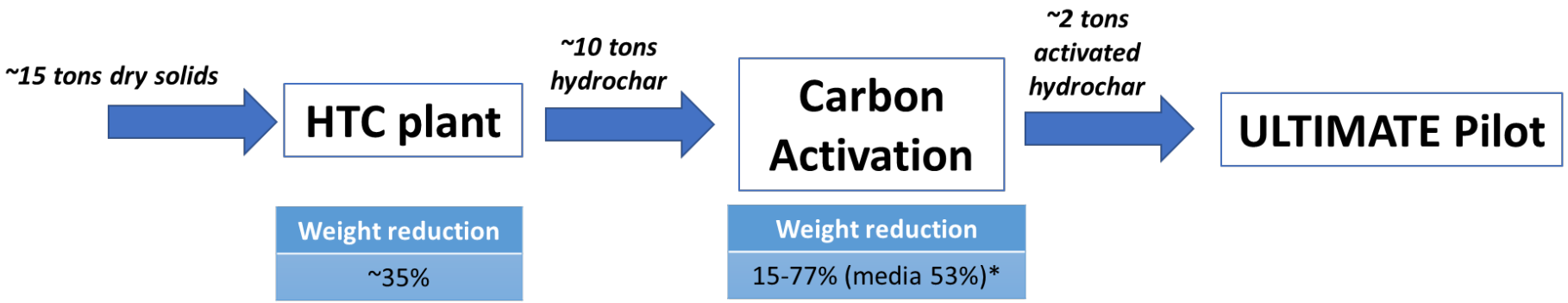
Adsorbent materials for COD removal

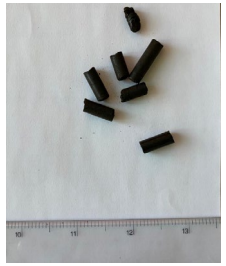
Activated Hydro-char from municipal sewage sludge

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



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Adsorbent materials for COD removal

Activated Hydro-char from municipal sewage sludge

Physical activation – ATT1

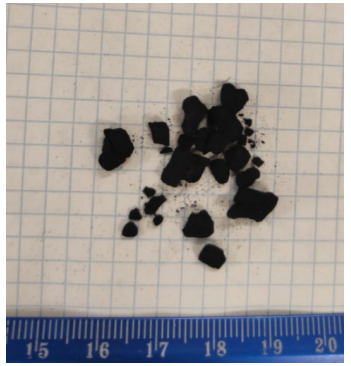
- Heating of the char pellets in a tubular oven up to 700°C (5°C/min) with N_2 purging.
- CO_2 flushing and isotherm for 2 hr.
- Cooling of the tubular furnace in N_2 purging.



47% WEIGHT LOSS

Chemical activation – ATT4

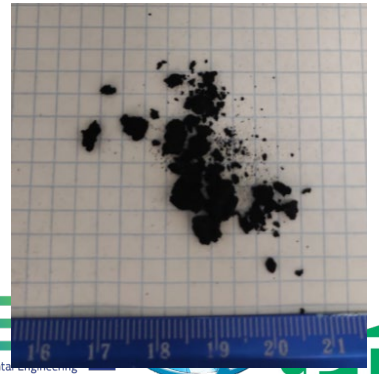
- Impregnation of char pellets in KOH aq. solution (KOH to char ratio: 1:1) at 60°C for 6 hr.
- Drying of the impregnated char at 105°C.
- Heating in a tubular oven up to 600°C (5°C/min), isotherm at 600°C for 1 hr and cooling (5°C/min) with N_2 purging.
- Washing with 1M HCl and demi water (up to pH 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	

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

Adsorbent materials characterization

Leaching test

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)**

BET analysis

	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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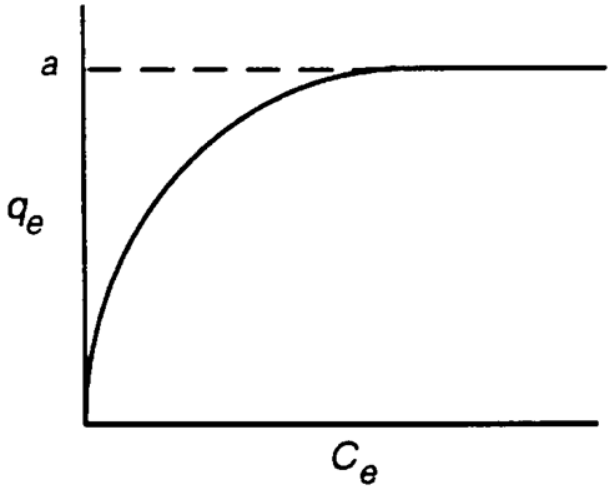
Adsorbent materials for COD removal

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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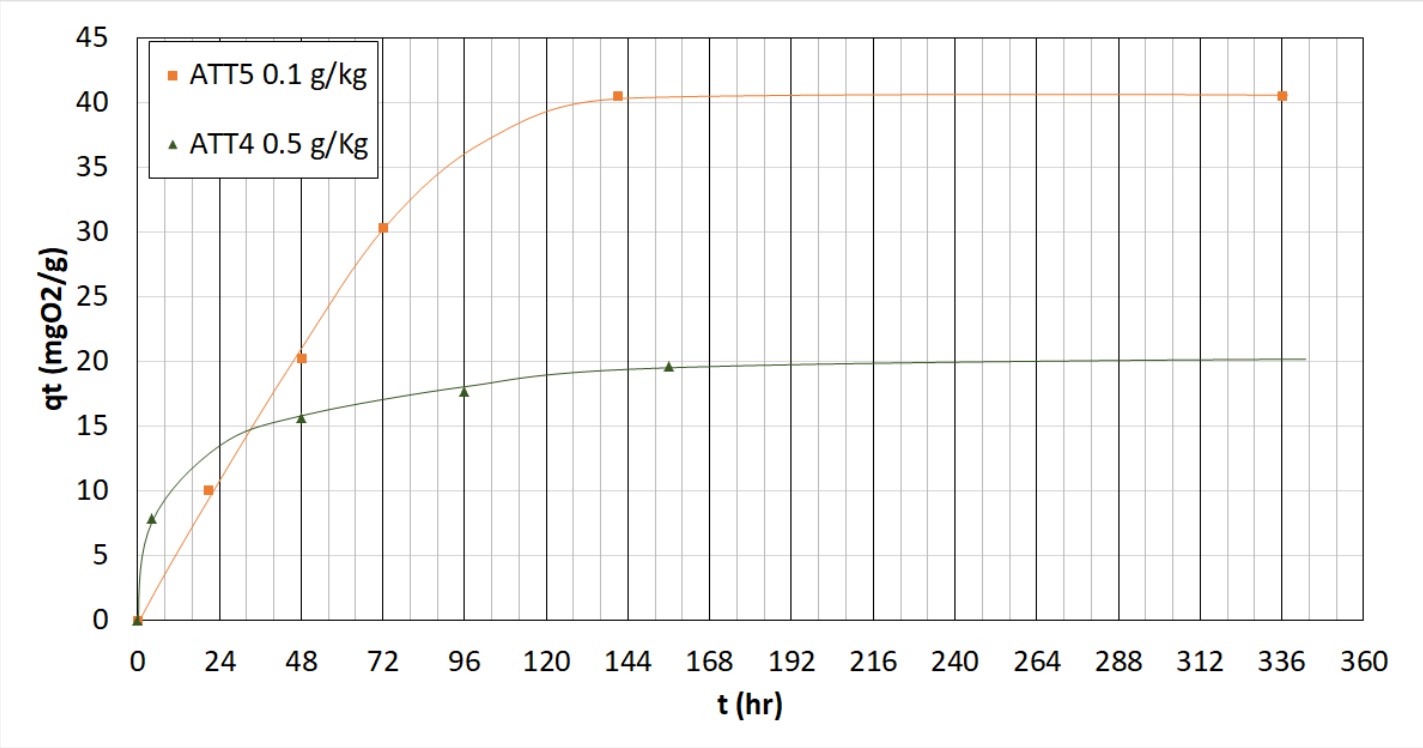
Adsorbent materials for COD removal

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

SOLVAY

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

Softening tests

Solvay by-product and OOS were compared to pure laboratory lime and soda ash.

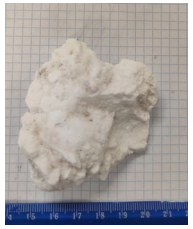
Lime process



$Ca(OH)_2$	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.

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

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),

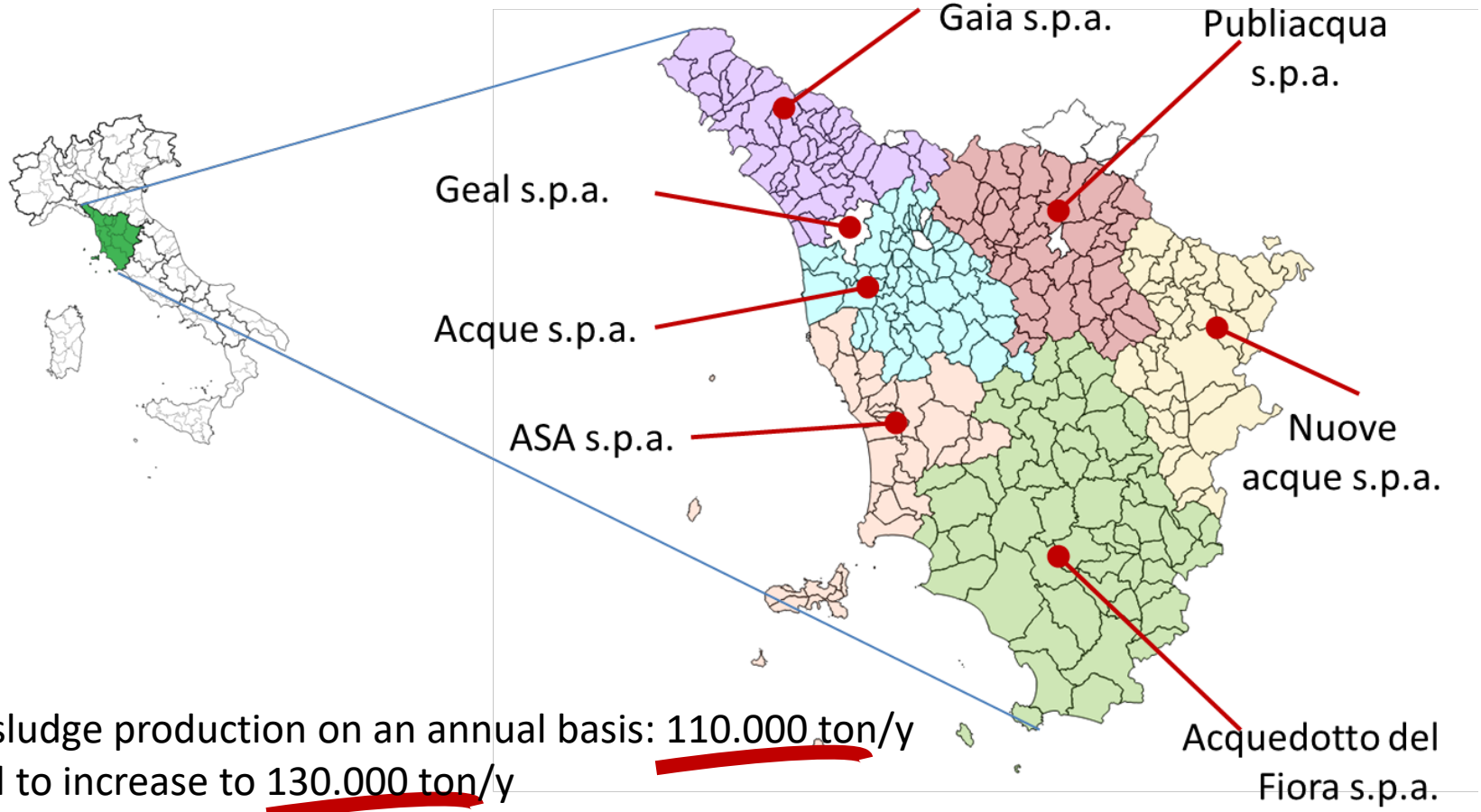


ULTIMATE
WATER SMART INDUSTRIAL SYMBIOSIS

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

Hydrothermal carbonization (HTC)









Gas (<5%)

Sludge (primary, secondary, digested)

HTC
T = 180 - 250 °C
P = 10 - 30 bar
t = 0.5 - 6 h

Slurry (>95%)

Solids (Hydrochar)

Process water

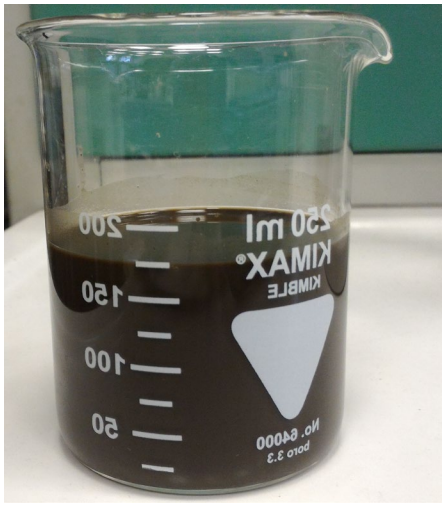
Hydrothermal carbonization (HTC)



1 Untreated sludge



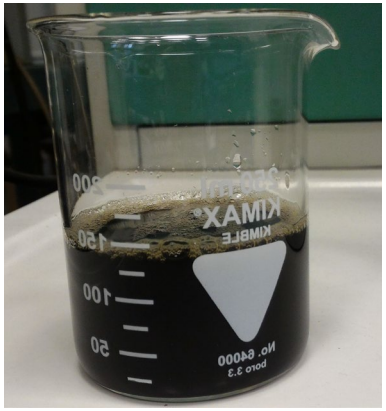
2 HTC reactor



3 Slurry

4 Hydrochar



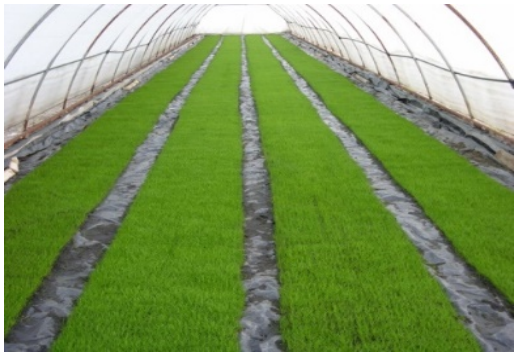


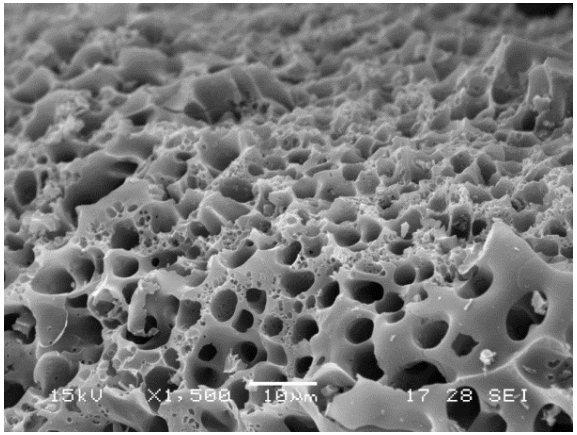
5 Process water

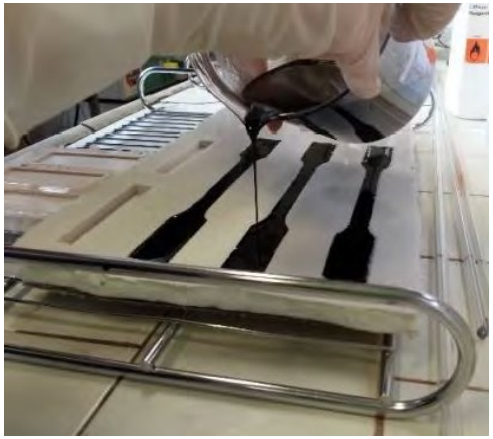
Valorization of HTC's products

- 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

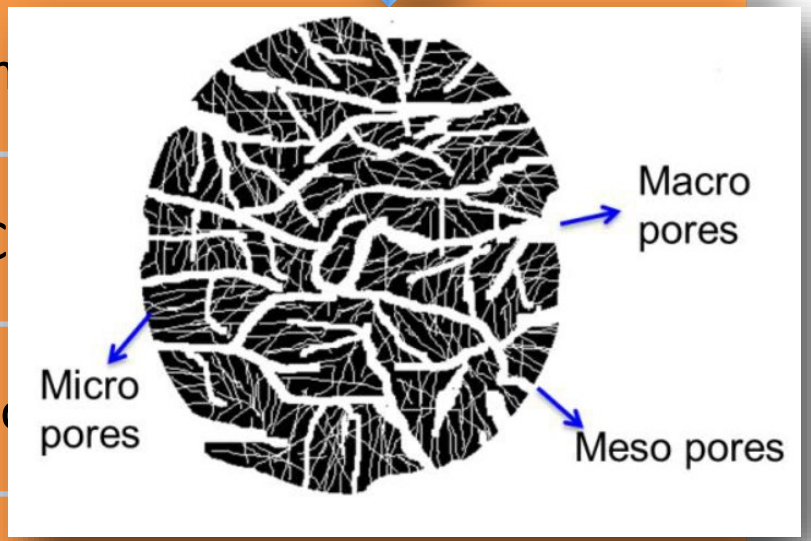
Activating agent: KOH, H_3PO_4

Tem

C

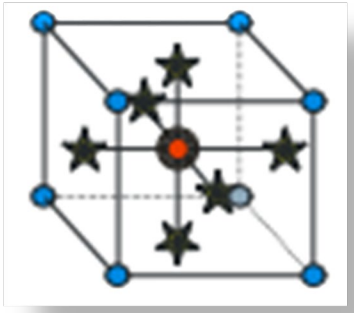
P



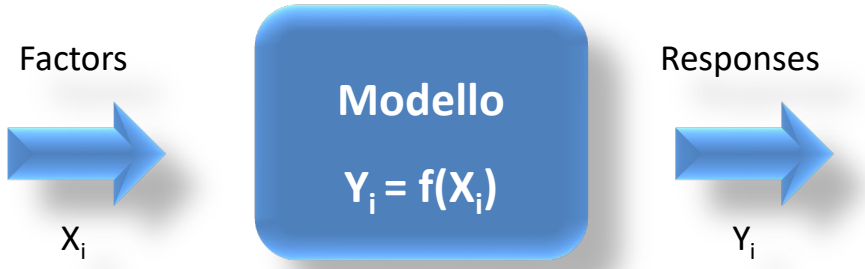


Design of Experiments (DoE)

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



$$Y = A - B + C + AB + A^2 + B^2$$

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

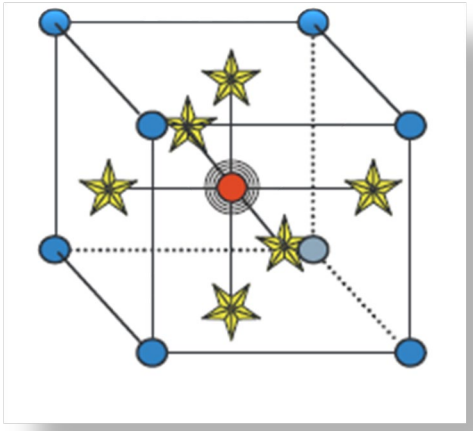
Terbuthylazine was selected as target compounds to evaluat the adsorption capacity. TBA has replaced atrazine as a broad-spectrum herbicide in most of the EU countries, becoming one the most detected compounds in surface and ground waters, coastal and marine areas.

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

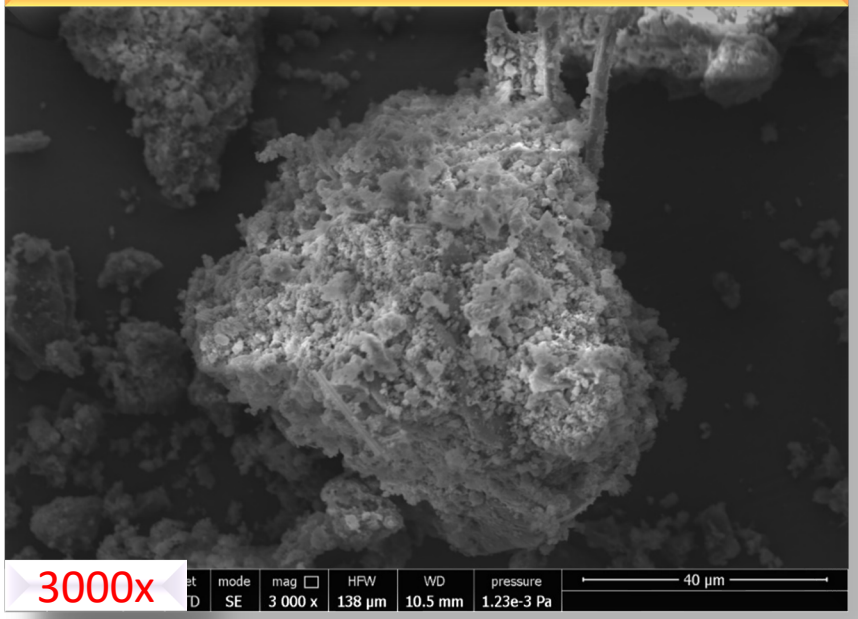
Center points

Axial points

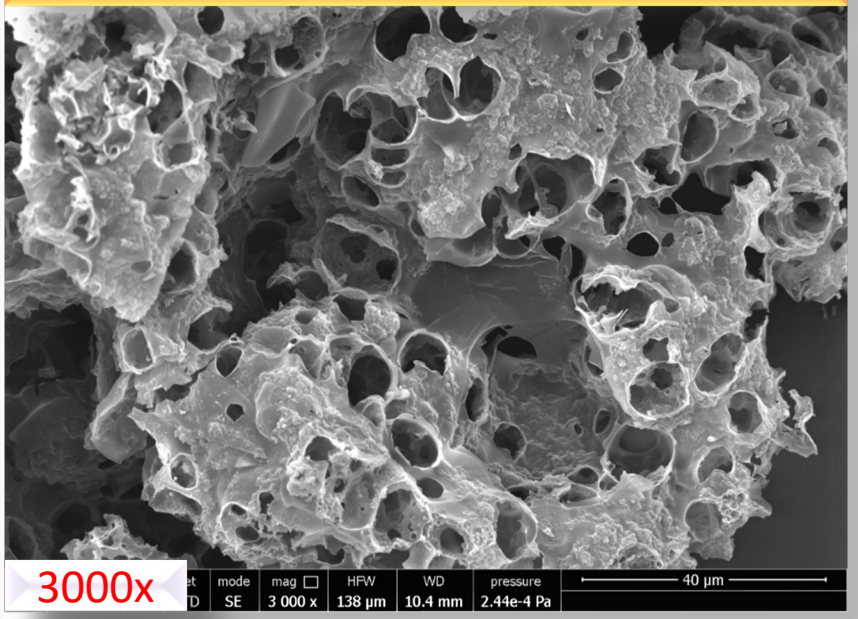
Run	Tempera-ture (°C)	Time (min)	KOH:HC (wt/wt)
1	750	60	3
2	550	60	3
3	750	60	1
4	550	240	3
5	550	240	1
6	750	240	1
7	650	150	2
8	750	240	3
9	550	240	1
10	650	150	2
11	750	240	1
12	550	240	3
13	750	60	1
14	750	240	3
15	650	150	2
16	650	150	2
17	550	60	3
18	750	60	3
19	550	60	1
20	550	60	1
21	650	150	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

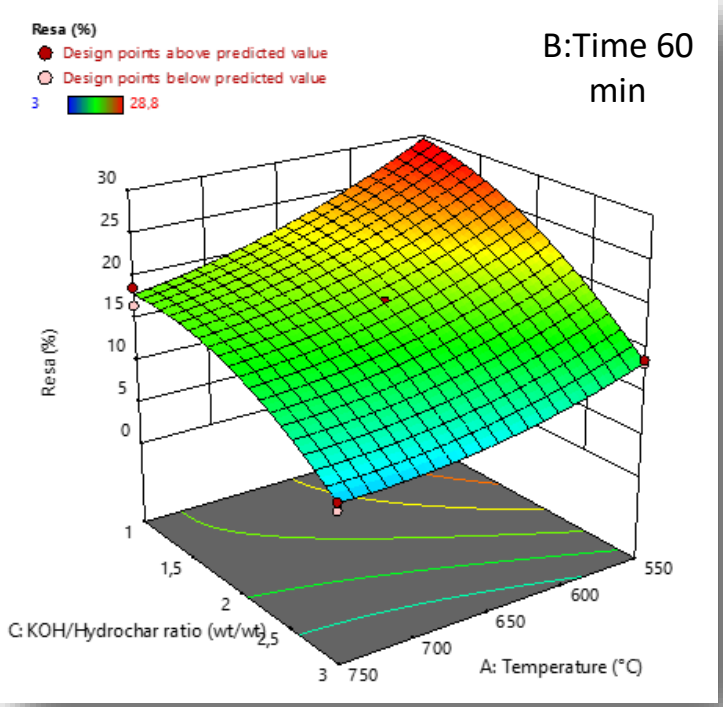
HYDROCHAR



ACTIVATED HYDROCHAR



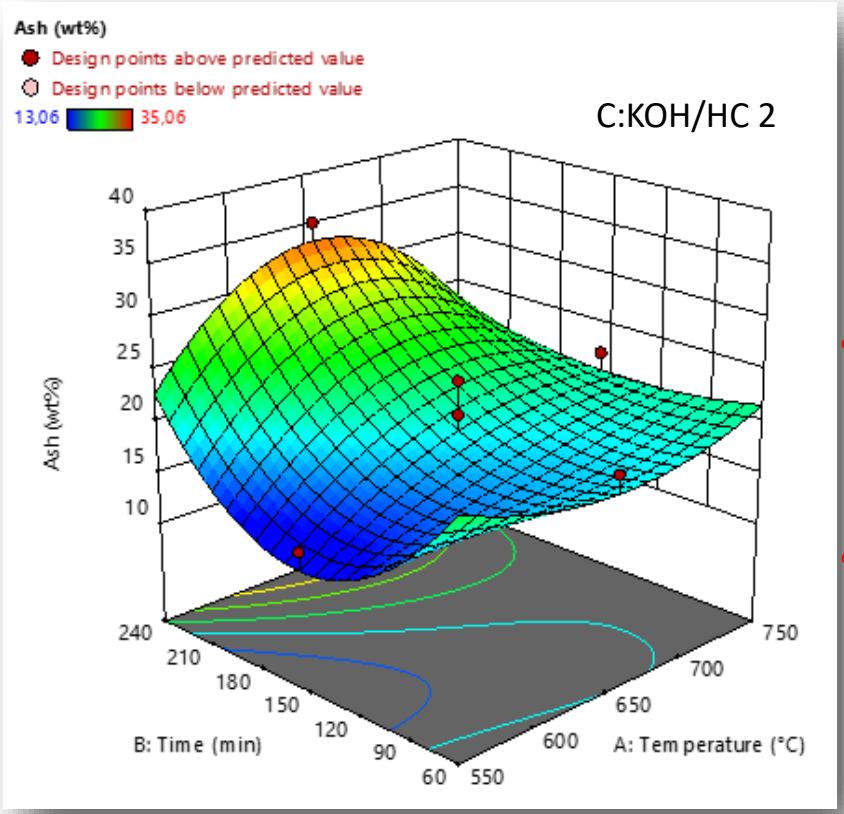
Yield



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

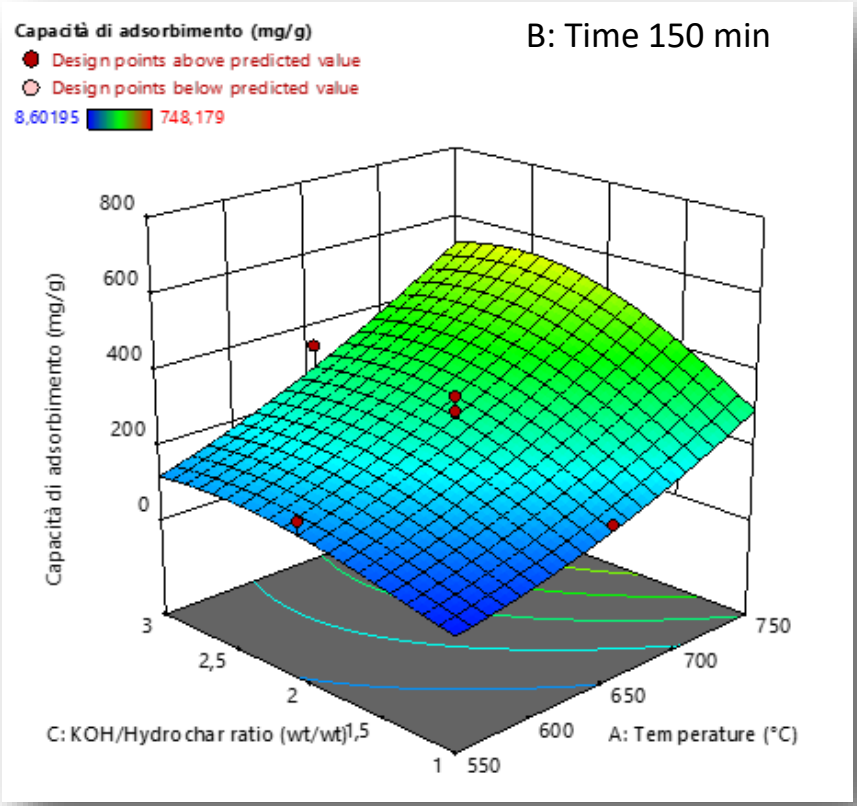
Results – Ash conten t



Source	Sum of Squares	df	Mean Square	F-value	p-value	
Block	39,32	1	39,32			
Model	397,45	9	44,16	8,63	< 0.0001	significant
A-Temperature	40,14	1	40,14	7,84	0,0123	
B-Time	108,93	1	108,93	21,29	0,0002	
C-KOH/HC ratio	21,02	1	21,02	4,11	0,0587	
AB	1,41	1	1,41	0,2756	0,6064	
AC	79,34	1	79,34	15,51	0,0011	
A^2	36,78	1	36,78	7,19	0,0158	
B^2	142,30	1	142,30	27,81	< 0.0001	
A^2B	85,30	1	85,30	16,67	0,0008	
AB^2	36,90	1	36,90	7,21	0,0156	
Residual	86,99	17	5,12			
Lack of Fit	13,29	5	2,66	0,4326	0,8175	not significant
Pure 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

Results - Models and Optimization

Yield

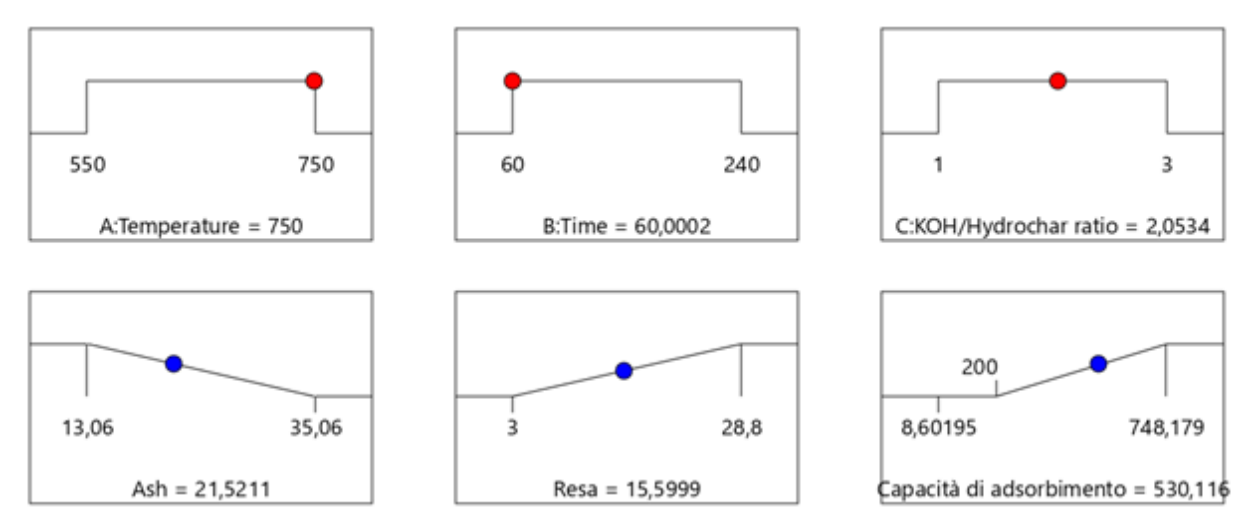
$$y = 17{,}29 - 4{,}52\,\mathbf{A} + 1{,}27\,\mathbf{B} - 6{,}53\,\mathbf{C} - 0{,}2406\,\mathbf{AB} + 1{,}51\,\mathbf{AC} - 1{,}57\,\mathbf{A^2} + 2{,}62\,\mathbf{B^2} - 2{,}89\,\mathbf{C^2} - 3{,}08\,\mathbf{A^2B}$$

Ash content

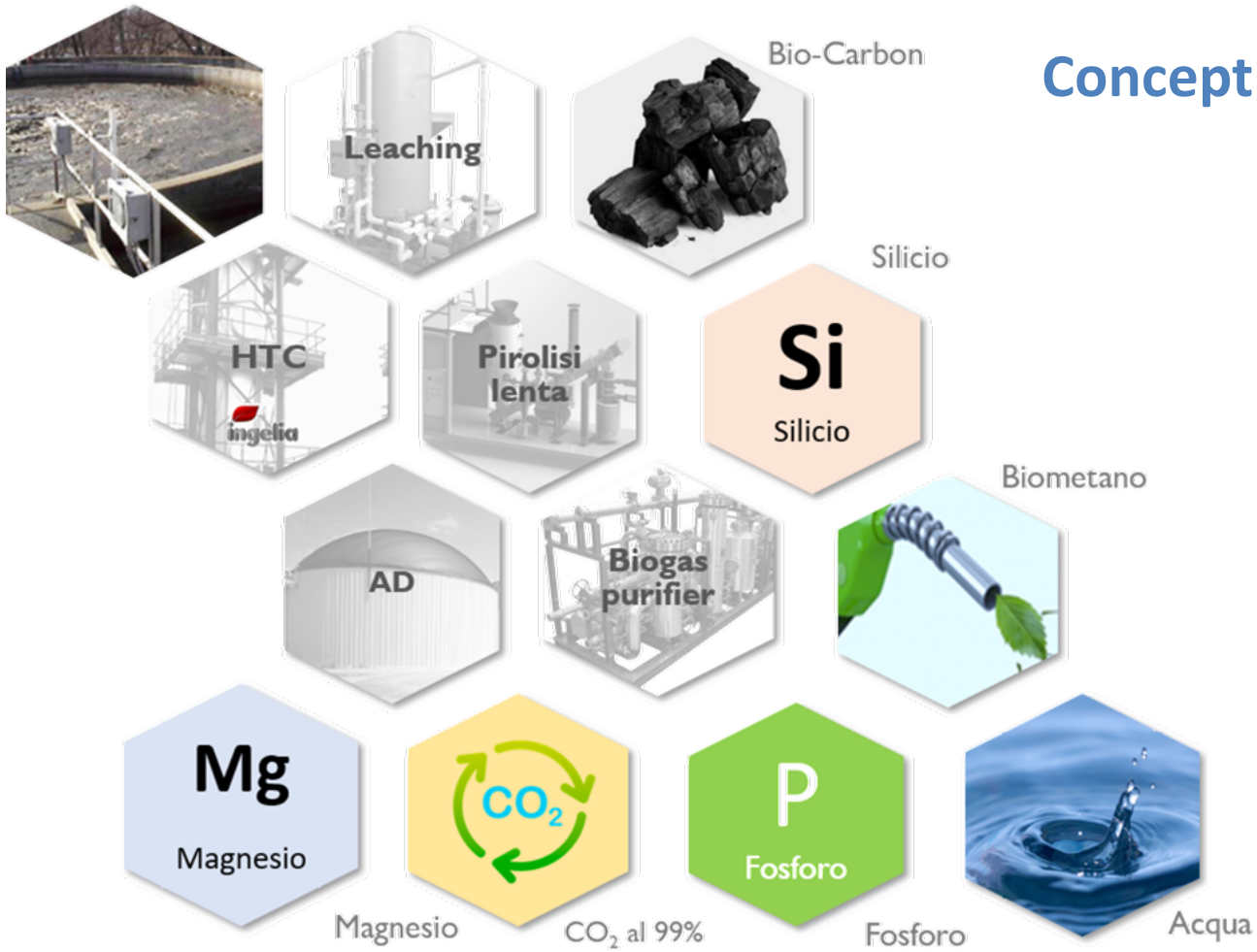
$$y = 19{,}22 + 4{,}48\,\mathbf{A} + 7{,}38\,\mathbf{B} - 1{,}08\,\mathbf{C} + 0{,}2969\,\mathbf{AB} - 2{,}23\,\mathbf{AC} - 3{,}42\,\mathbf{A^2} + 6{,}72\,\mathbf{B^2} - 6{,}93\,\mathbf{A^2B} - 4{,}56\,\mathbf{AB^2}$$

Adsorption capacity

$$y^2 = 16{,}64 + 6{,}08\,\mathbf{A} + 0{,}7732\,\mathbf{B} + 2{,}86\,\mathbf{C} - 0{,}9822\,\mathbf{AB} + 0{,}9929\,\mathbf{BC} - 2{,}66\,\mathbf{C^2}$$



Concept


Leaching
Bio-Carbon
HTC
ingelia
Pirolisi lenta
Silicio
Si
Silicio
AD
Biogas purifier
Biometano
Mg
Magnesio
CO2
P
Fosforo
Magnesio
CO2 al 99%
Fosforo
Acqua

Acknowledgements

Thanks for your attention!

UNIVERSITÀ DEGLI STUDI FIRENZE
DICEA DIPARTIMENTO DI INGEGNERIA CIVILE E AMBIENTALE

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

About CirTec



Cellulose recovery from sewage



Screening and filtration



Evaporation and scrubbing



Sludge dewatering



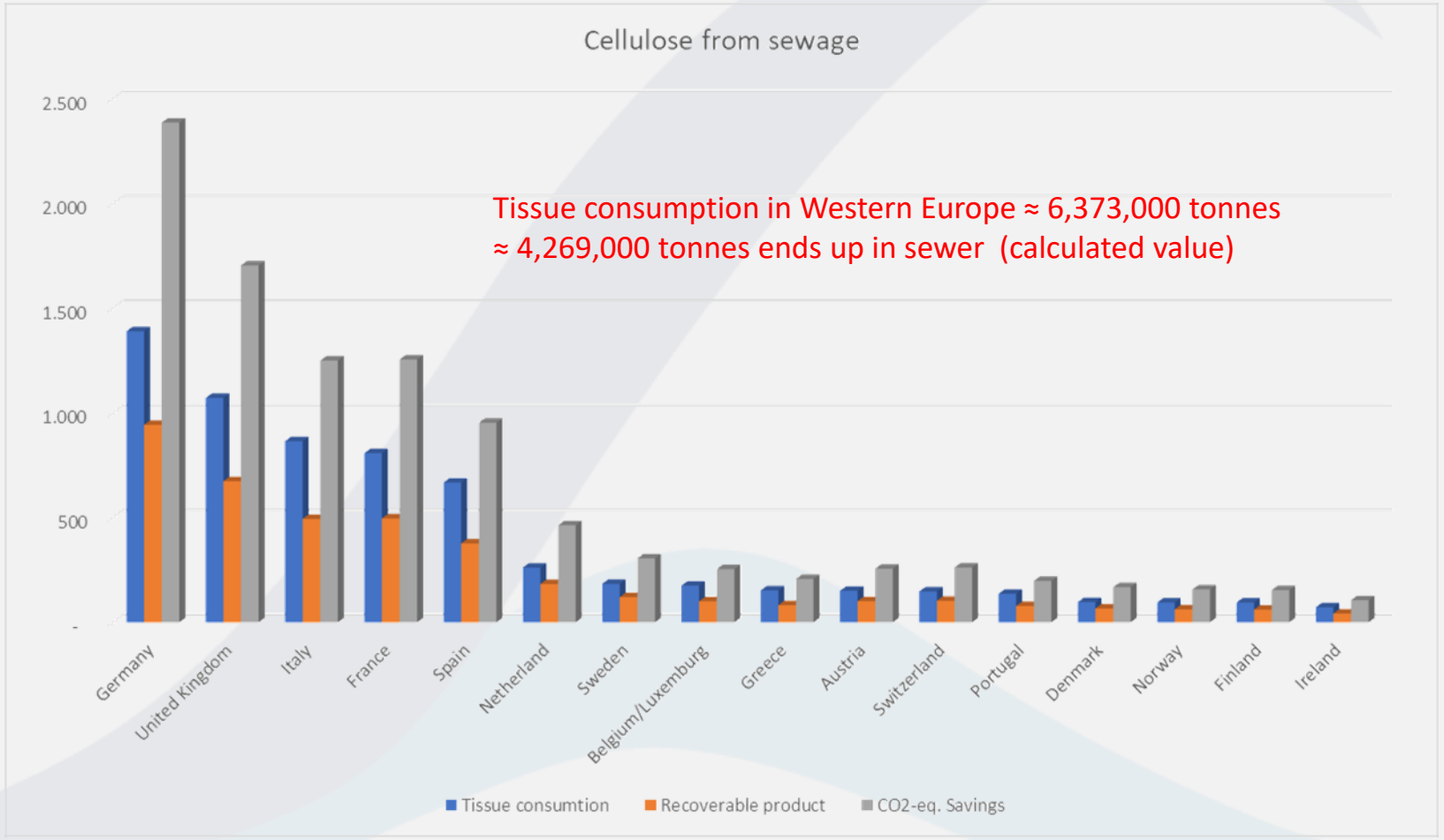
Sludge drying



Recovery and valorisation of cellulose from sewage

What is it about?

X 1.000 tonnes



Tissue consumption in Western Europe ≈ 6,373,000 tonnes
≈ 4,269,000 tonnes ends up in sewer (calculated value)

Dynamic rotating belt finescreens for primary treatment

Saving energy by removing solids





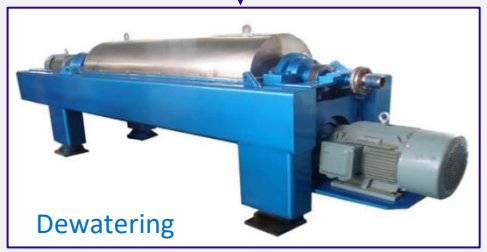




RAS

WAS

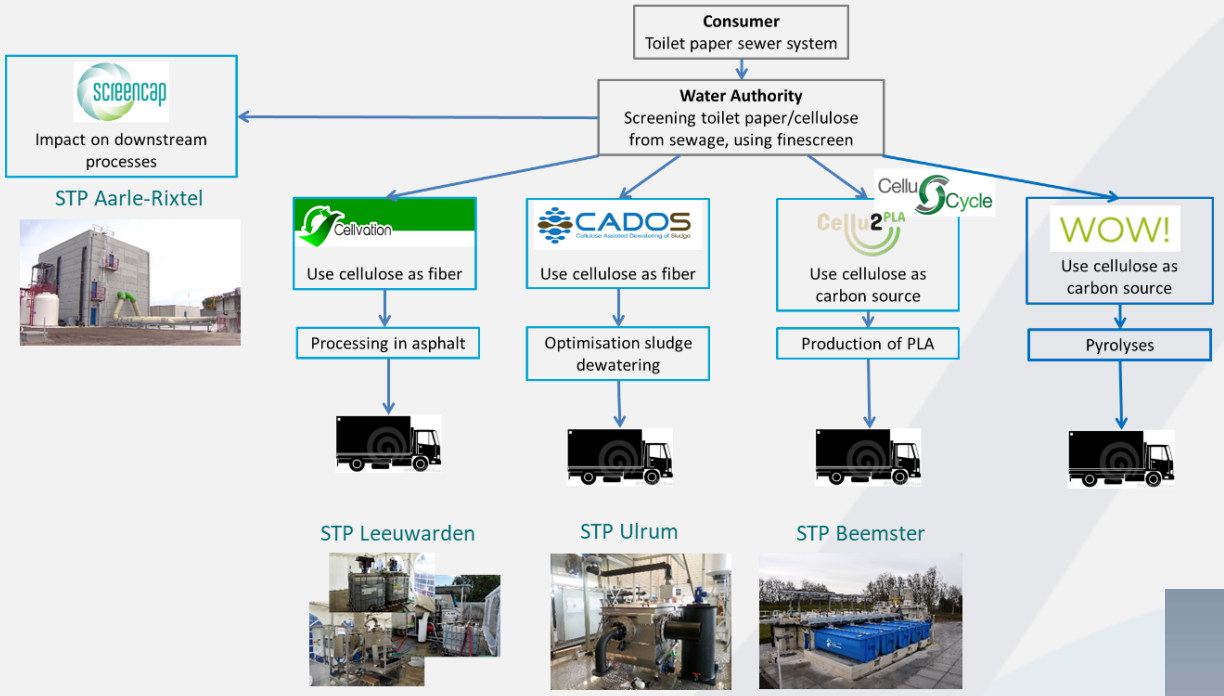




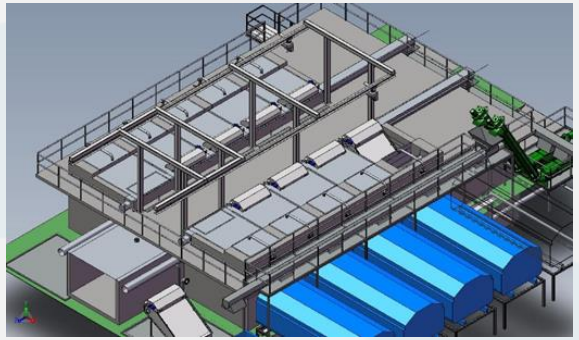
knowledge development through small and large-scale research

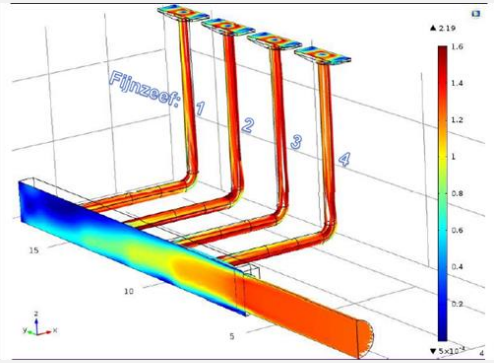
SMART-Plant

Impact on dewaterability, denitrification, control, flow distribution, etc









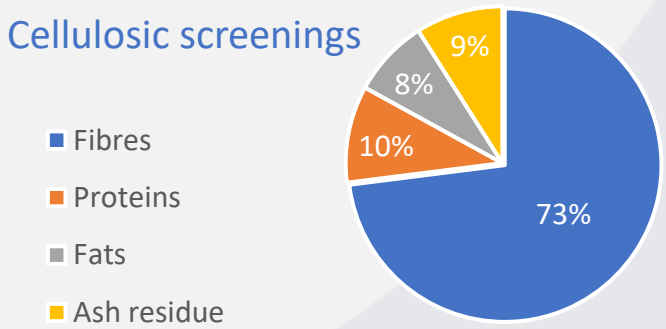
CFD analyses

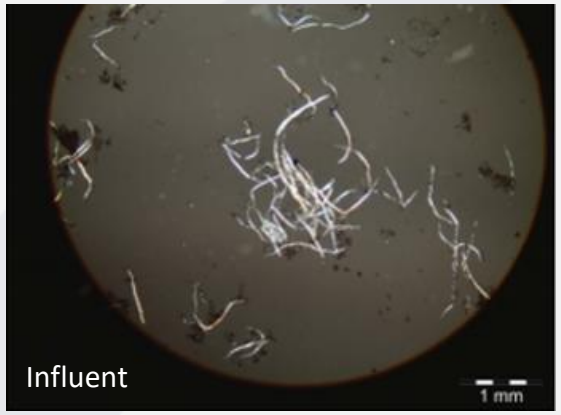
CIRTEC

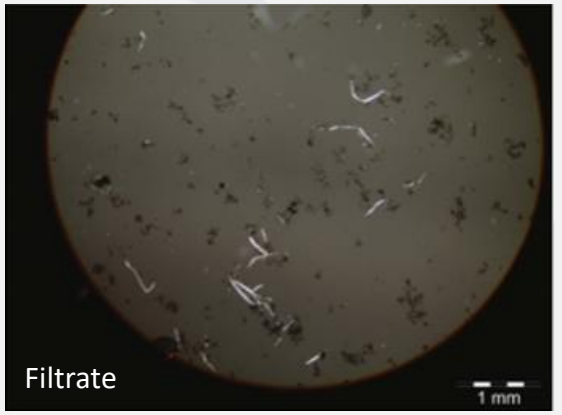
Impact of dynamic rotating belt finesieves

Application of dynamic rotating belt fine sieves for primary treatment

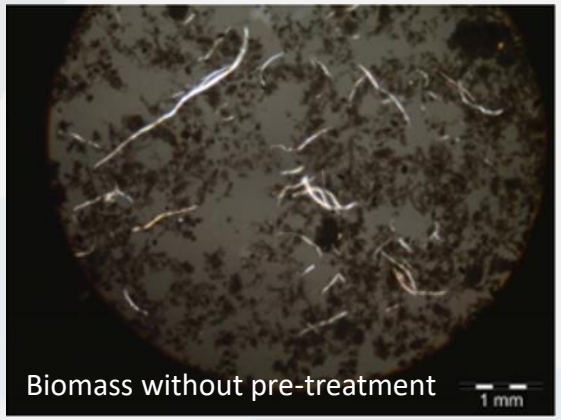
- Reduction of energy requirement (15 to 20%);
- Less sludge (20%) = less sludge dewatering;
- Reduction of chemical use (approx. 20%);
- Lower maintenance costs;
- a marketable recovered raw material;
- Reduction of the CO_2 footprint

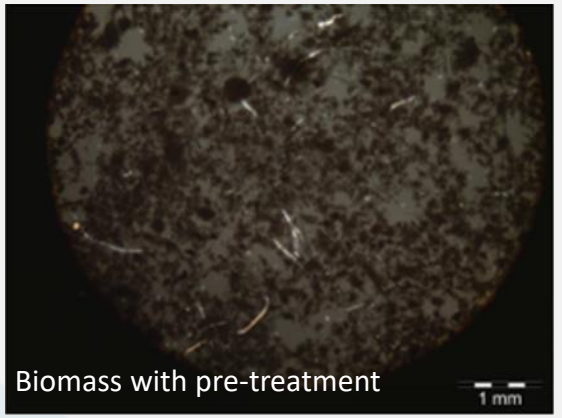






Visible reduction of fibers in raw influent





Difference in fiber content in activated sludge (after 12 months)

In-line cellulose extraction

Screenings are not salable (too many polluting components)







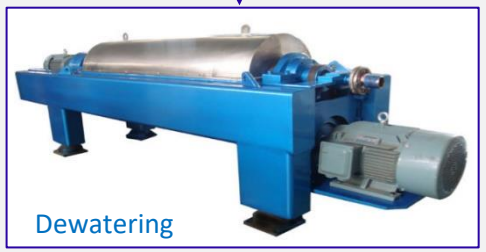


RAS

WAS







SMART-Plant: Pilot installation at a capacity of 120 m^3/h (expected 300 mg/l TSS)







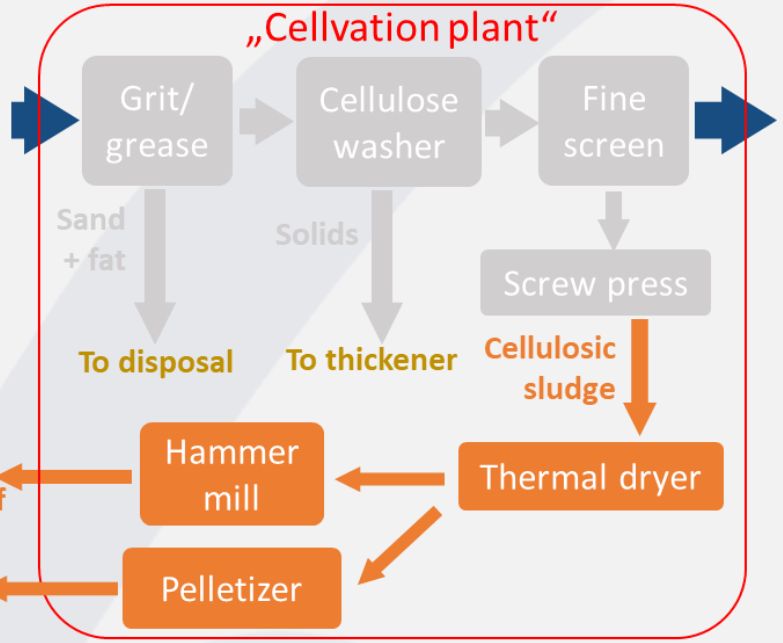




In-line cellulose extraction

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



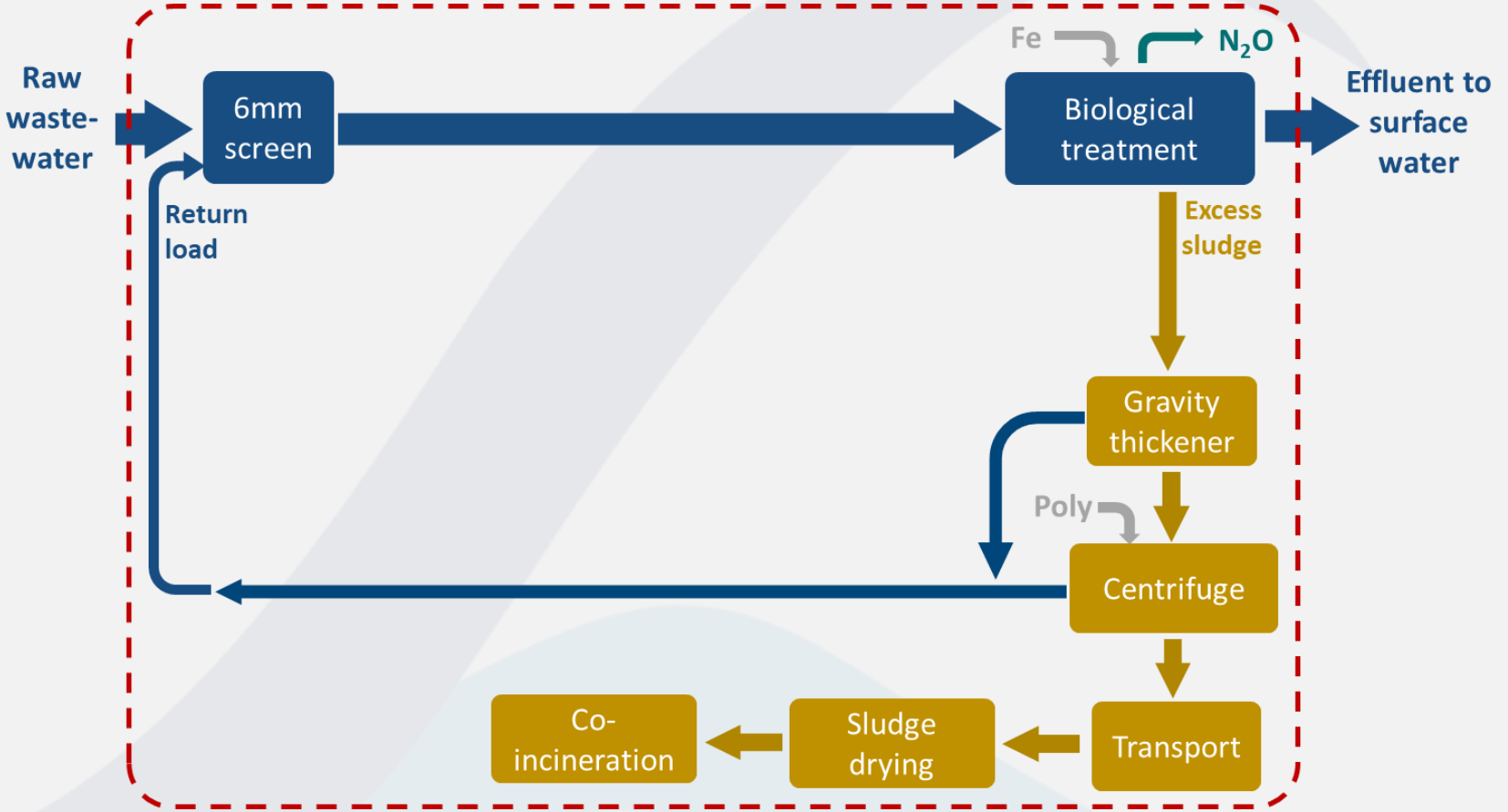
TSS	198,72	mg/l
COD	477,16	mg/l
BOD	228,31	mg/l
Ntot	35,67	mg/l
PO_4-P	9,11	mg/l

Recell®

TSS	44,80%
COD	21,00%
BOD	21,00%
Ntot	4,10%
PO_4-P	3,10%

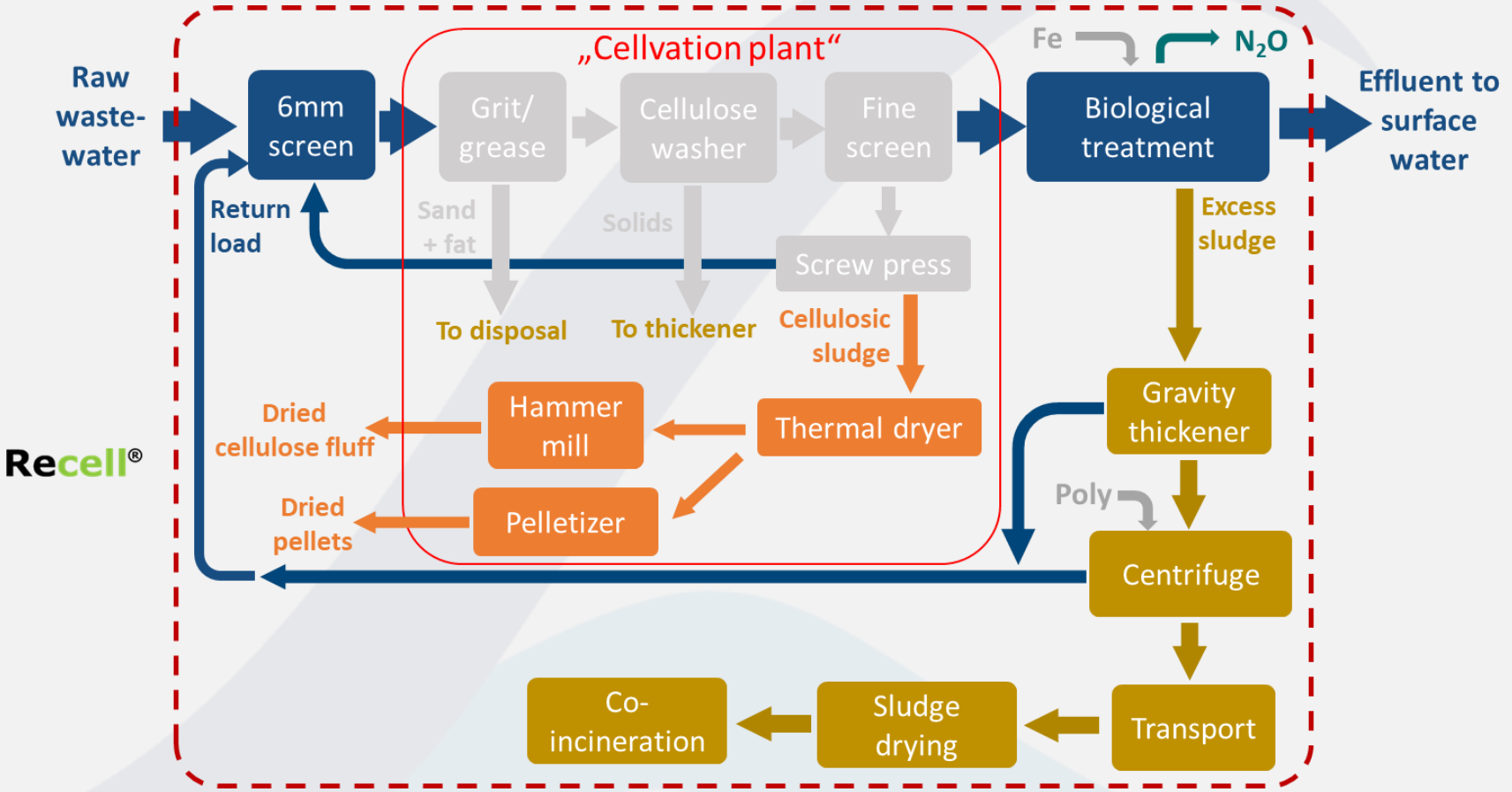
LCA of SMARTech1 - cellulose recovery

System boundaries



LCA of SMARTech1 - cellulose recovery

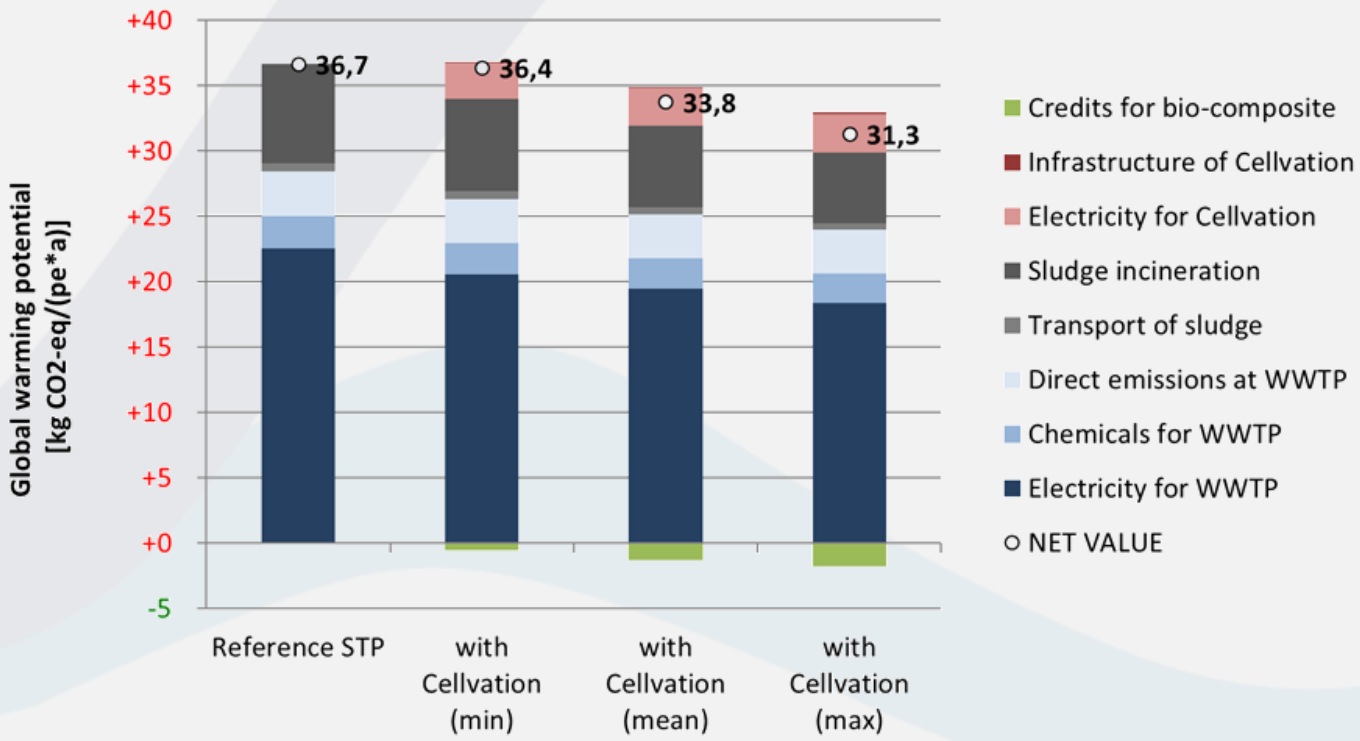
System boundaries



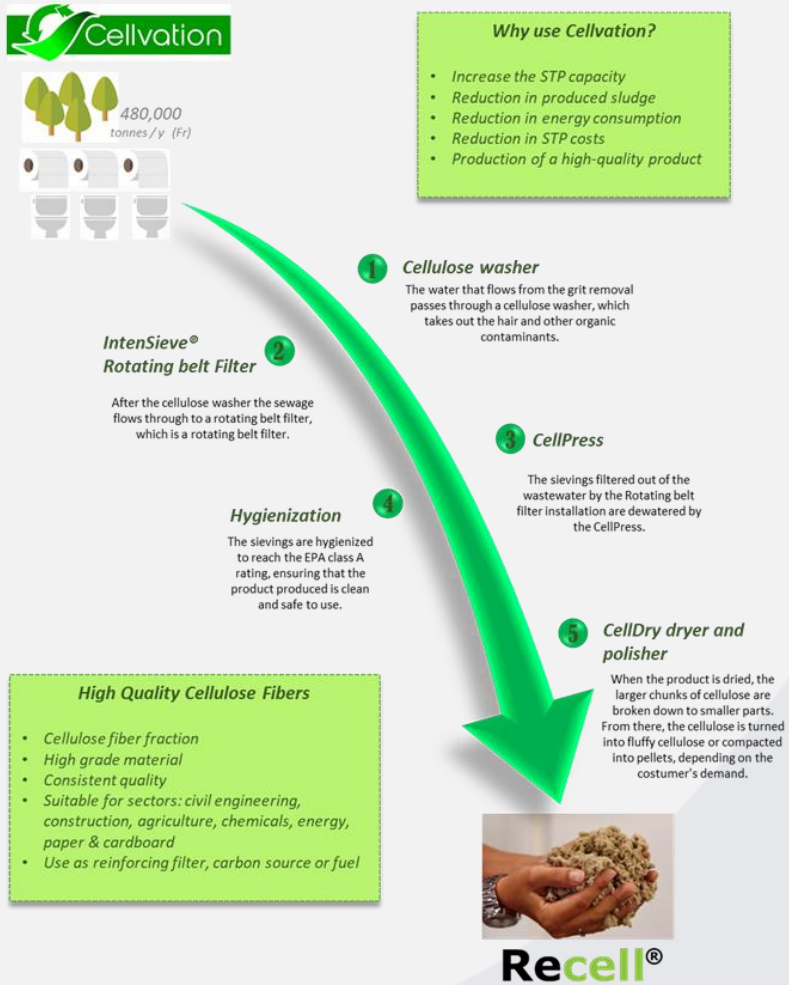
LCA of SMARTech1 - cellulose recovery

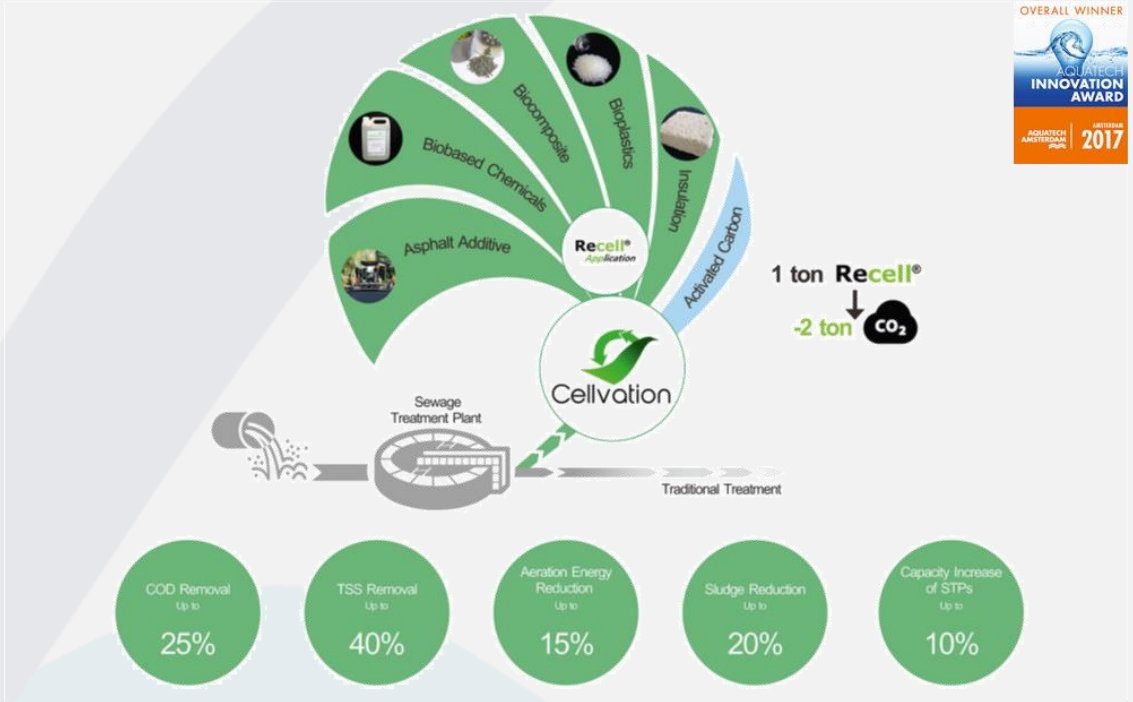
Conclusions

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





OVERALL WINNER AQUATECH INNOVATION AWARD AMSTERDAM 2017

SMART-Plant

CIRTEC

Cellvation

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

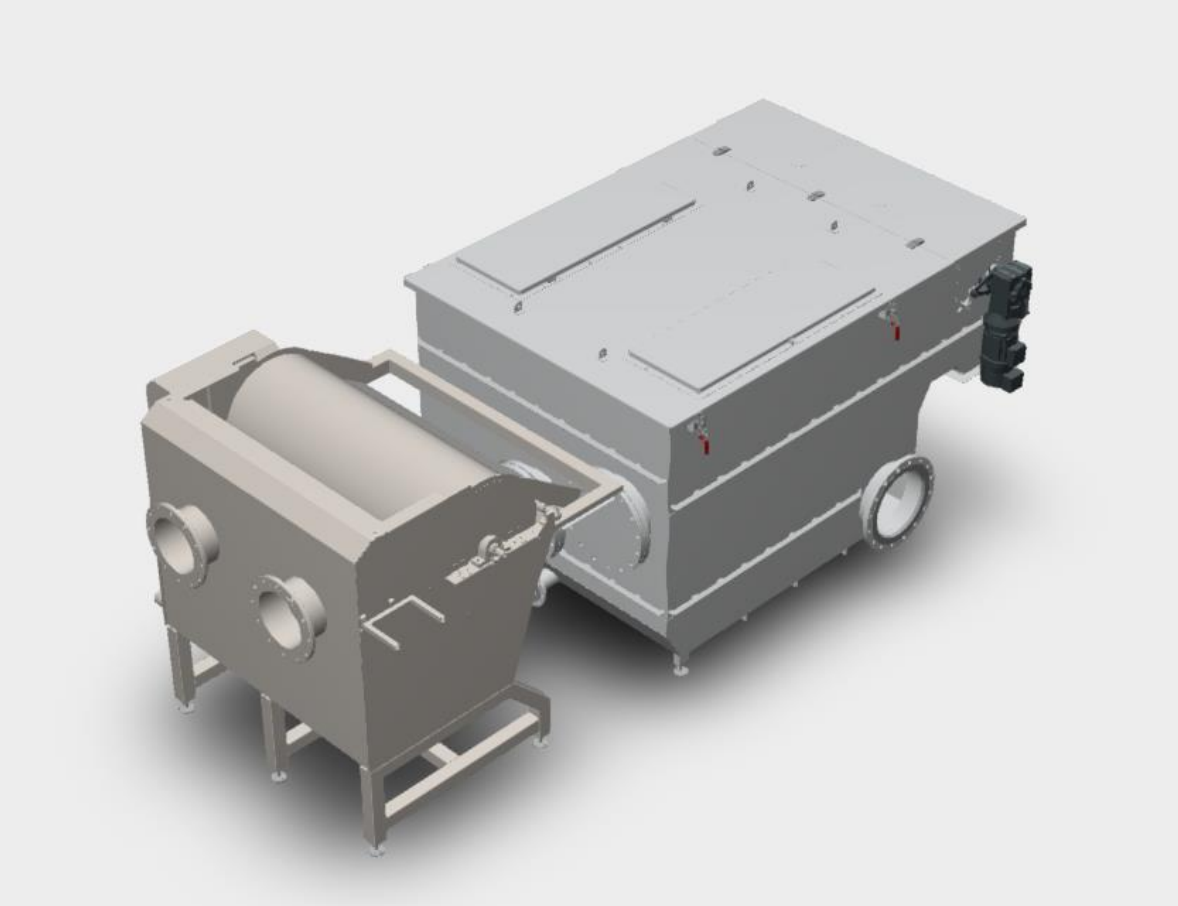

Road constructor KWS uses recycled toilet paper to improve asphalt pavement in Amsterdam


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

algen algal technology centre

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**

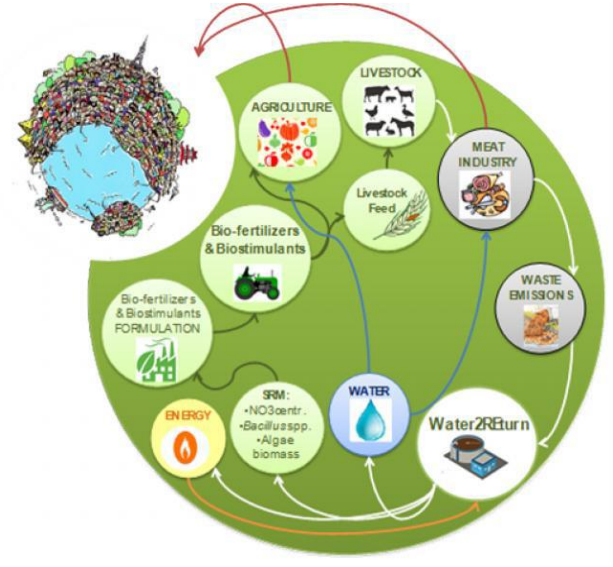
... CONTAINED IN INDUSTRIAL WASTEWATER.

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

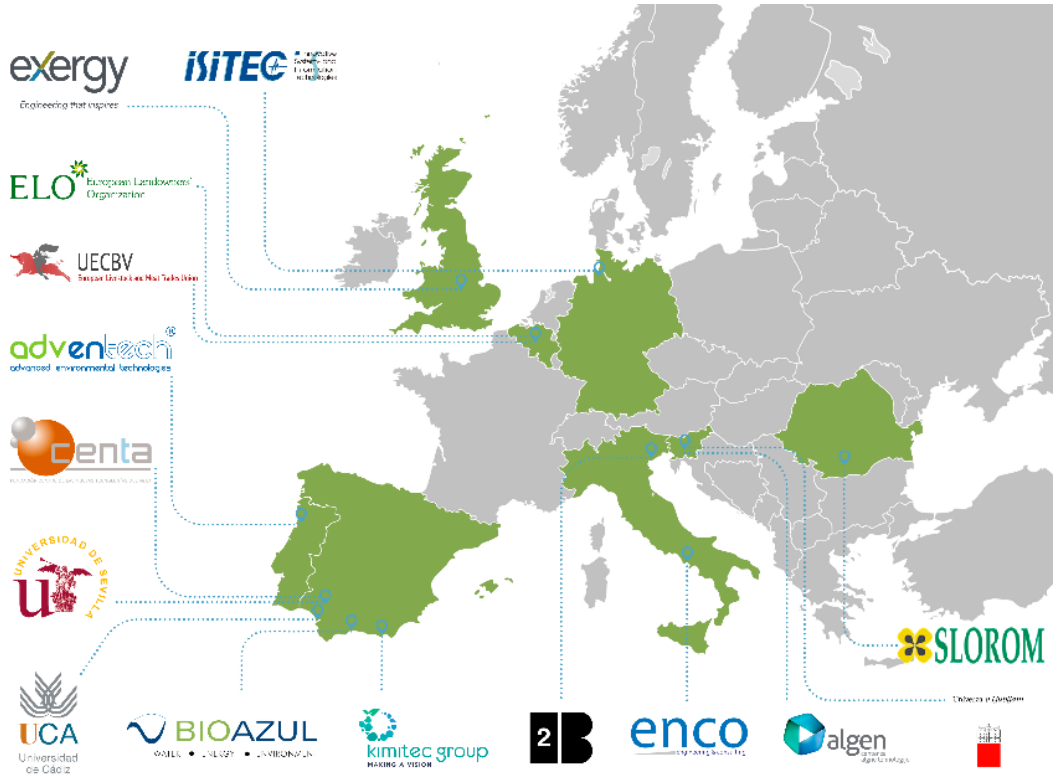
- **recover and recycle nutrients from slaughterhouse wastewater** in the framework of a **Circular Economy model;**
- recovered nutrients are turned into **value added products for the agro-chemical industry**, for the **agricultural sector;**
- solve slaughterhouse wastewater management problem and **reduced costs related to water consumption**



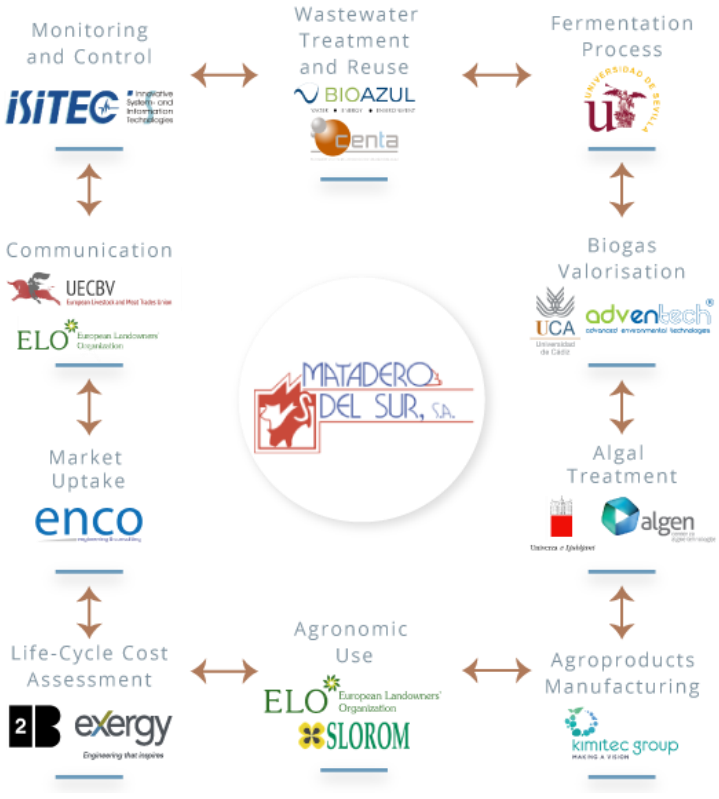
Products

- 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
UNIVERSIDAD DE SEVILLA
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

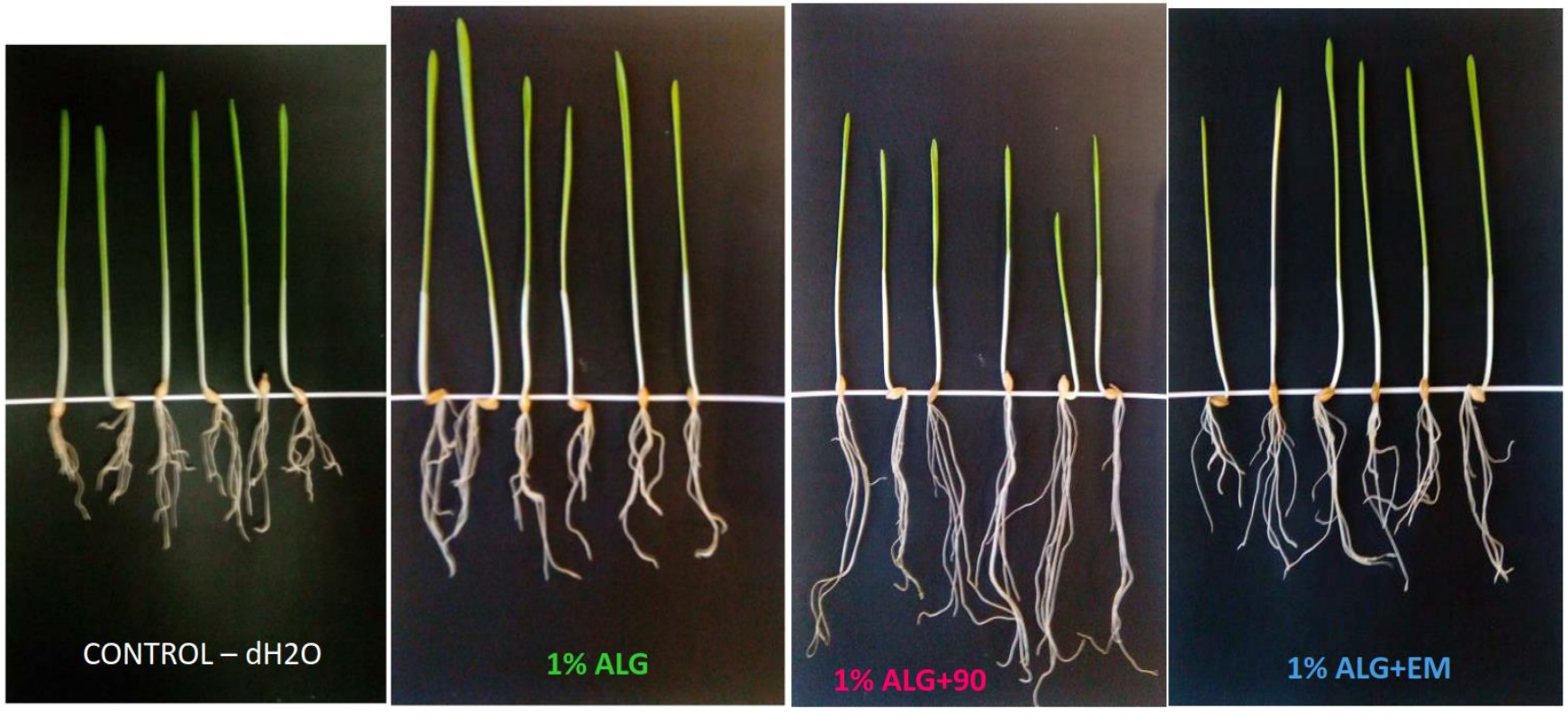
Small test installation Ljubljana





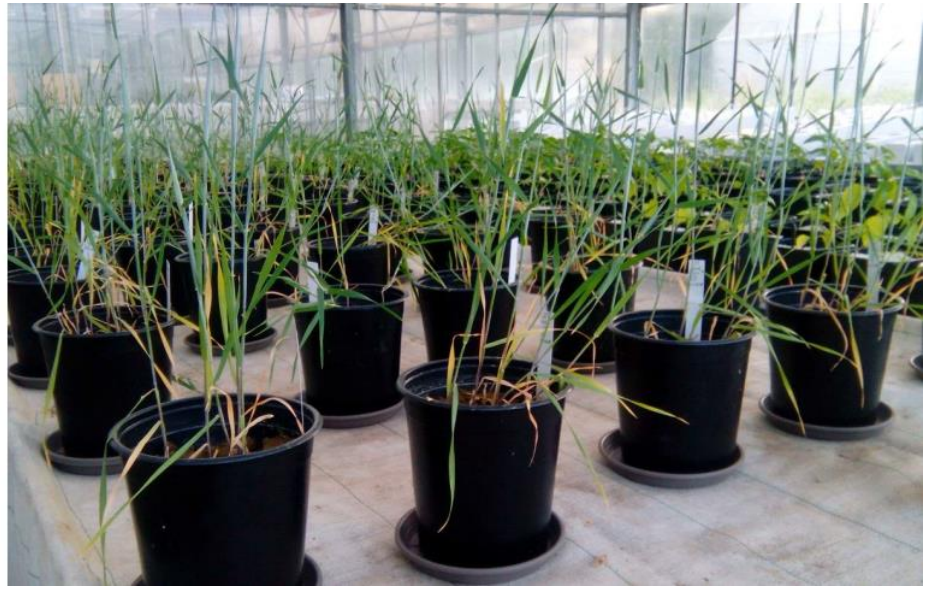



Preliminary Sprouting tests

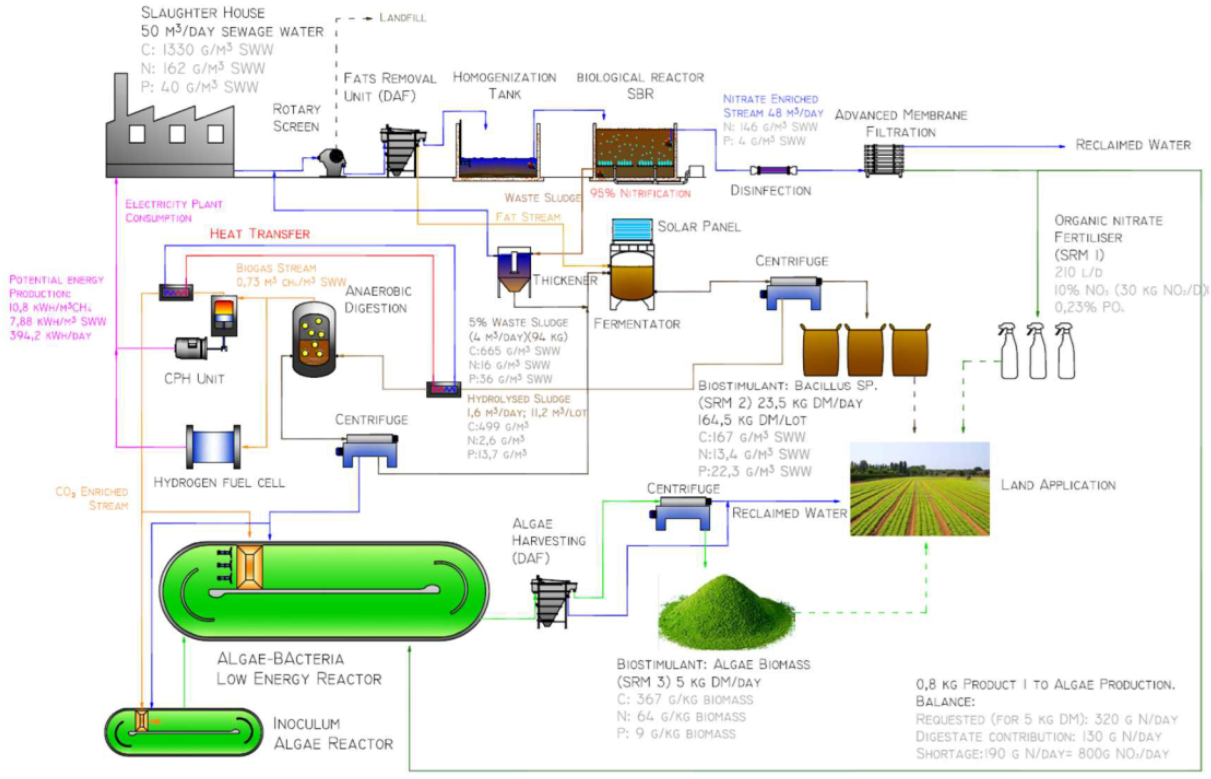


Pot tests

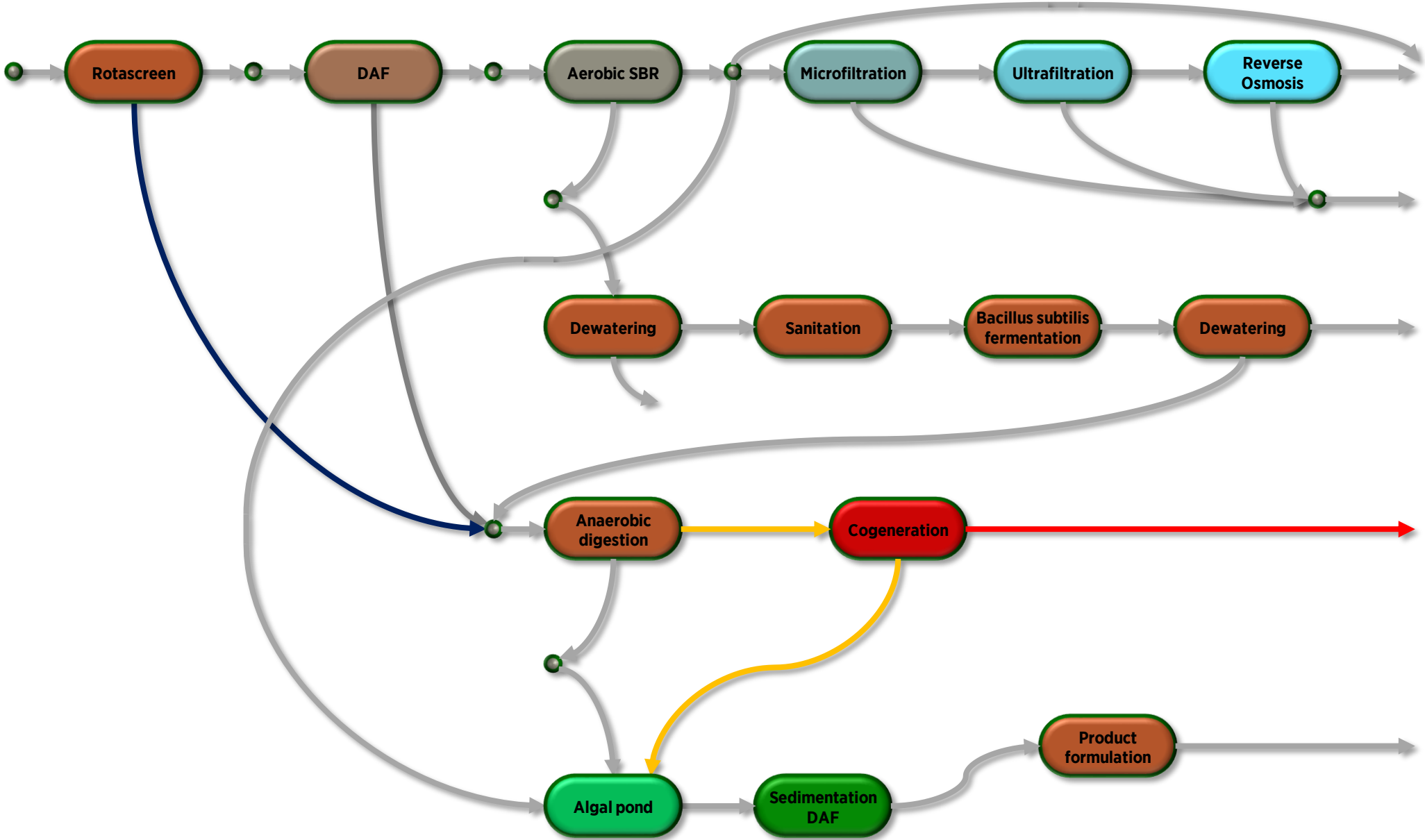




Process


SLAUGHTER HOUSE
50 M³/DAY SEWAGE WATER
C: 1330 G/M³ SWW
N: 162 G/M³ SWW
P: 40 G/M³ SWW
LANDFILL
ROTARY SCREEN
FATS REMOVAL UNIT (DAF)
HOMOGENIZATION TANK
BIOLOGICAL REACTOR SBR
NITRATE ENRICHED STREAM 48 M³/DAY
N: 146 G/M³ SWW
P: 4 G/M³ SWW
ADVANCED MEMBRANE FILTRATION
RECLAIMED WATER
DISINFECTION
95% NITRIFICATION
WASTE SLUDGE
FAT STREAM
ELECTRICITY PLANT CONSUMPTION
HEAT TRANSFER
SOLAR PANEL
CENTRIFUGE
THICKENER
FERMENTATOR
ORGANIC NITRATE FERTILISER (SRM 1)
210 L/D
10% NO₃ (30 KG NO₃/D)
0,23% PO₄
BIOGAS STREAM
0,73 M³ CH₄/M³ SWW
POTENTIAL ENERGY PRODUCTION:
10,8 KWH/M³CH₄
7,88 KWH/M³ SWW
394,2 KWH/DAY
ANAEROBIC DIGESTION
CPH UNIT
5% WASTE SLUDGE
(4 M³/DAY)(94 KG)
C:665 G/M³ SWW
N:16 G/M³ SWW
P:36 G/M³ SWW
HYDROLYSED SLUDGE
1,6 M³/DAY; 11,2 M³/LOT
C:499 G/M³
N:2,6 G/M³
P:13,7 G/M³
CENTRIFUGE
HYDROGEN FUEL CELL
BIOSTIMULANT: BACILLUS SP.
(SRM 2) 23,5 KG DM/DAY
164,5 KG DM/LOT
C:167 G/M³ SWW
N:13,4 G/M³ SWW
P:22,3 G/M³ SWW
CO₂ ENRICHED STREAM
CENTRIFUGE
RECLAIMED WATER
LAND APPLICATION
ALGAE HARVESTING (DAF)
ALGAE-BACTERIA LOW ENERGY REACTOR
INOCULUM ALGAE REACTOR
BIOSTIMULANT: ALGAE BIOMASS
(SRM 3) 5 KG DM/DAY
C: 367 G/KG BIOMASS
N: 64 G/KG BIOMASS
P: 9 G/KG BIOMASS
0,8 KG PRODUCT I TO ALGAE PRODUCTION.
BALANCE:
REQUESTED (FOR 5 KG DM): 320 G N/DAY
DIGESTATE CONTRIBUTION: 130 G N/DAY
SHORTAGE:190 G N/DAY= 800G NO₃/DAY

Process


Rotascreen
DAF
Aerobic SBR
Microfiltration
Ultrafiltration
Reverse Osmosis
Dewatering
Sanitation
Bacillus subtilis fermentation
Dewatering
Anaerobic digestion
Cogeneration
Algal pond
Sedimentation DAF
Product formulation

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

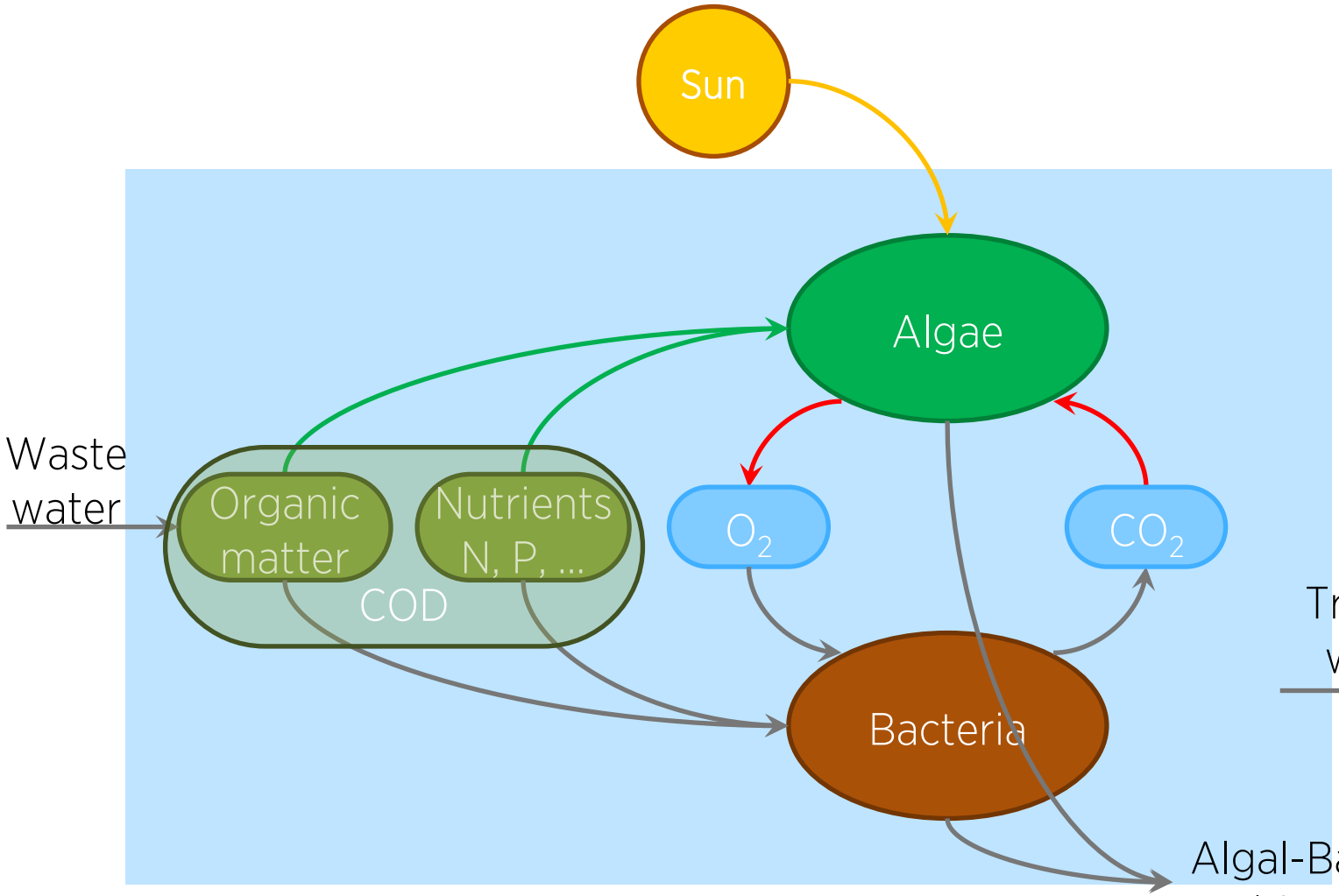
Thank you for attention

Questions

Where do algae fit?

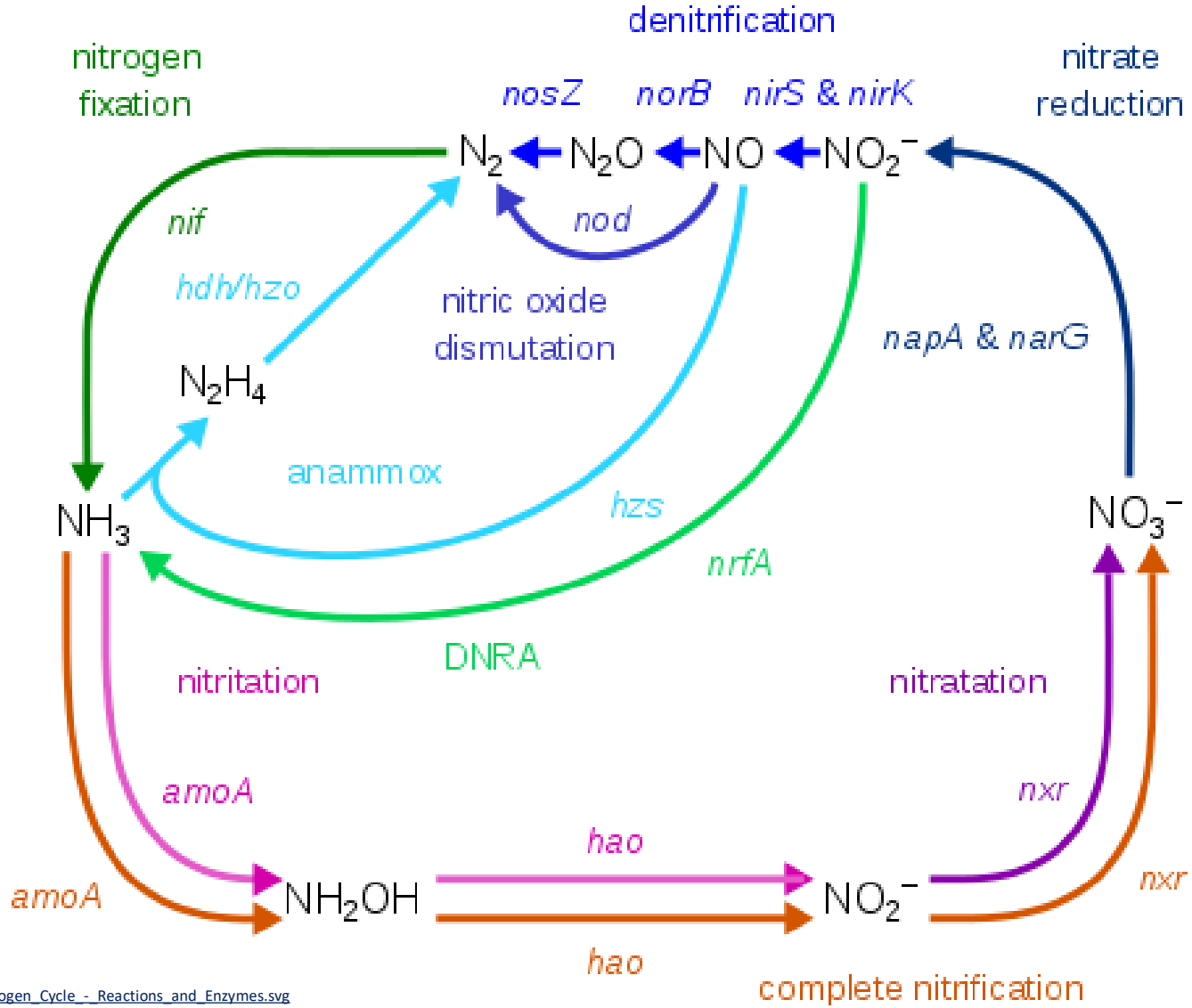
- More than one option
- Depends on
  - Wastewater
  - Area available
  - Use of algal biomass
  - Legislative requirements

Basic concept



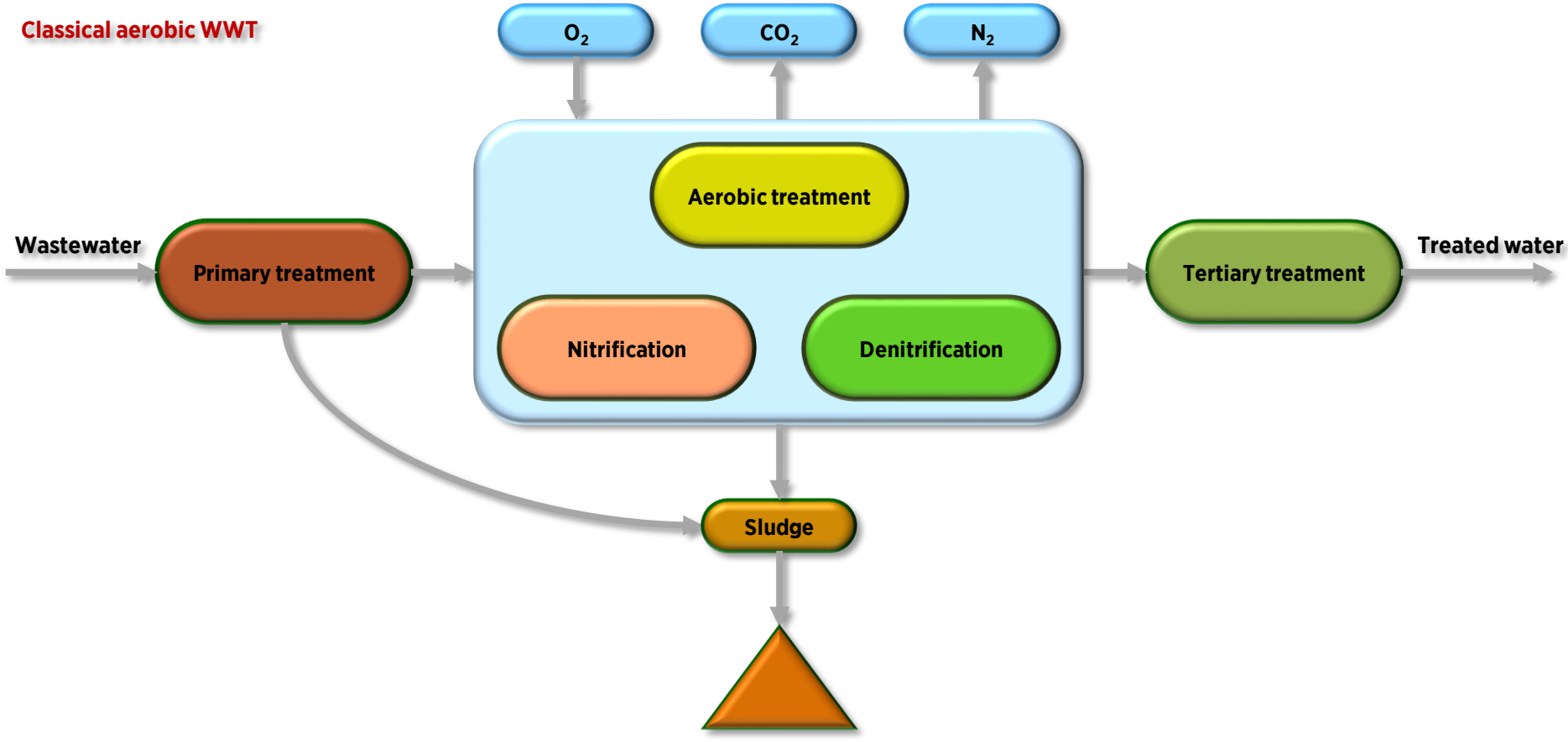
- Treatment by symbiotic algal bacterial community
- O2 provided in-situ (from sunlight)
- CO2 recycled in-situ
- Better matched community, more diverse community ↔ better nutrient and micropollutant removal
- More biomass ↔ more nutrients and energy recycled

Nitrogen

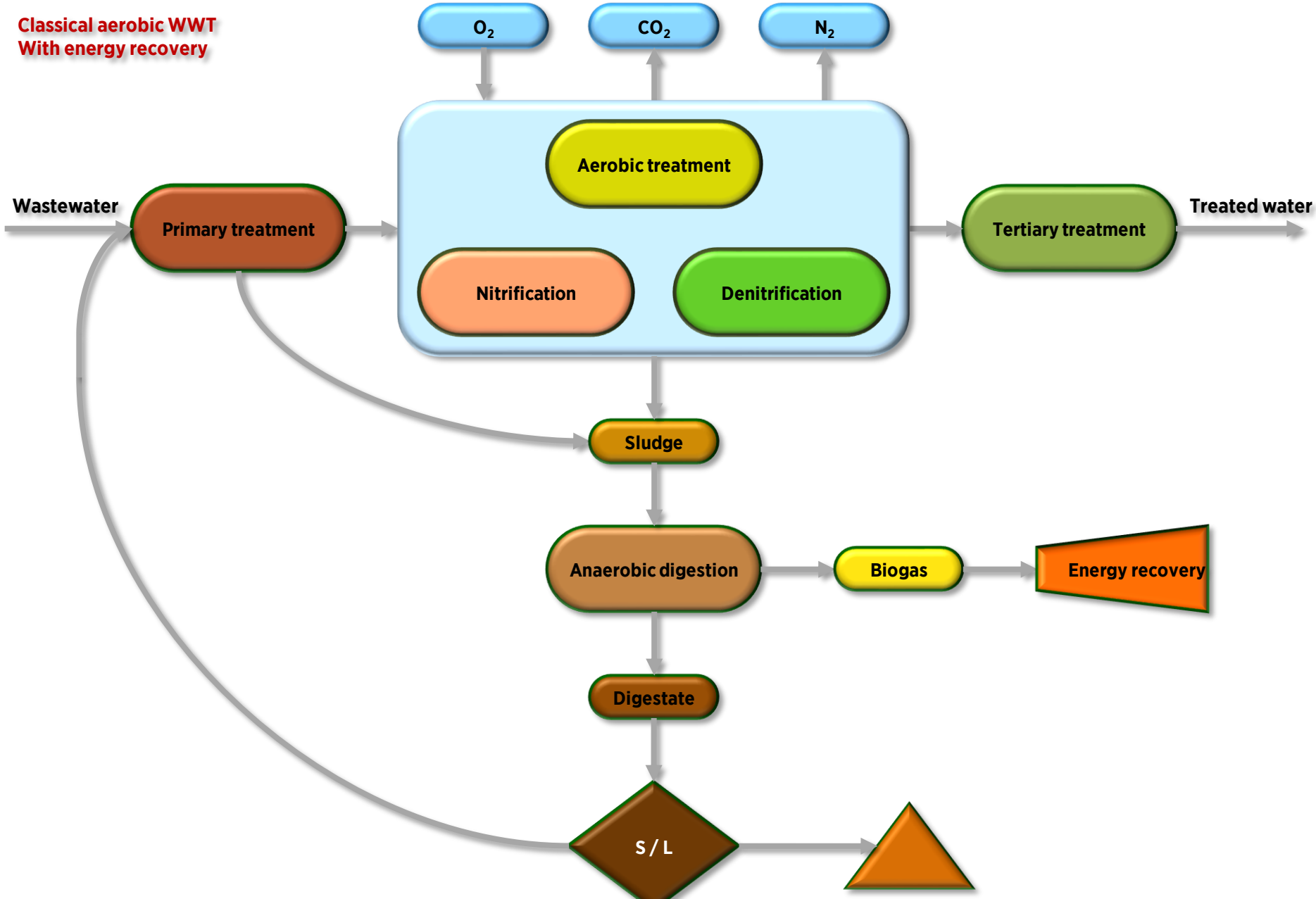


https://en.wikipedia.org/wiki/Nitrogen_cycle#/media/File:Nitrogen_Cycle_-_Reactions_and_Enzymes.svg

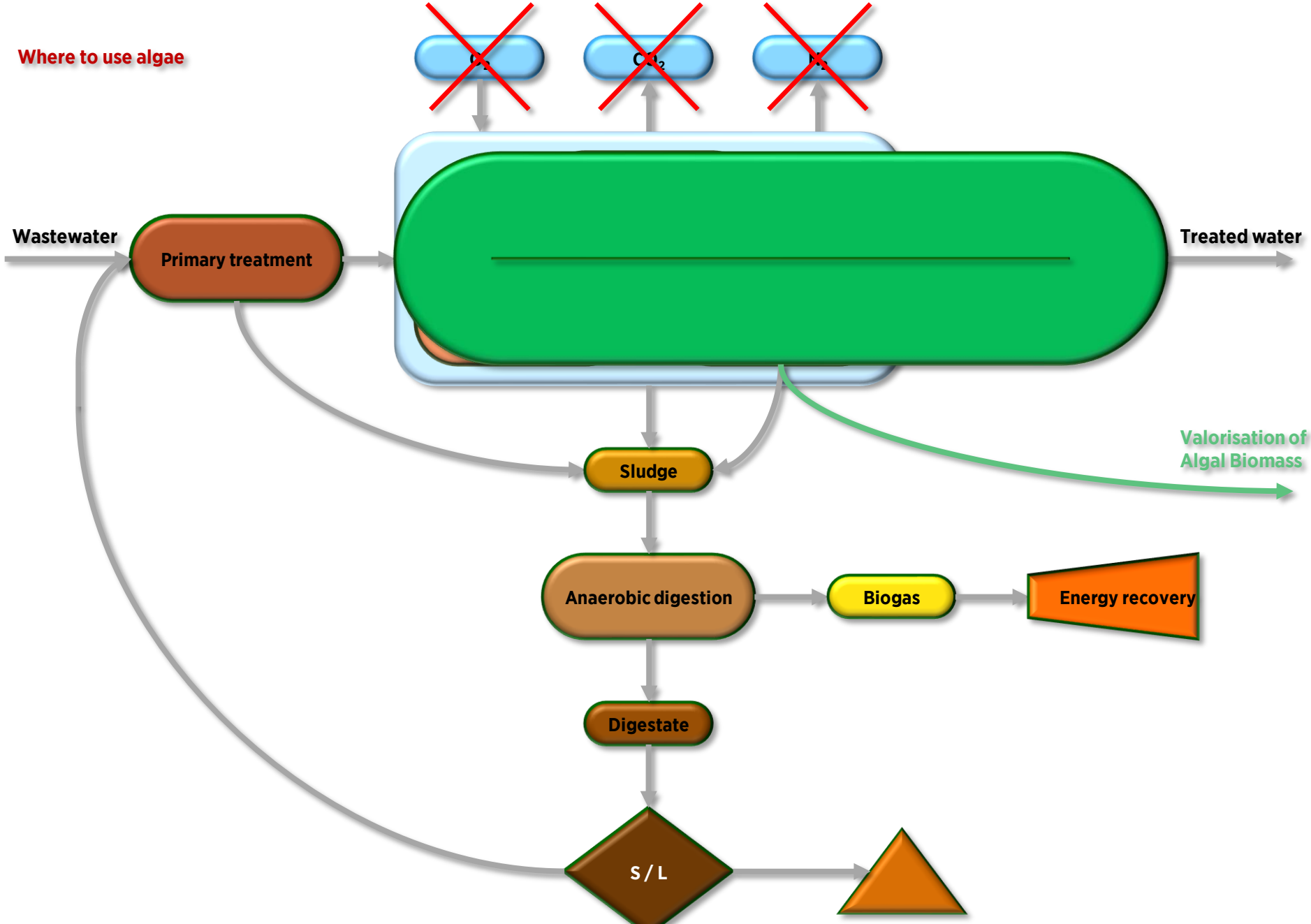
Classical aerobic WWT



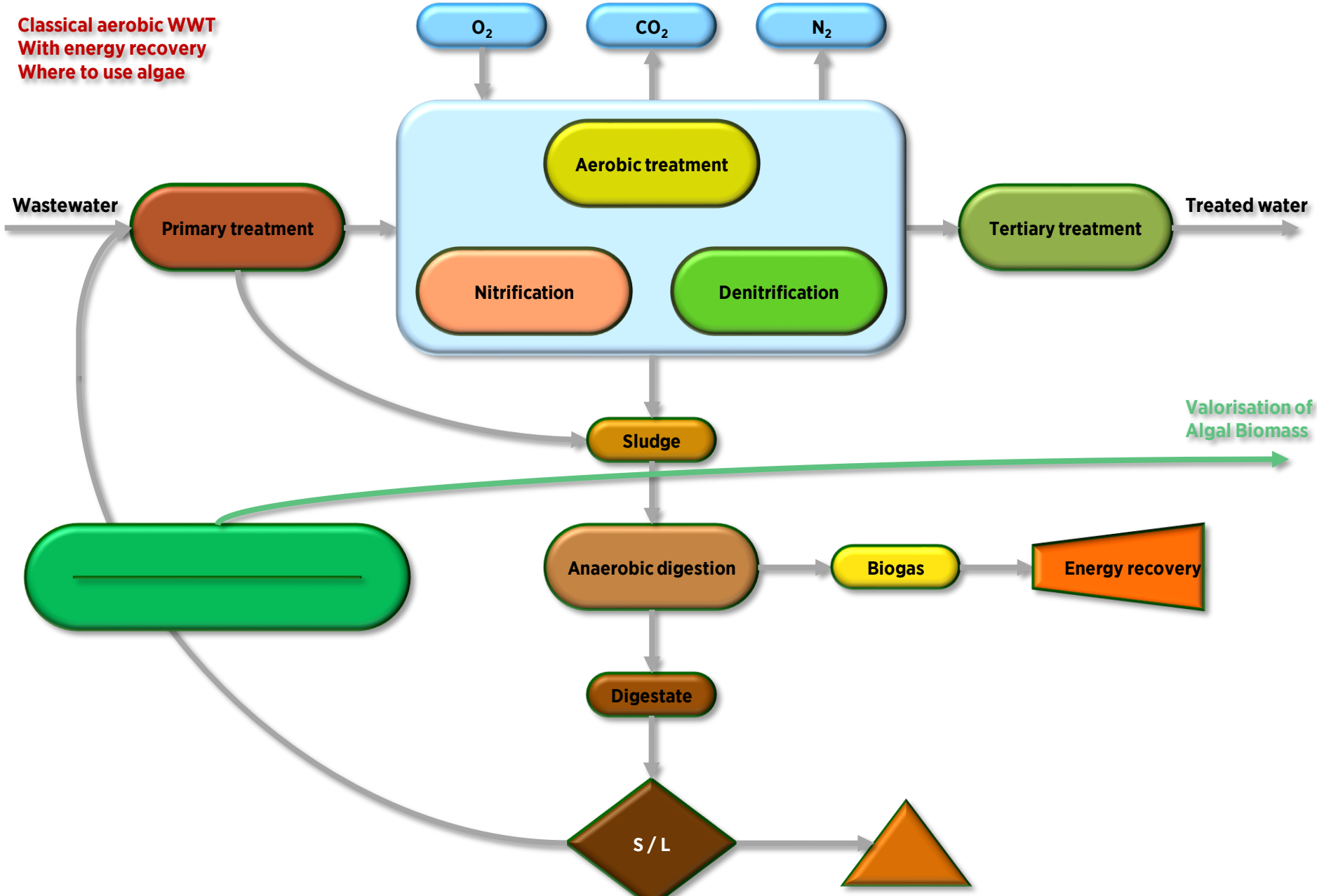
Classical aerobic WWT
With energy recovery



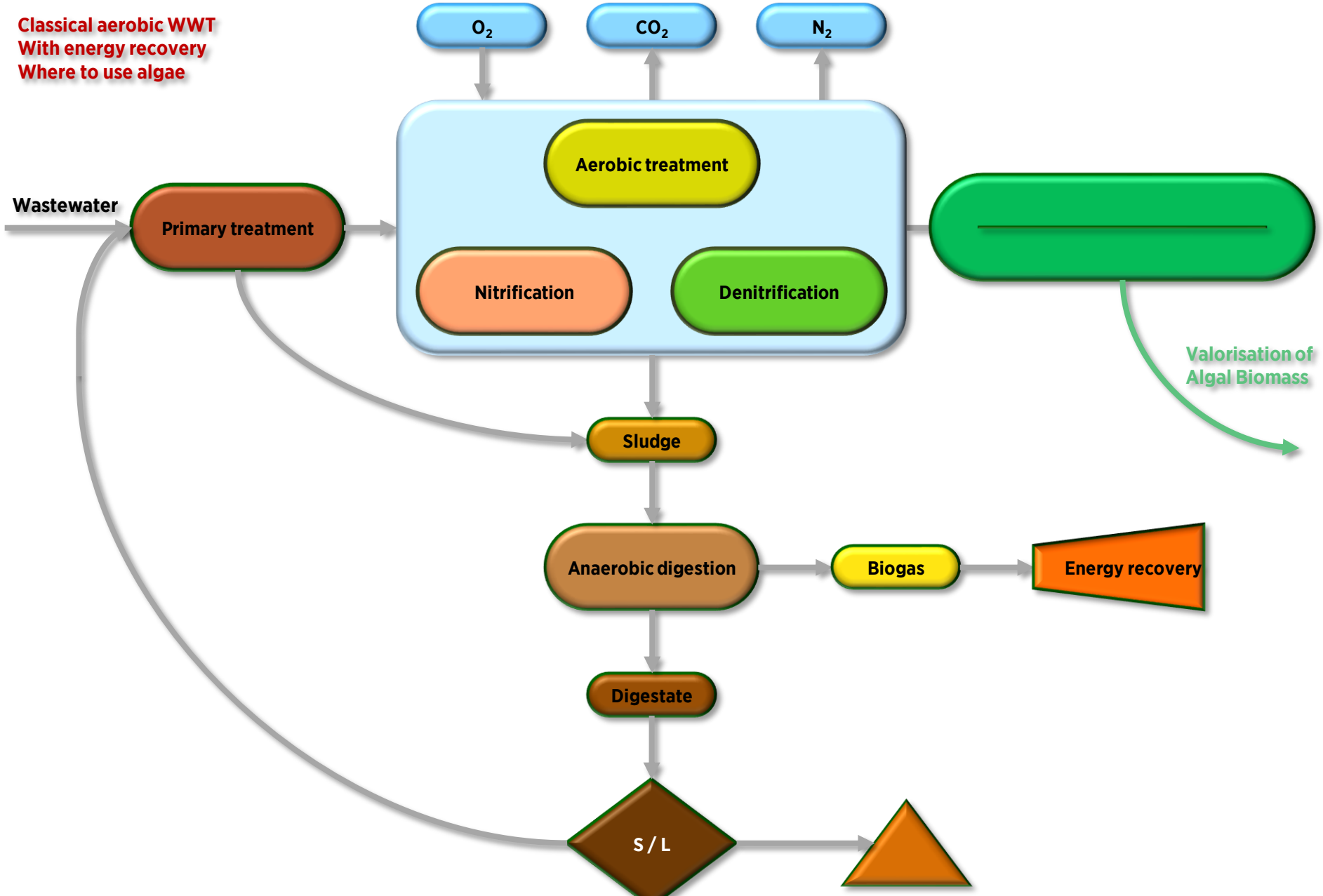
Where to use algae



Classical aerobic WWT
With energy recovery
Where to use algae

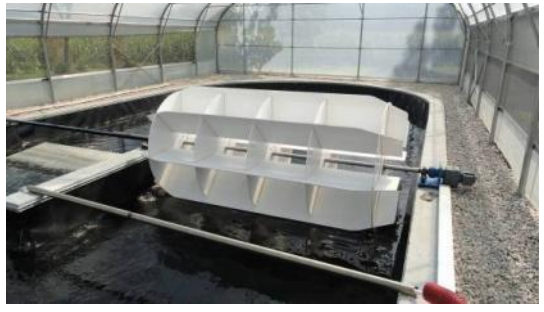


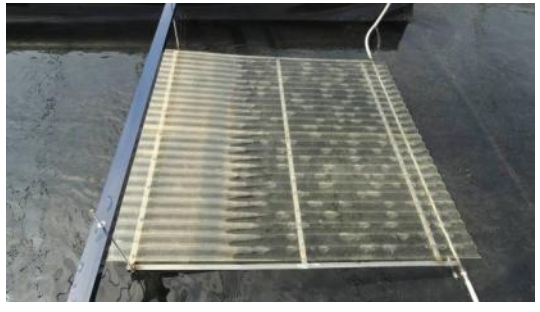
Classical aerobic WWT
With energy recovery
Where to use algae



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







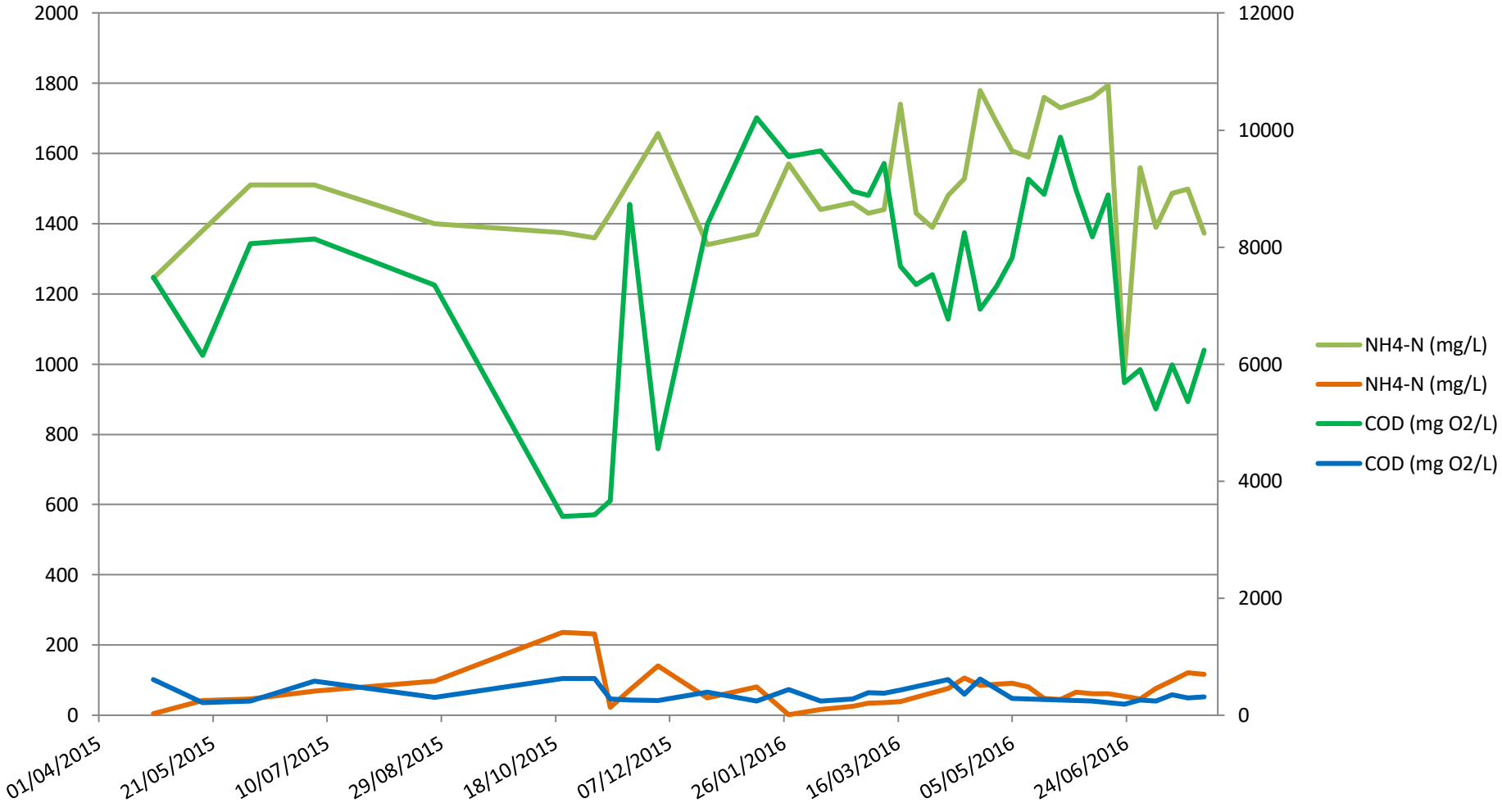




S/L Separation
Anaerobic filter

Digestate color!

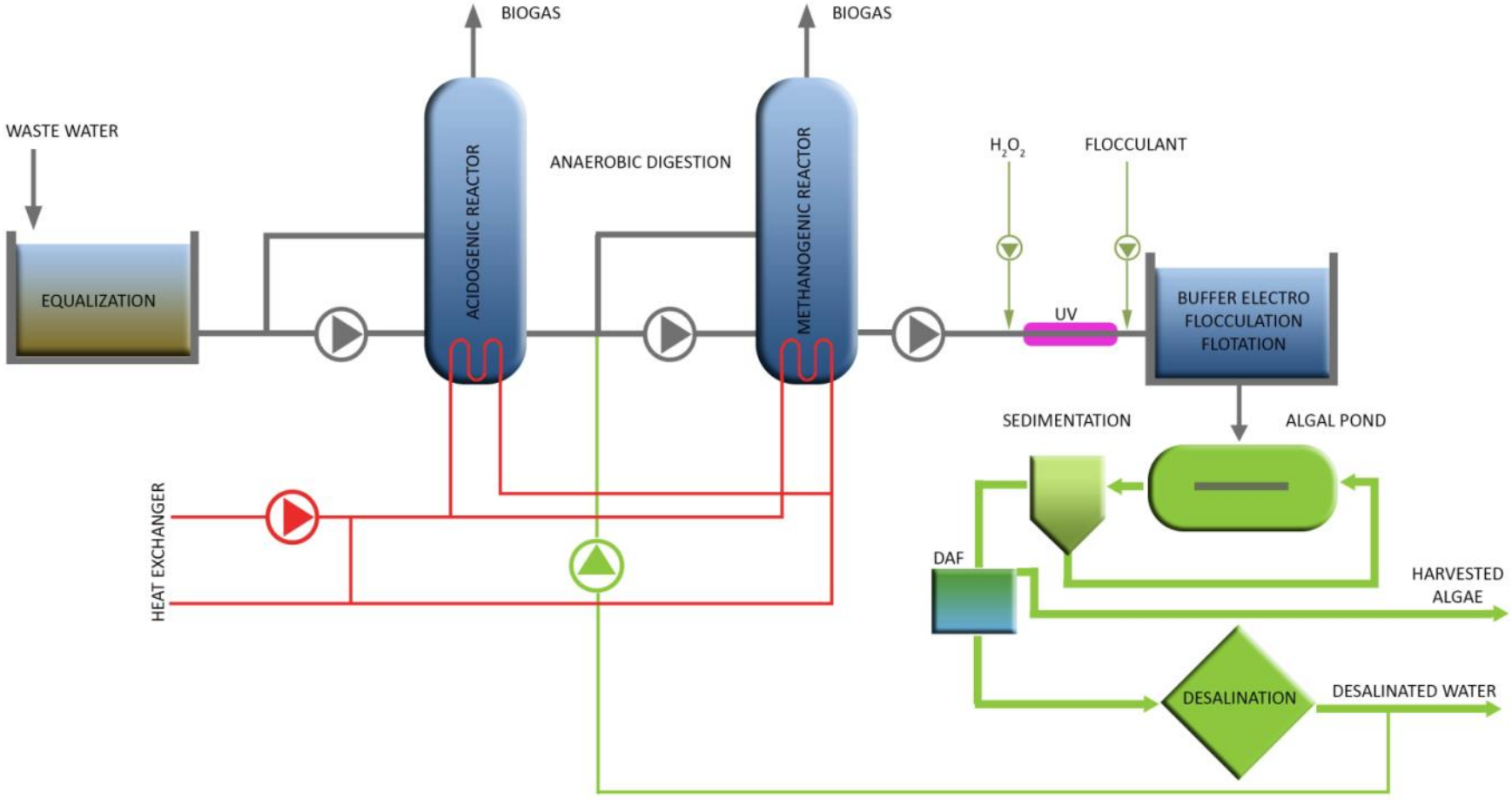
Algaebiogas



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

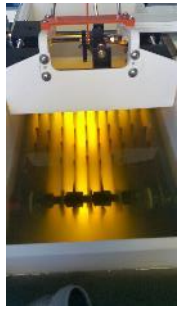

BIOGAS
BIOGAS
WASTE WATER
EQUALIZATION
ACIDOGENIC REACTOR
ANAEROBIC DIGESTION
METHANOGENIC REACTOR
H_2O_2
FLOCCULANT
UV
BUFFER ELECTRO FLOCCULATION FLOTATION
SEDIMENTATION
ALGAL POND
HEAT EXCHANGER
DAF
HARVESTED ALGAE
DESALINATION
DESALINATED WATER

Saltgae – demo Ljubljana







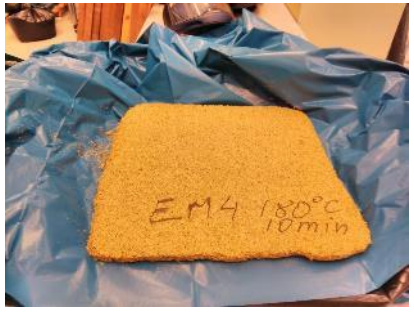





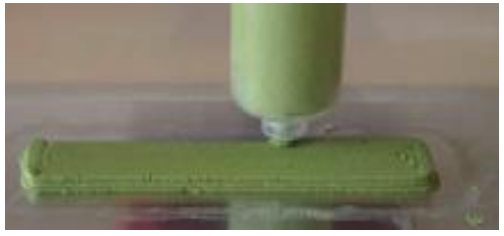


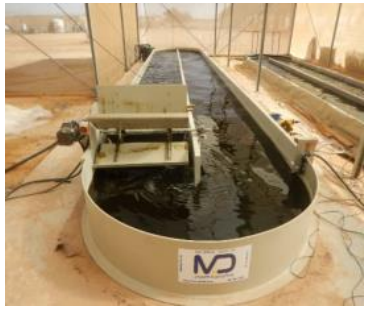
Saltgae – demo Camporosso, Arava, applications












Grant Agreement No 869318

ULTIMATE
WATER SMART INDUSTRIAL SYMBIOSIS

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**

✓ **territorial conditions**

✓ **technical and non technical constraints**

Different industrial sectors to be linked each other, each one having its own business targets, needs and specifications.

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

Regulatory (e.g. **"end of waste"**), environmental, and social constraints, as function of local, regional and national conditions

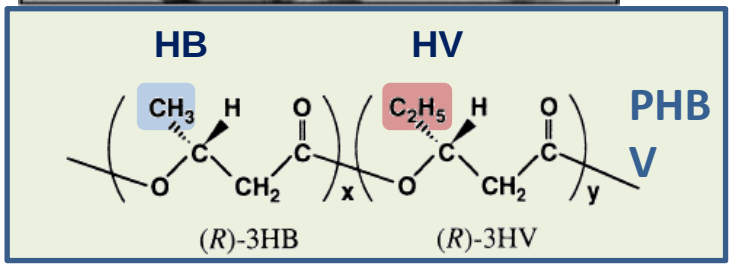
Why focusing on PHA?



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

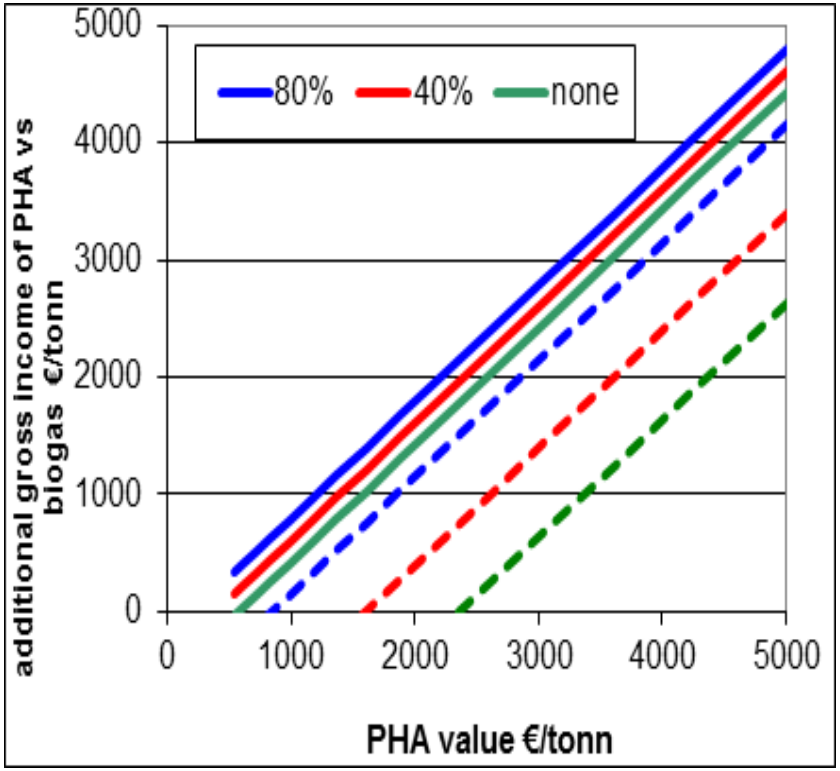
Already under investigation at TRL 6

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**

Income only, production costs not included



- 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)

An old story: PHA is often present in activated sludge

- Enhanced bio-P removal
- Bulking control

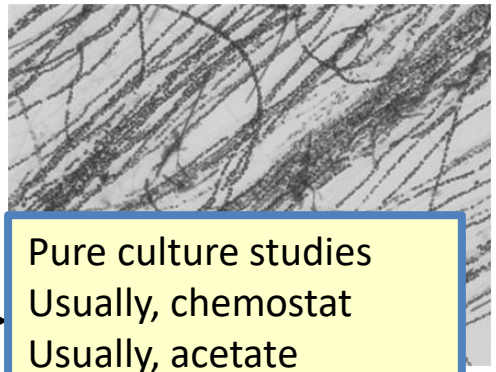
Late 80'

Time-changing conditions are imposed to the microbial consortium (non Monod-like growth)
-anaerobic/anoxic /aerobic cycles,
-and/or feast & famine

Half 90'

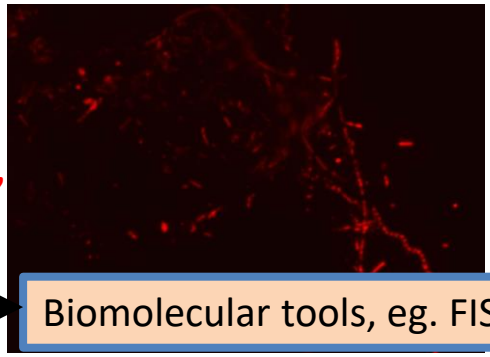
Physiological adaptation of each microbial species

Early 90'



Pure culture studies
Usually, chemostat
Usually, acetate

Early 00'



Biomolecular tools, eg. FISH

Selection of species that are more adaptable to growth under changing conditions

Mixed culture studies
Usually, SBR
Usually, VFA



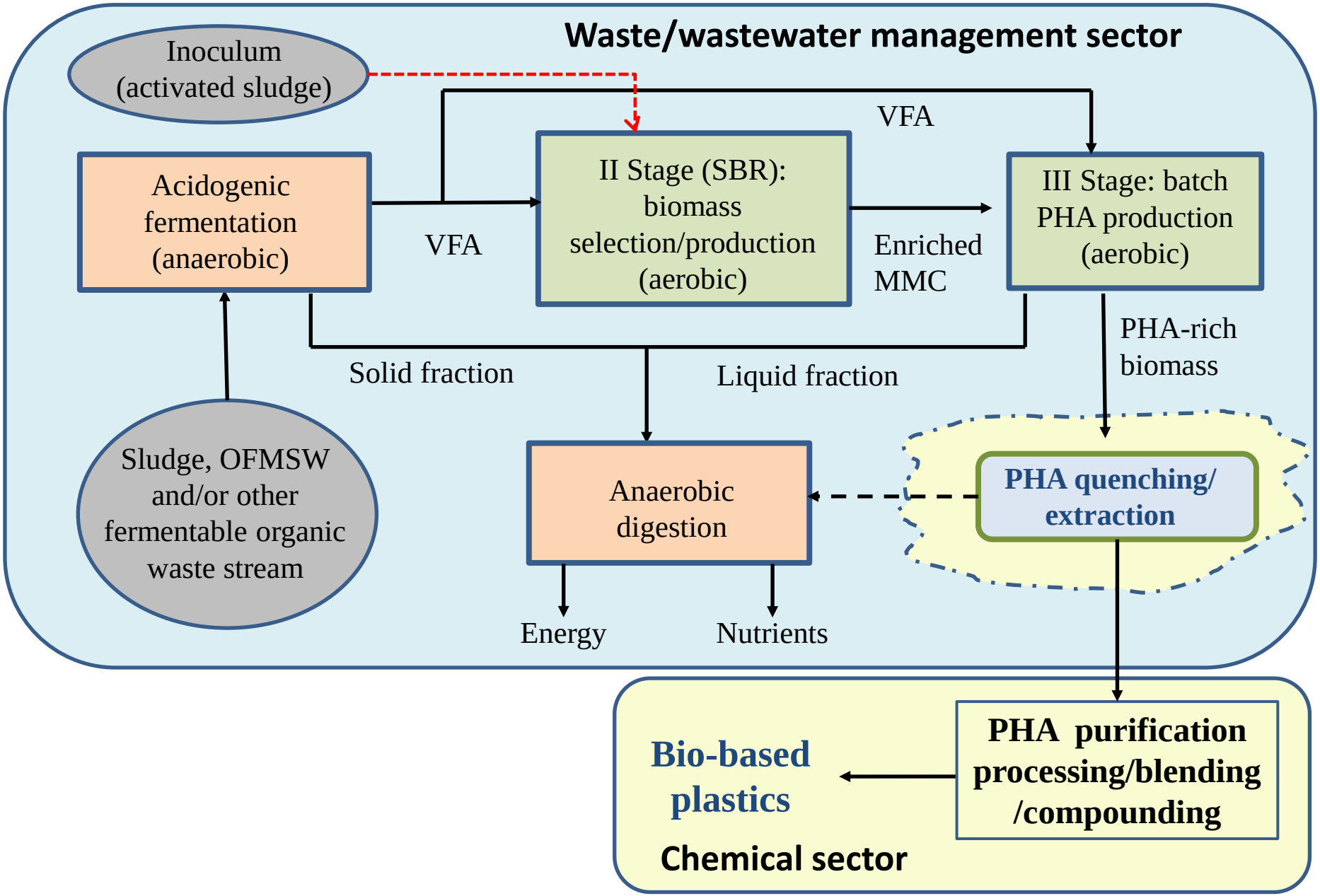
Mixed culture studies
Usually, batch

Half 00'

Toward PHA production

✓Ad hoc regulation of the process towards dynamic storage response
✓acidogenic fermentation to increase VFA
✓True feedstock
✓Scaling up

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.

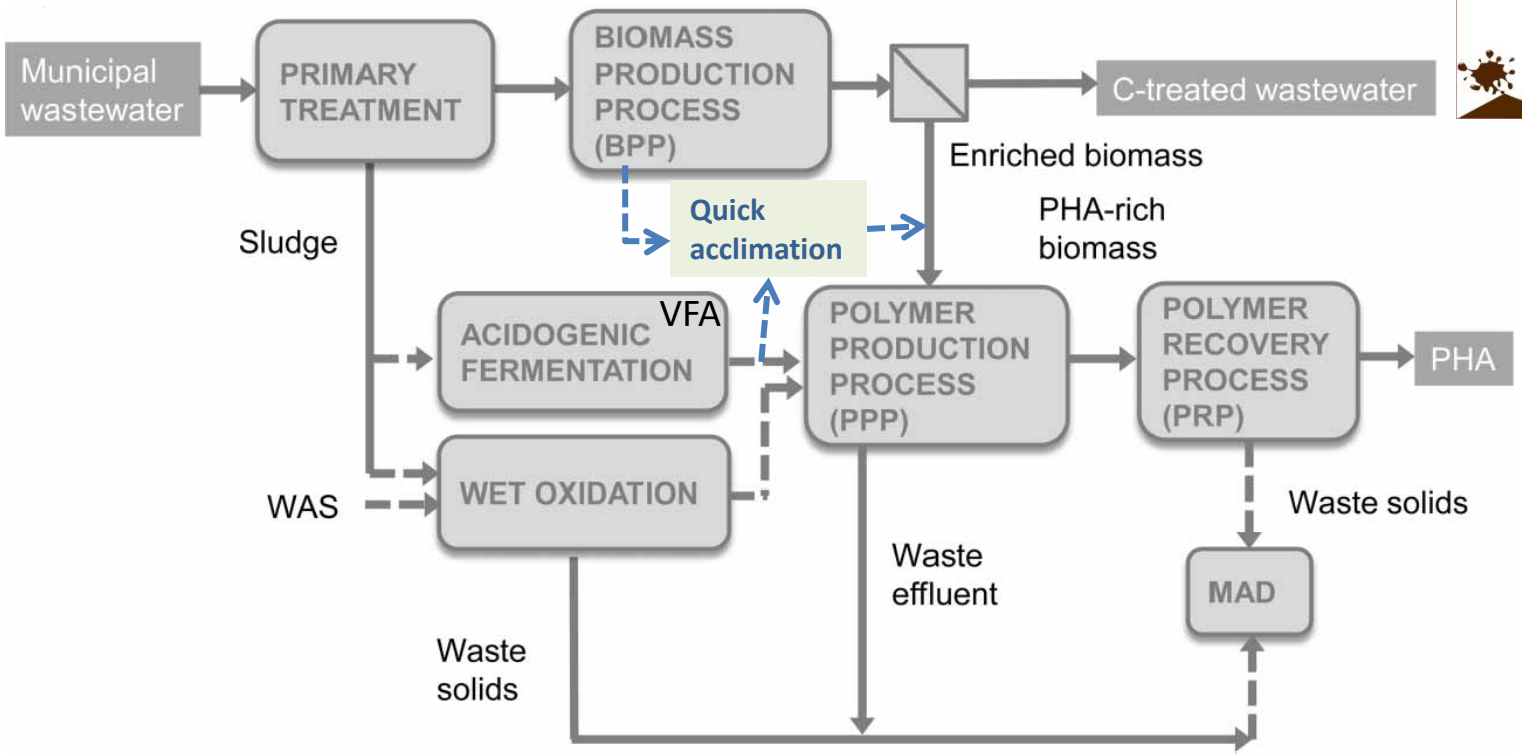


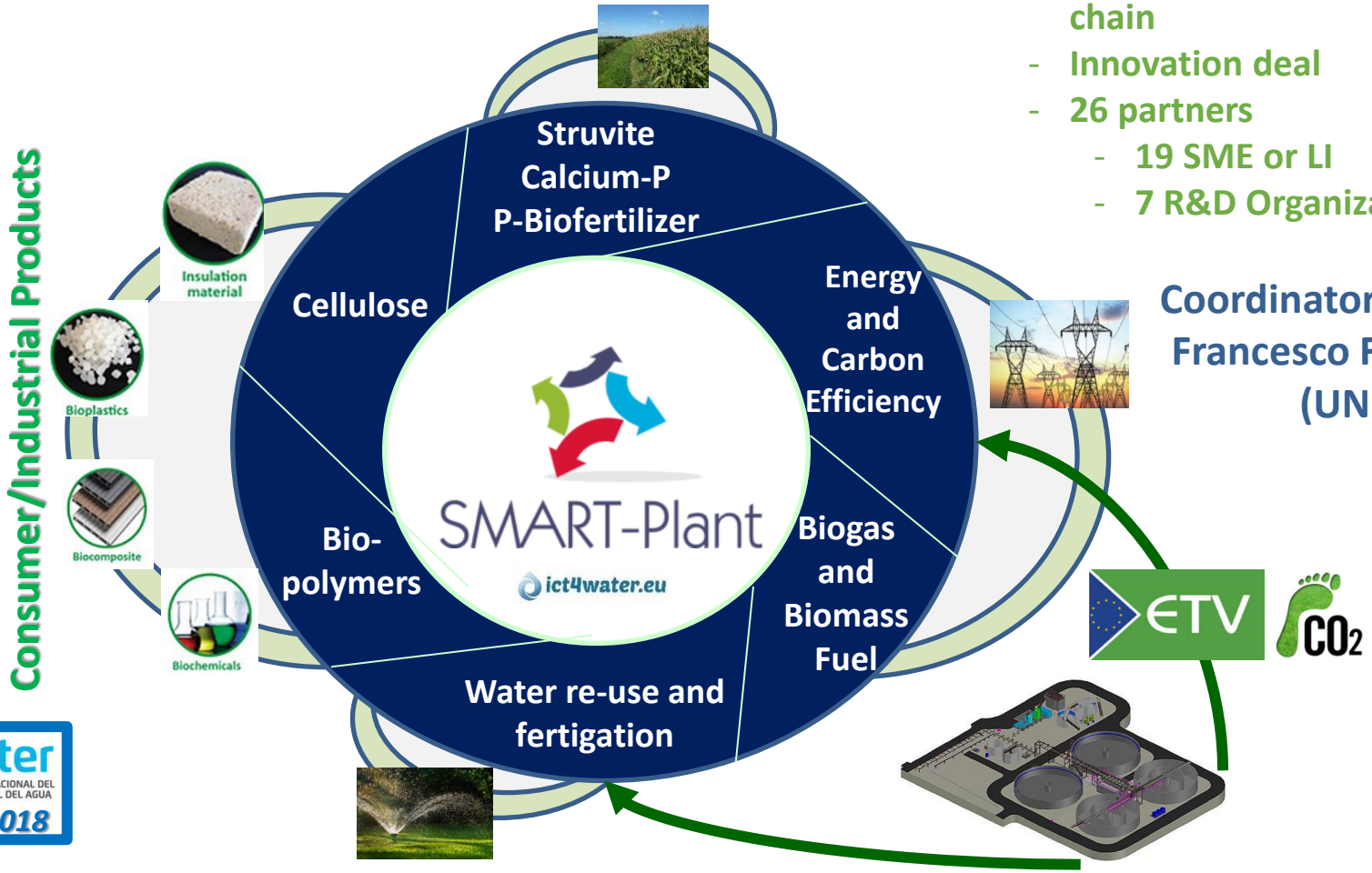
Figure 1 | Schematic process flow diagram of municipal wastewater and sludge treatment in conjunction with PHA production under study in the project Routes (MAD = mesophilic anaerobic digestion). Laboratory-scale studies are conducted on BPP, PPP and PRP (La Sapienza University of Rome/AnoxKaldnes), 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

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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 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	4a ETV	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**

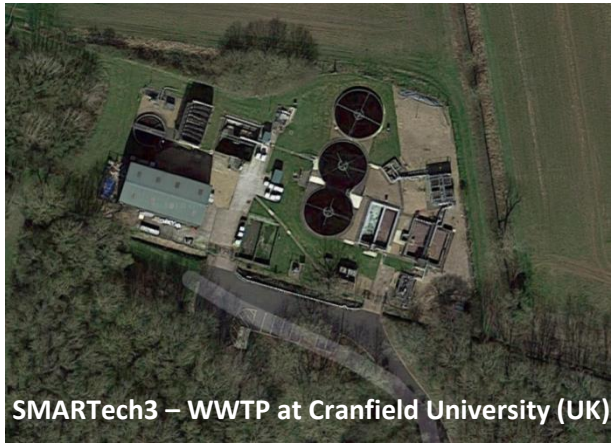
SMARTechs integrated in existing WWTPs (revamped/upgraded to WRRFs)



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

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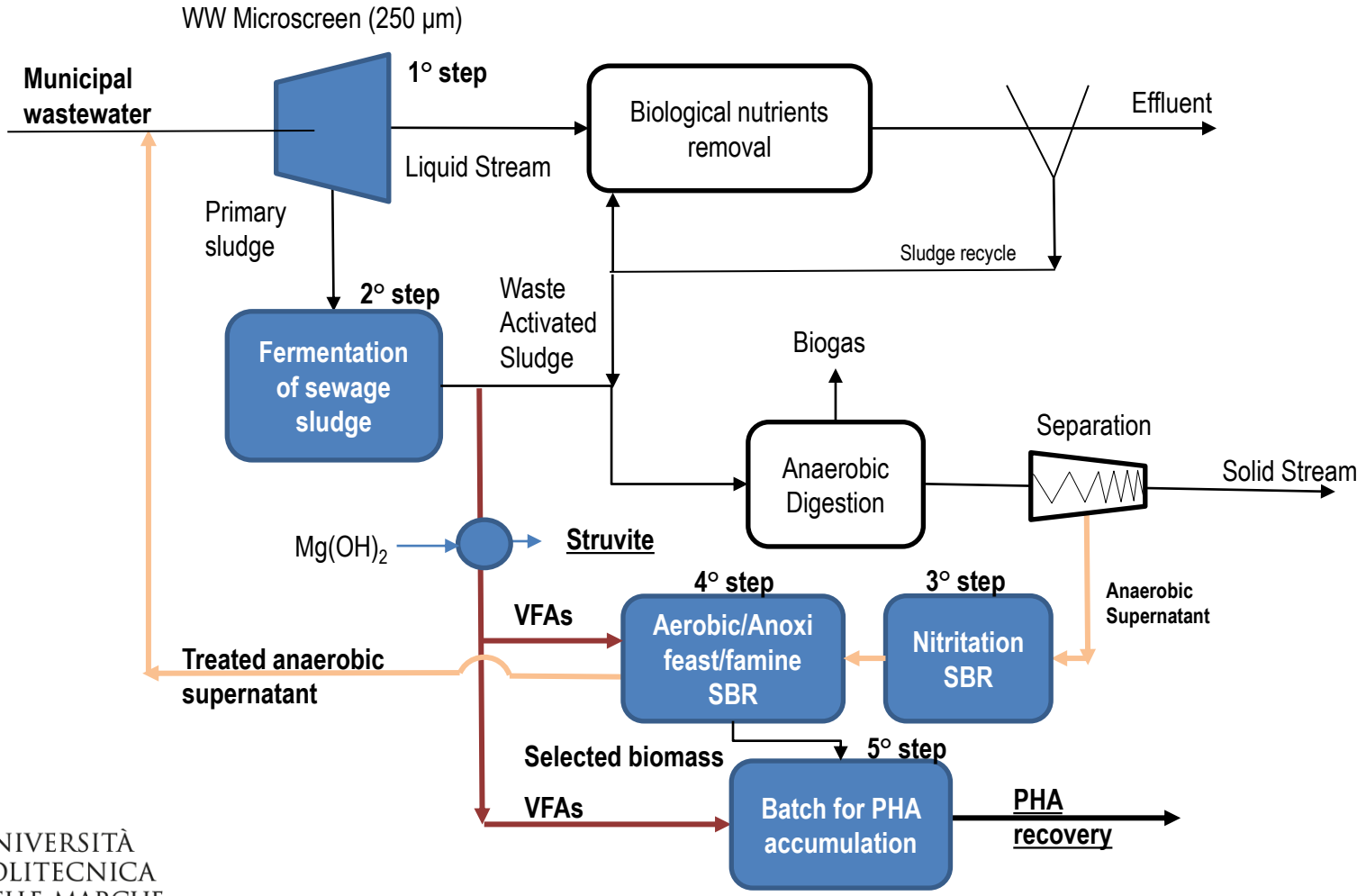
Sidestream S.C.E.P.P.H.A.R.: Short-Cut Enhanced Phosphorus and PHA recovery (Smartech 5)

SMART-Plant
Supported by the Horizon 2020 Framework Programme of the European Union
www.smart-plant.eu



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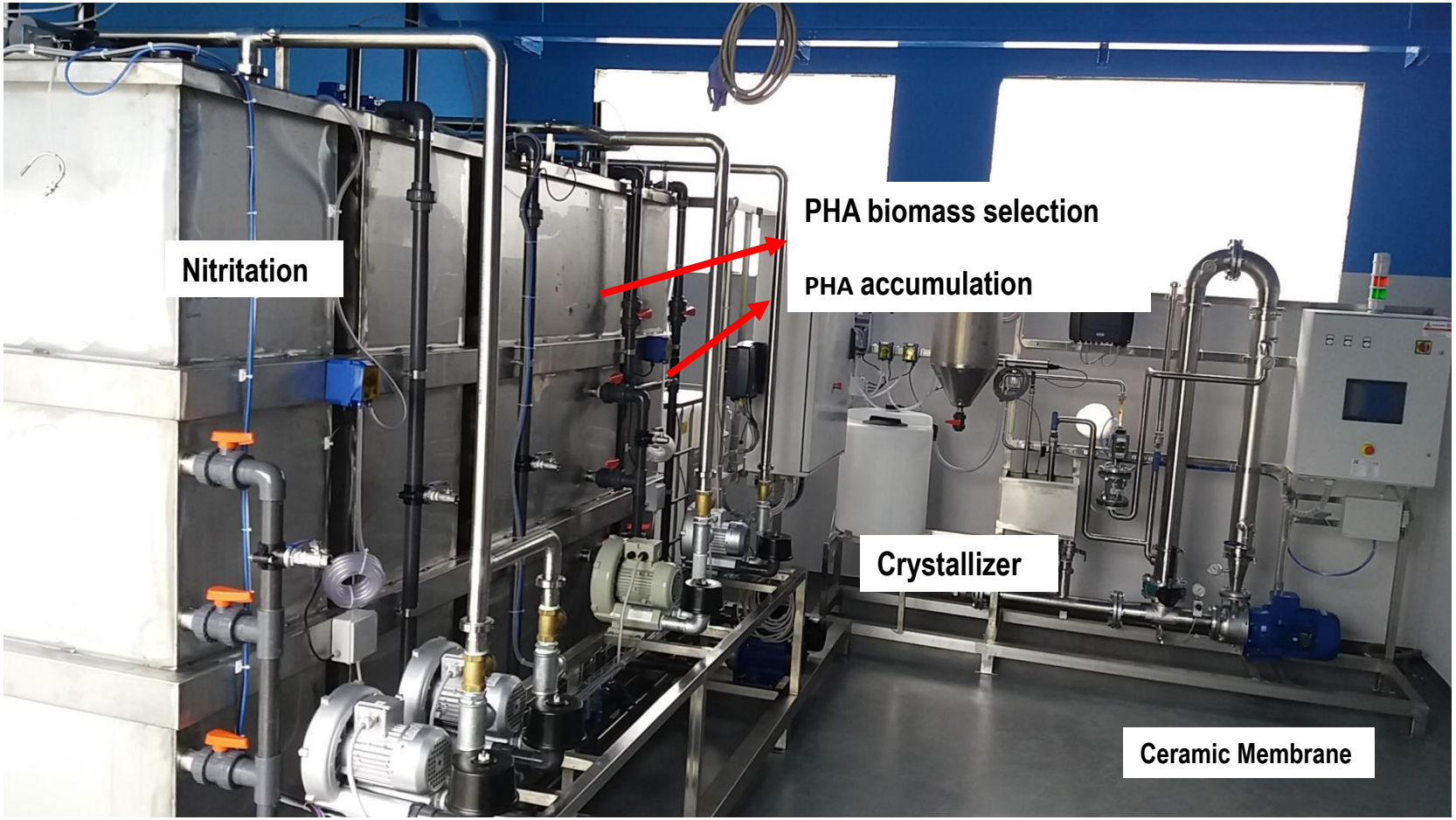
Conca et al. Long-term validation of polyhydroxyalkanoates production potential from the sidestream of municipal wastewater treatment plant at pilot scale
Chemical Engineering Journal, 390, 124627, 2020, https://doi.org/10.1016/j.cej.2020.124627

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
www.smart-plant.eu

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RESources from URban BIo-waSte
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**

THE FRAMEWORK PROGRAMME FOR RESEARCH AND INNOVATION
HORIZON 2020

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)

Feedstock (from industrial scale plants, on site)

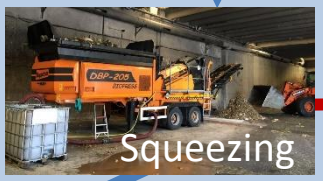
Urban wastewater



sludge

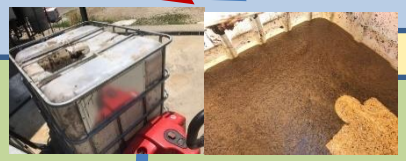
Organic fraction of Municipal Solid Waste





Solid phase to composting

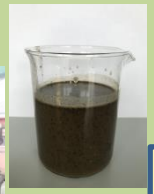
slurry



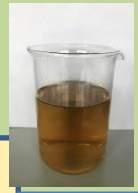
Storage



Acidogenic fermentation (anaerobic)



Solid/Liquid separation



VFAs

Solid phase to energy recovery



Anaerobic digestion

Upstream (on site)

air



Biomass production (aerobic SBR)

Process (on site)

air



Polymer production (aerobic batch)

Solid/liquid separation

liquid phase to energy recovery

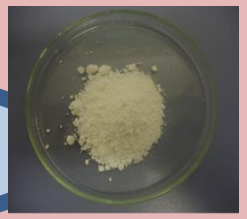
Quenching

Polymer-rich biomass



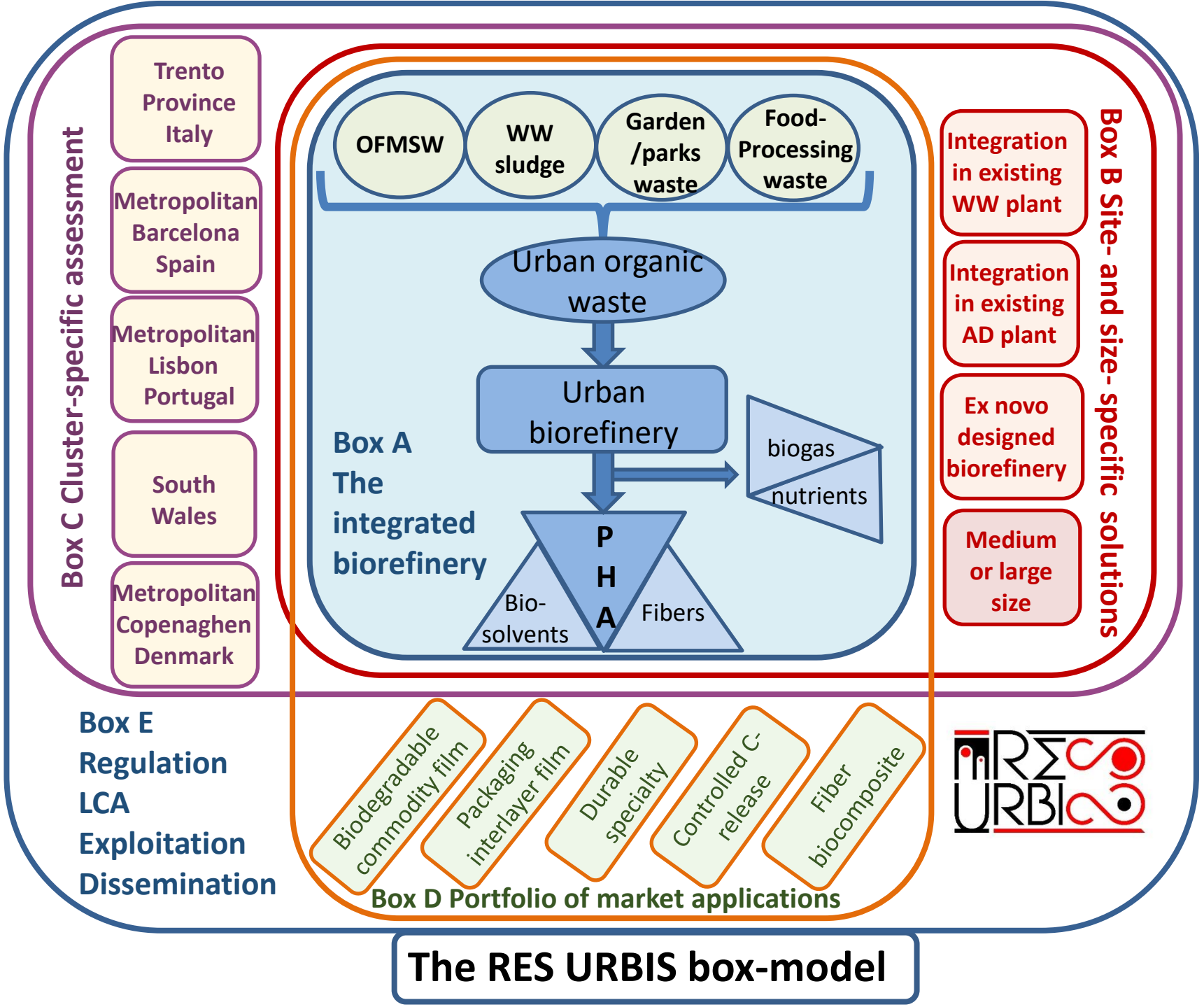
Extraction/ purification/ formulation

Energy



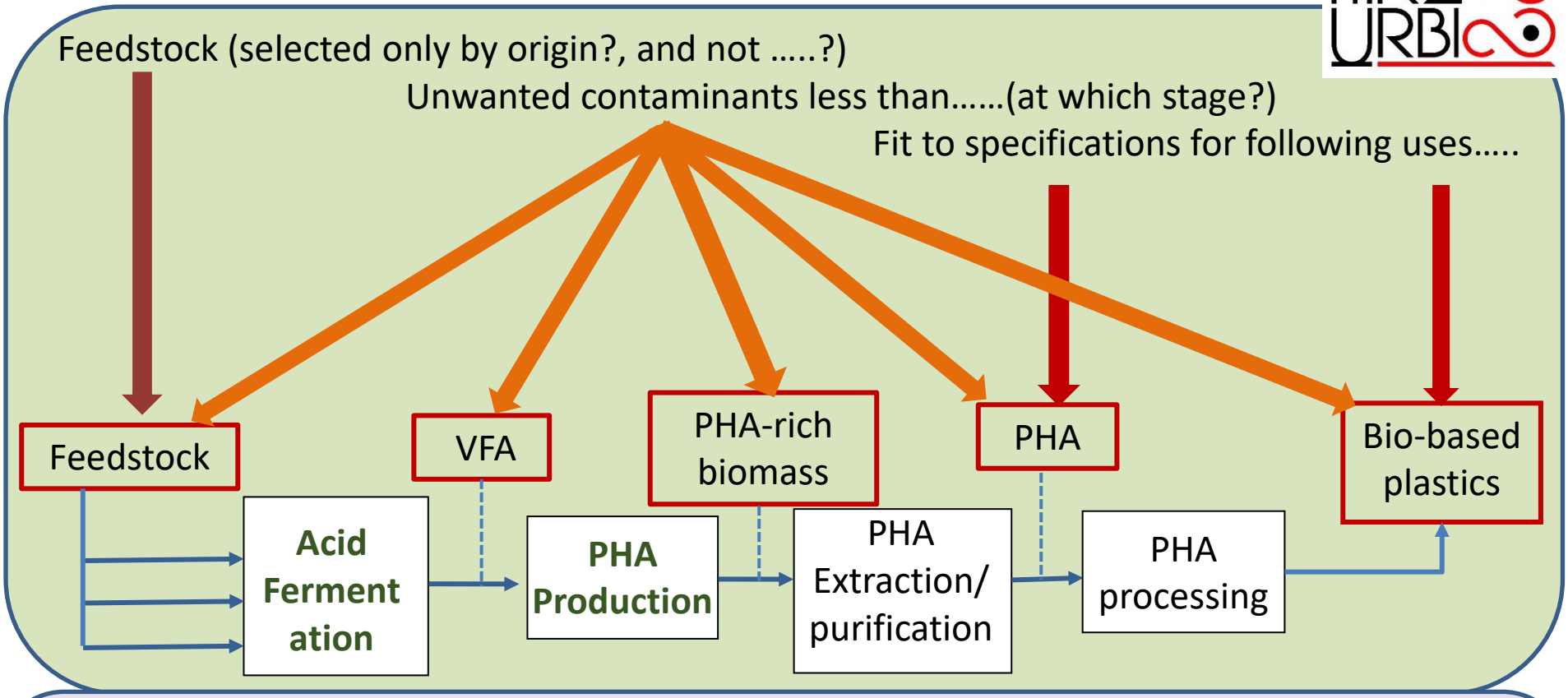
Bioplastics

Downstream (off-site)

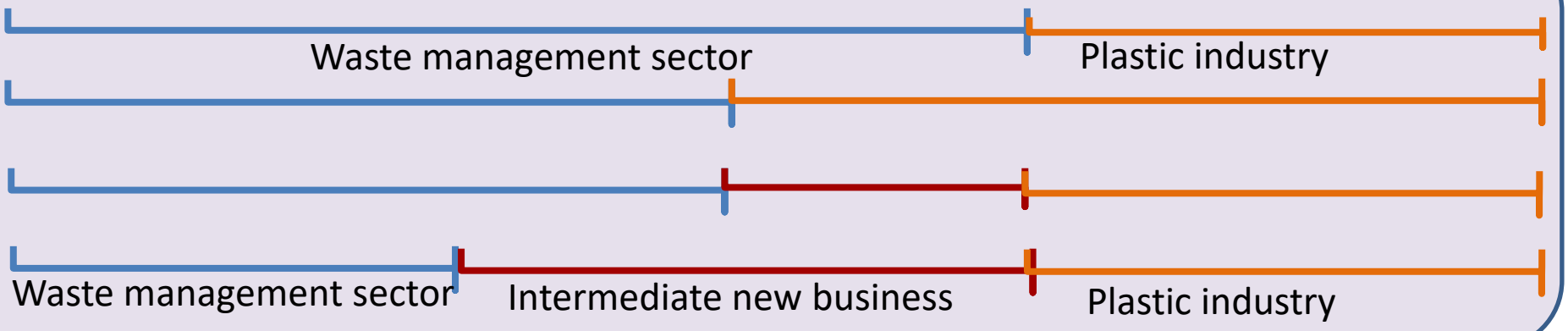


The RES URBIS box-model

“End of waste” criteria: where and how



Possible business segmentation



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.

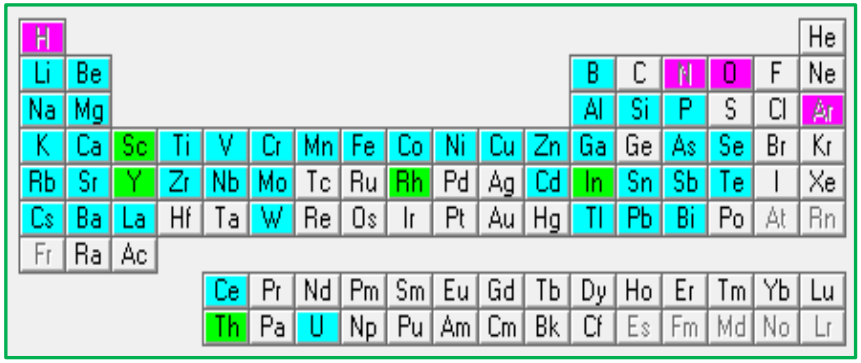
Analysis of contaminants in PHA samples

As function of:

- Feedstock
- Stabilization method
- Before/after extraction
- Extraction mehod

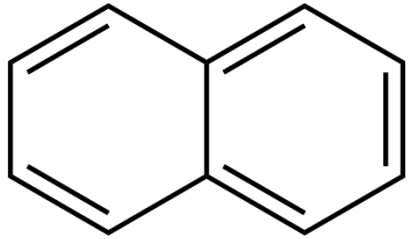
Inorganic elements, including toxic metals
>40

Astolfi ML. et al., Chemosphere, 259, 127472, 2020
https://doi.org/10.1016/j.chemosphere.2020.127472.



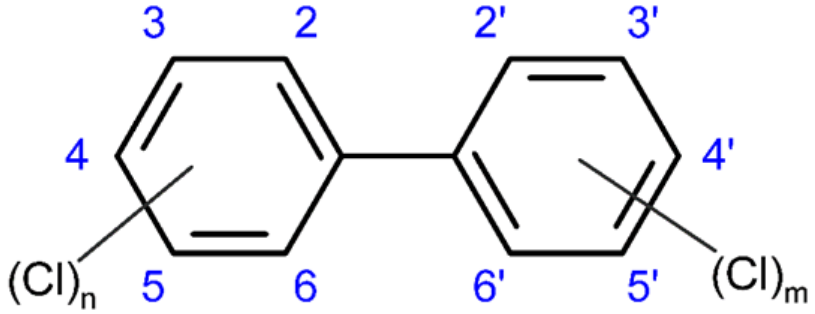
Polycyclic aromatic hydrocarbons (PAHs)
16 compounds

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

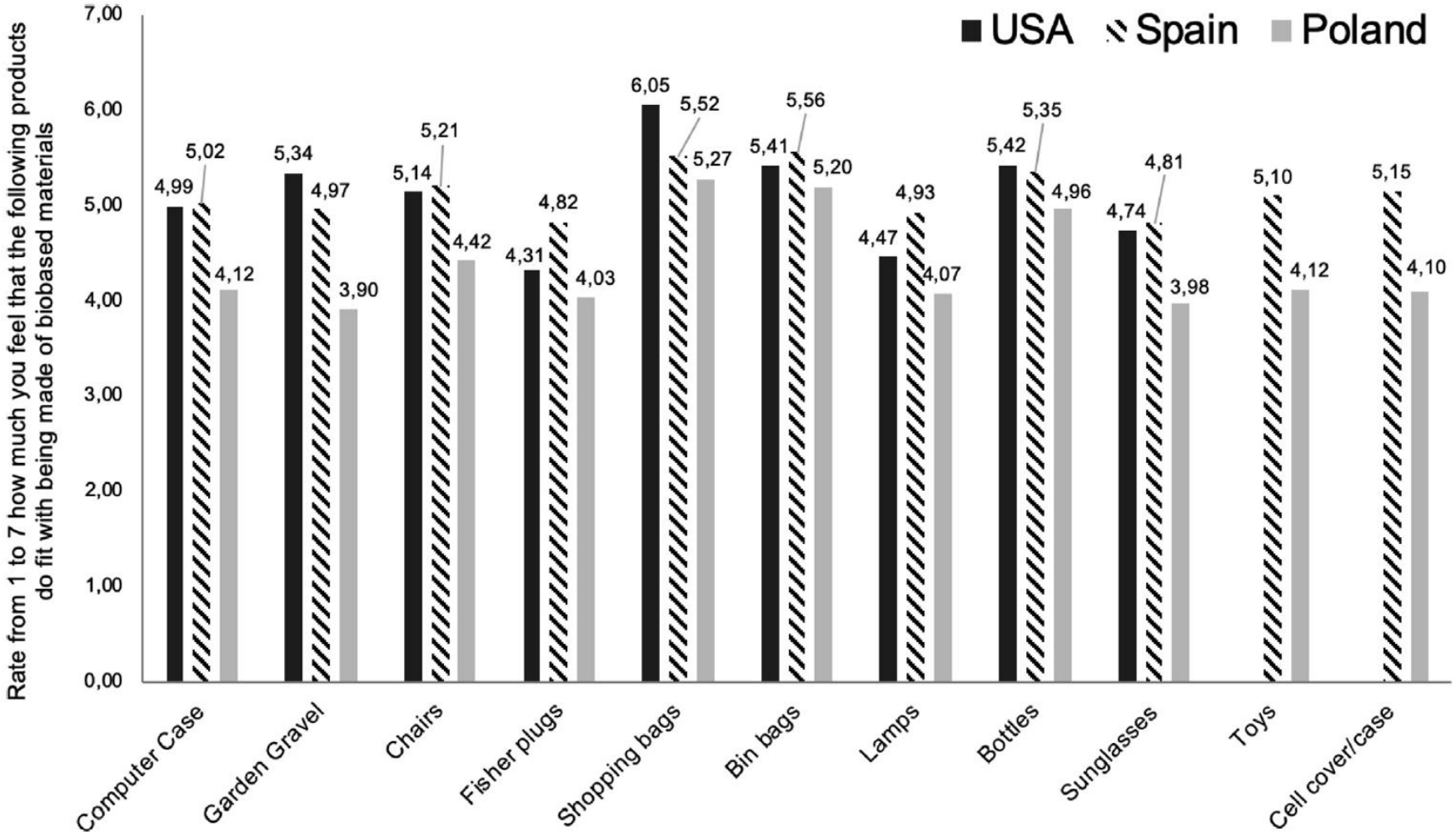
In the case of PHA production from urban organic waste these three points can be clearly defined:

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

ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

Online seminar on digitalization

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

May, 20th 2021

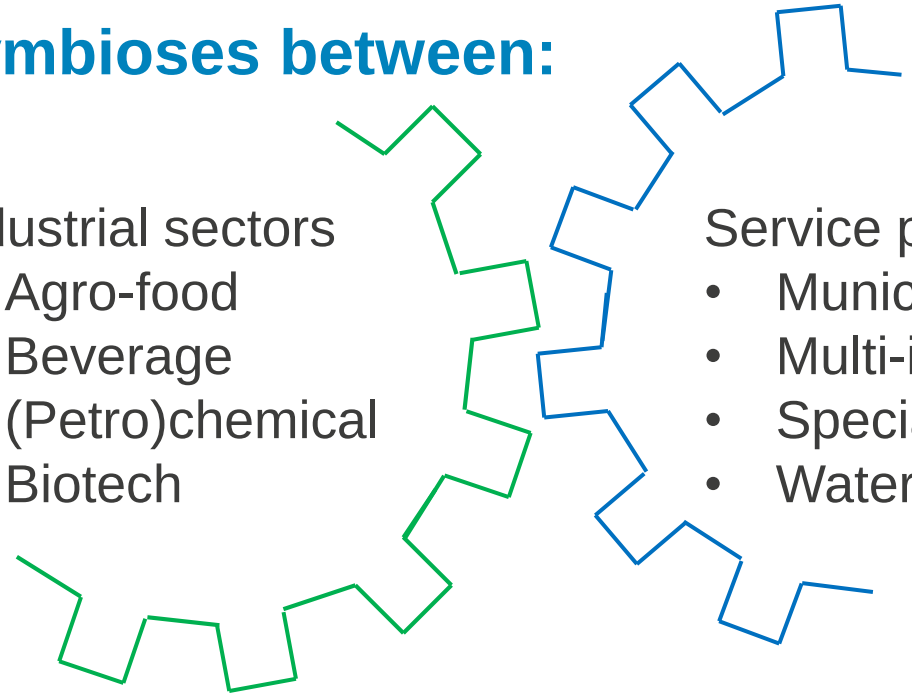


Ultimate (June 2020 – May 2024):

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



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





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

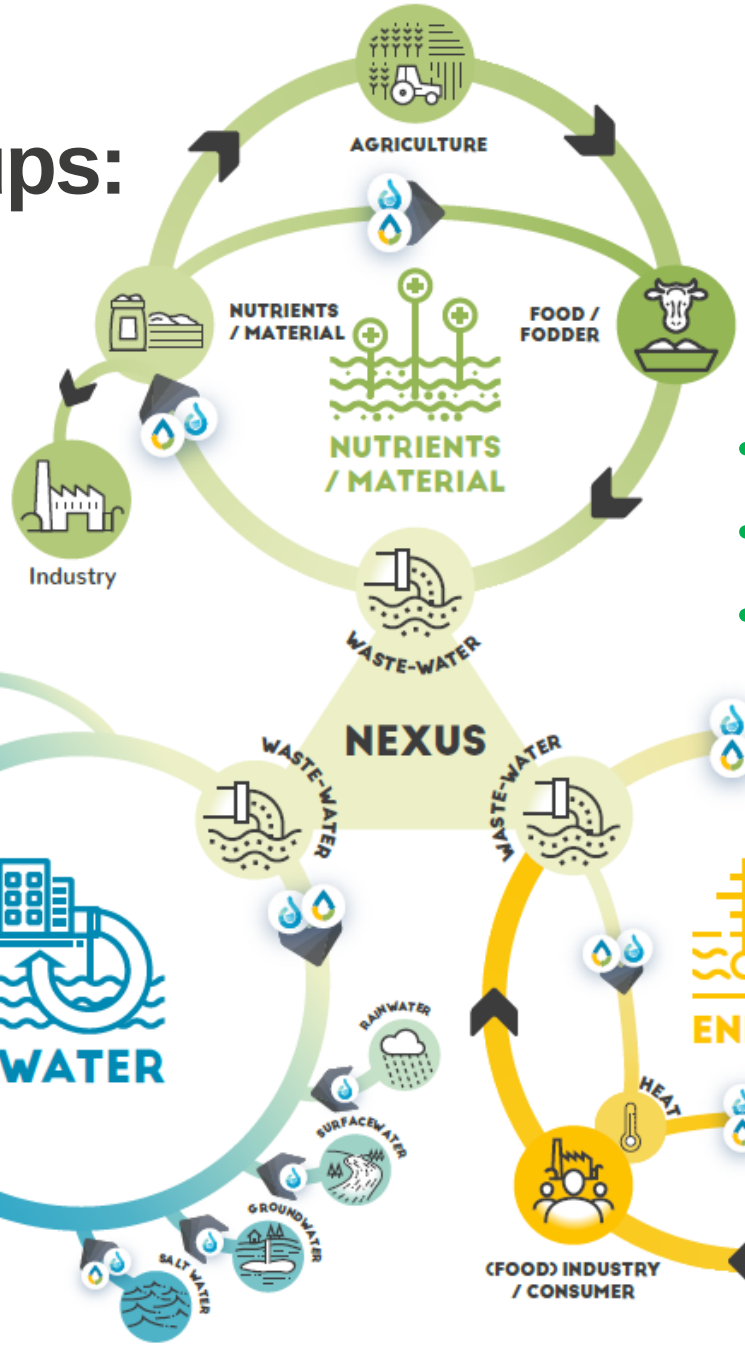


A. Kleyböcker

KOMPETENZZENTRUM Wasser Berlin

- Biogas technologies
- Heat recovery
- Digitalization

3 Cross-cutting Technology Groups: 9 Topics





F. Fatone C. Bruni

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- Nutrient recovery
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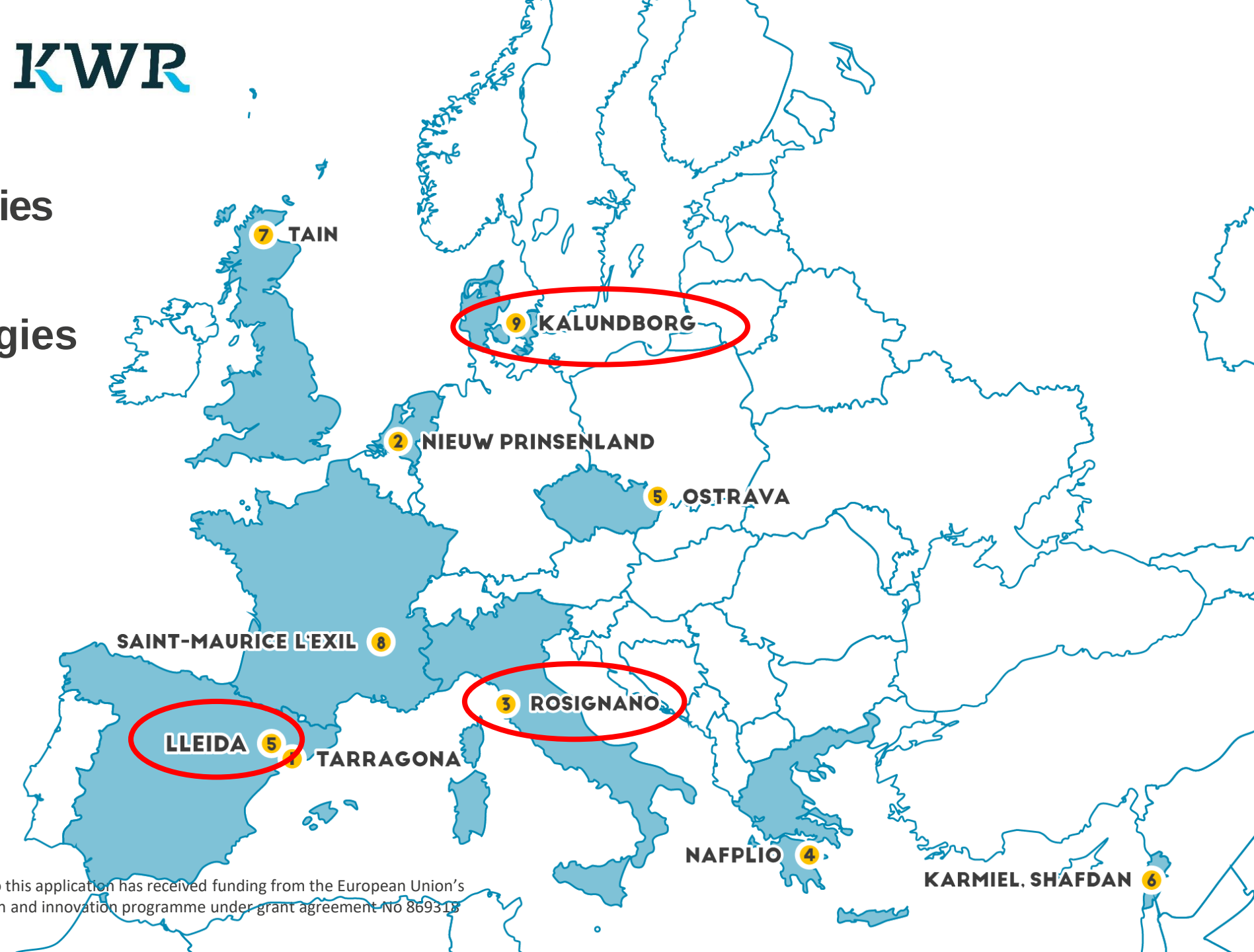

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Online seminar on digitalization

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



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

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

9 DEMOSITES

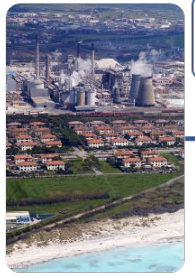
ULTIMATE will implement Water Smart Industrial Symbiosis in nine large-scale business cases from the international agro-food, petrochemical and biotech sector.

- 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)





Cecina municipality



Rosignano municipality

Unpredicted Saltwater intrusion

Unpredicted Saltwater intrusion

Cecina WWTP



Rosignano WWTP



Flow splitter

To surface water body

Aretusa WWRP



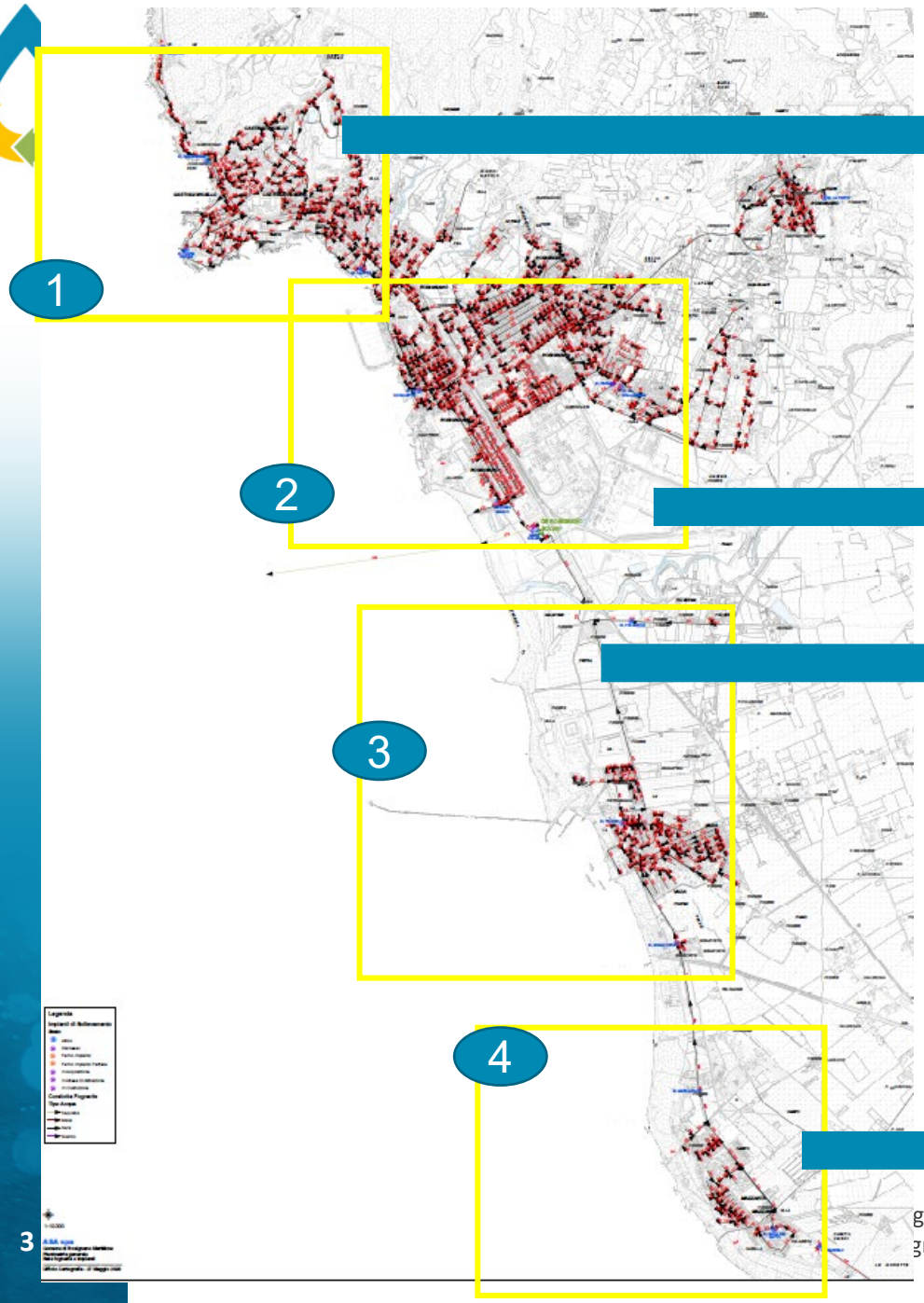
Groundwater

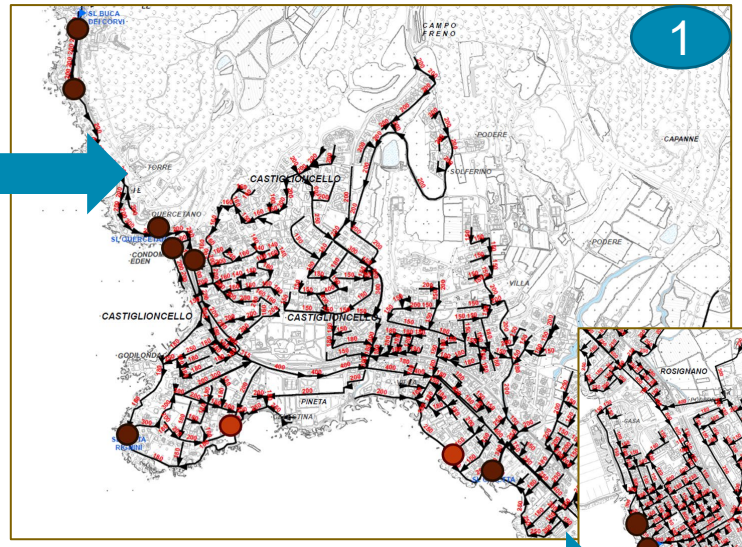
Unpredicted high unacceptable salinity

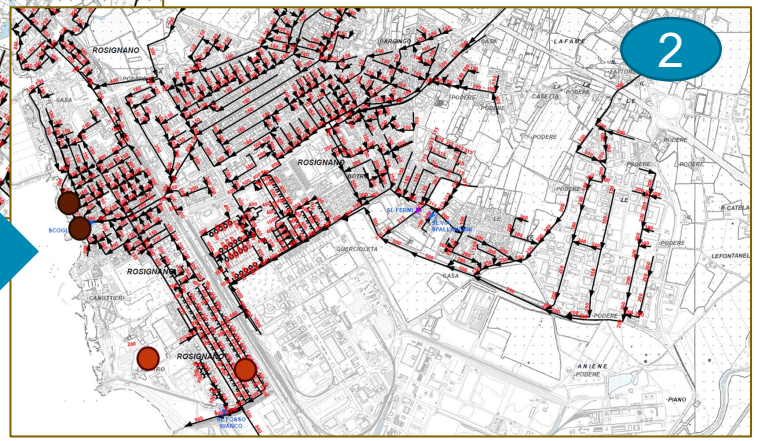
Solvay Industry

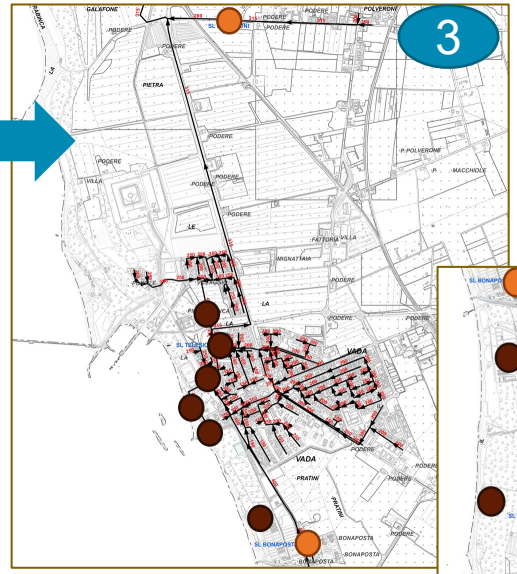


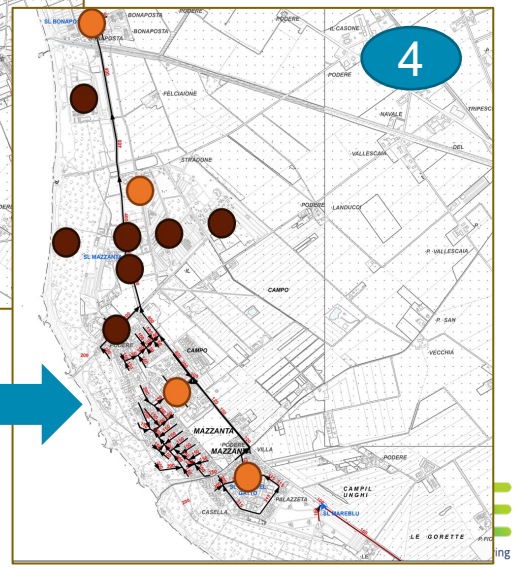
ROSIGNANO Targeted Sampling Campaign









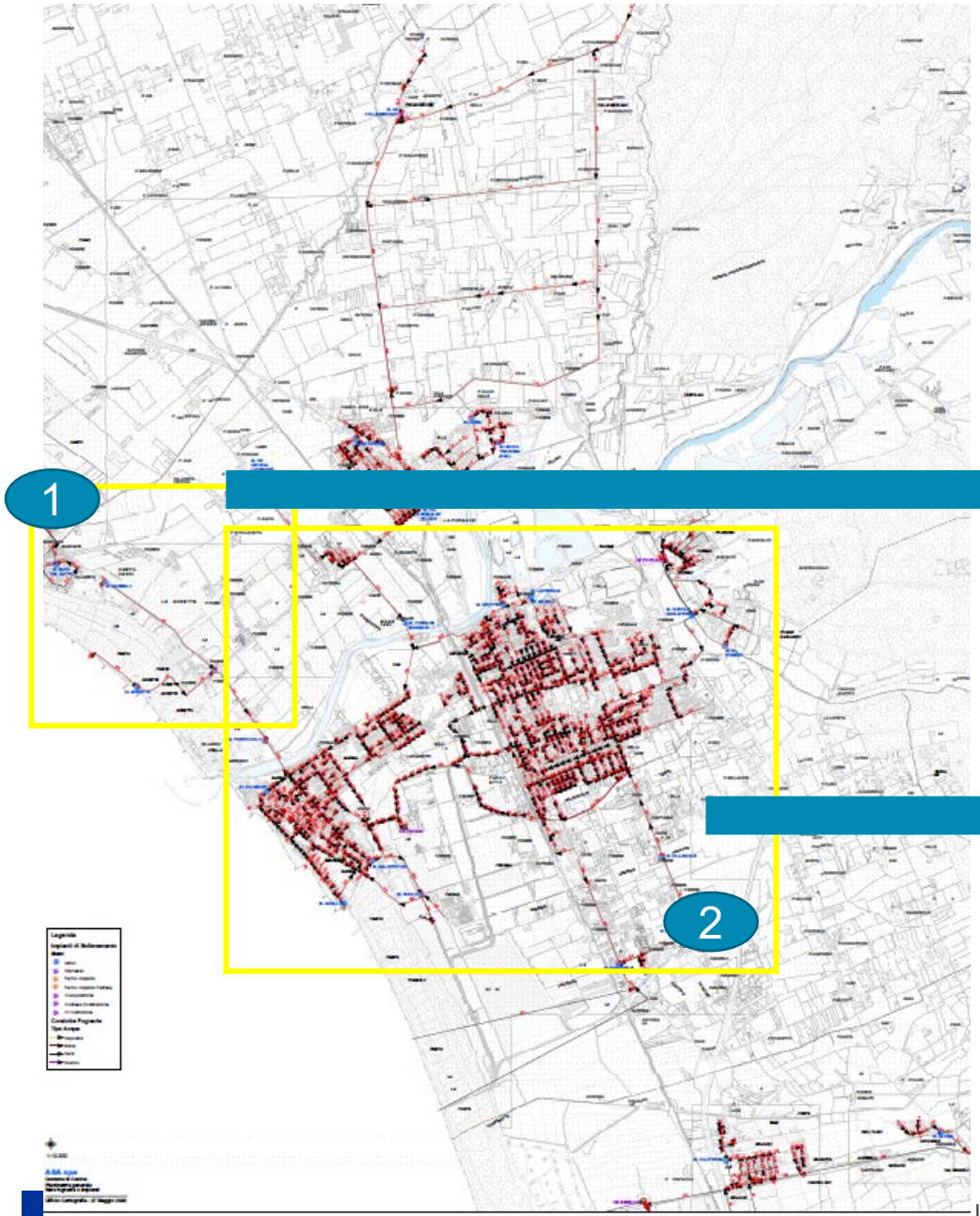


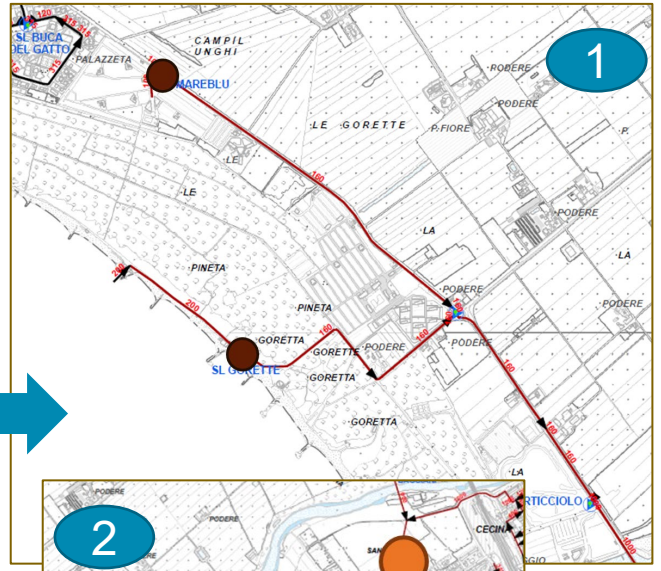
µS/cm

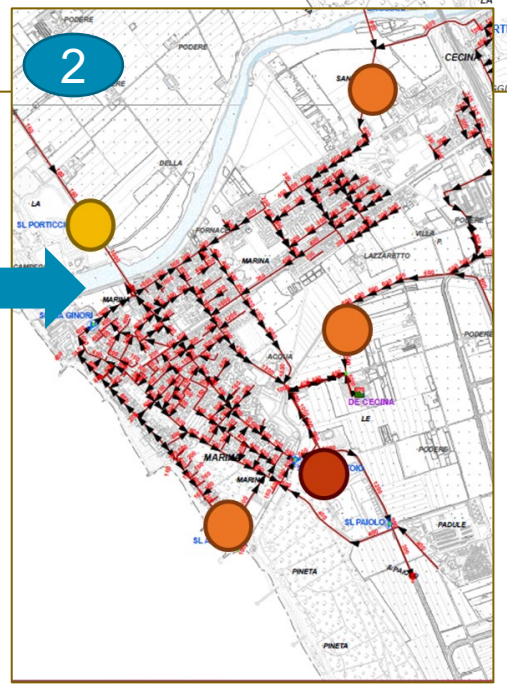
< 1800
1800-2000
2000-3000
3000-4000
> 4000

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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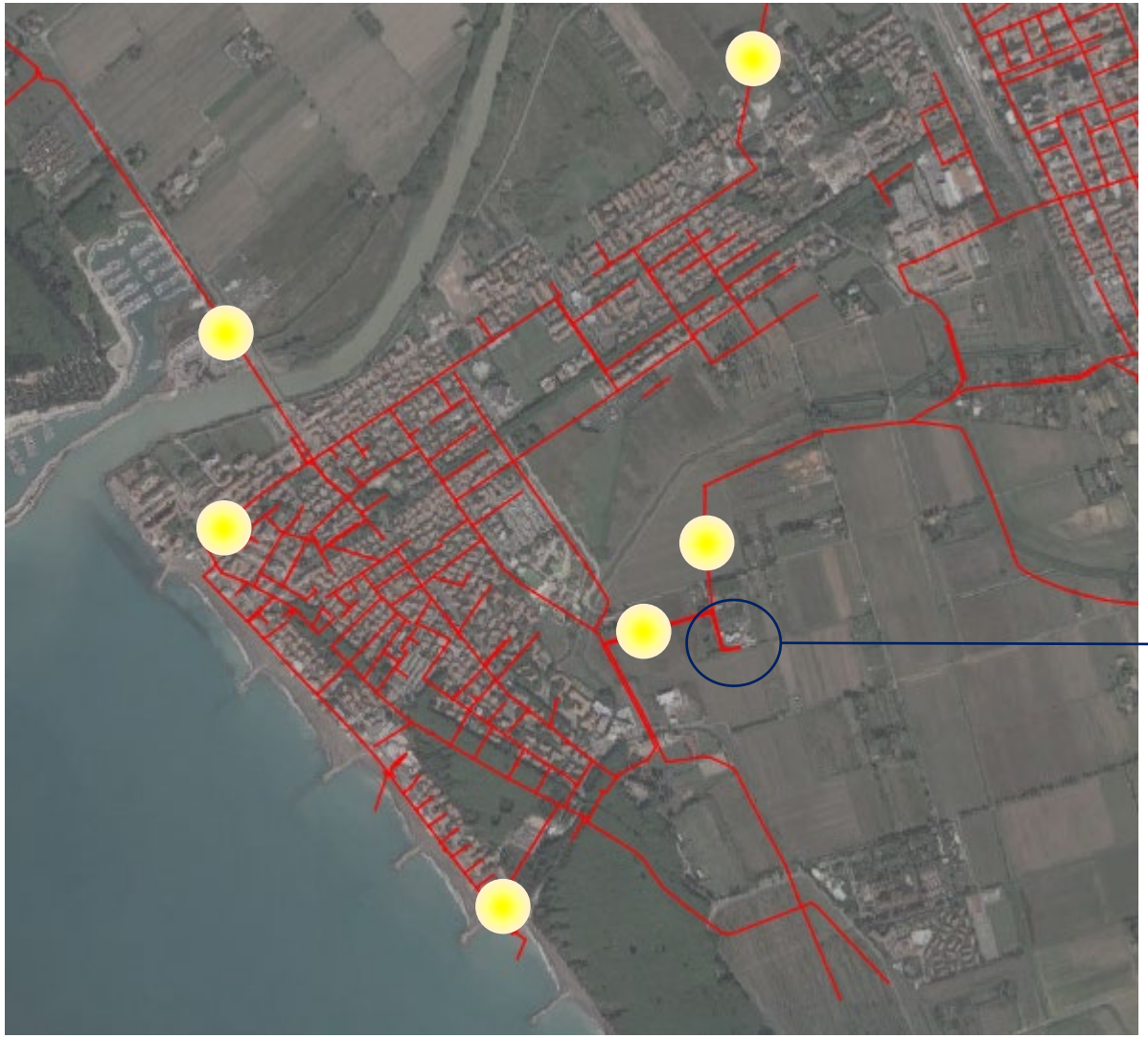
CECINA Sensor network



- ✓ 3 conductivity sensors in Cecina sewer network
- ✓ 4 flow sensors in Cecina sewer network
- ✓ 2 conductivity sensors at Cecina WWTP



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ROSIGNANO and ARETUSA Sensor network



Influent



ROSIGNANO WASTEWATER TREATMENT PLANT

Effluent

Influent



ARETUSA WASTEWATER REUSE PLANT

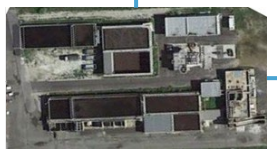
Effluent

- ✓ 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

Water and Waste Environmental Engineering
VEST Systems

Smart equalization before ARETUSA WWRP

Flow = 2458 ± 3241 m3/d
EC = 2661 ± 552 µS/cm
Surface water body


Rosignano WWTP

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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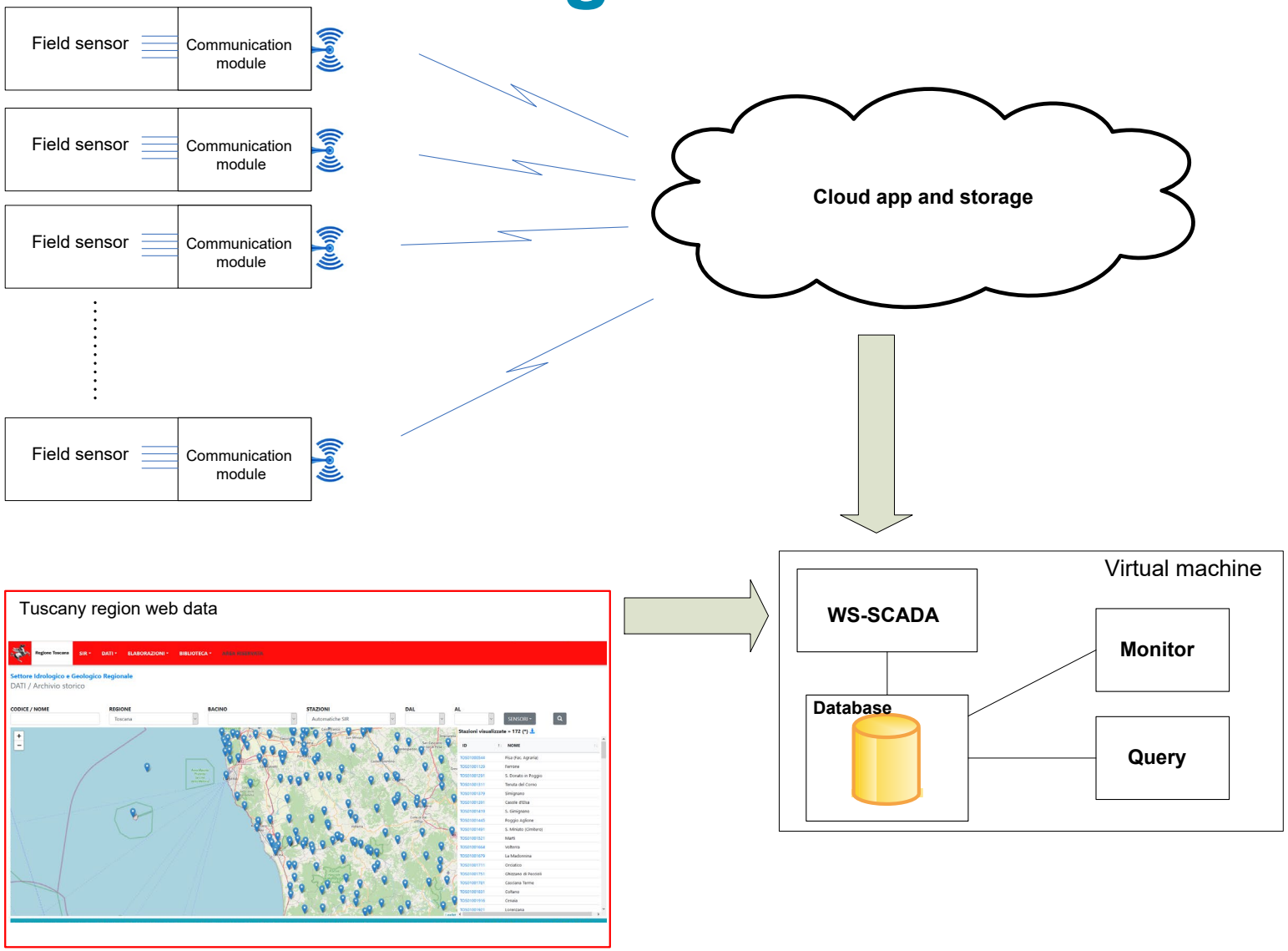
Real-time data monitoring



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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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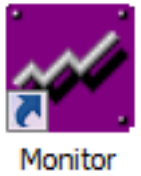
WS-SCADA software suite



WS-Scada (SCADA - *Supervisory Control And Data Acquisi*tion)



Monitor



Query

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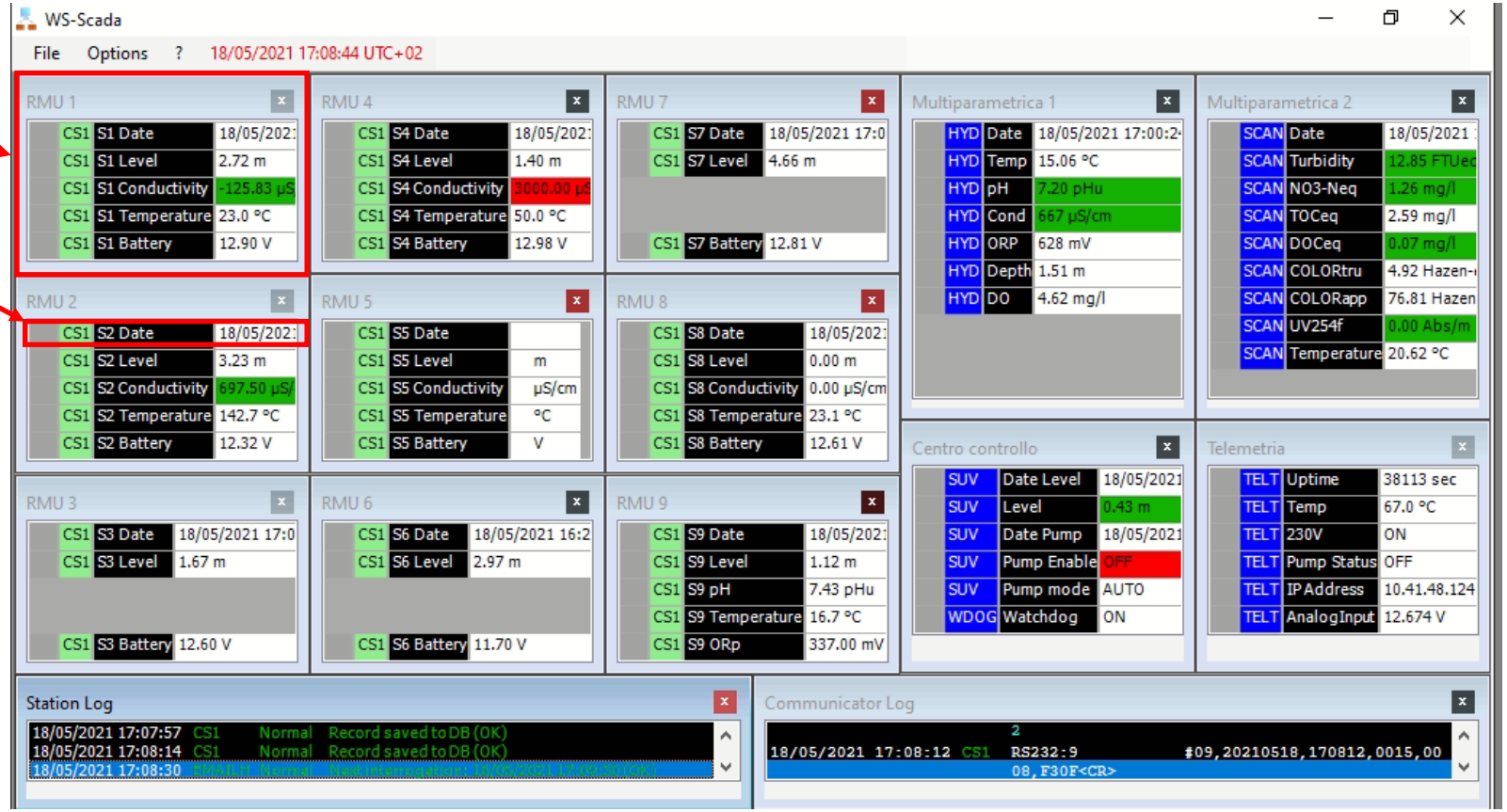
WS-SCADA software suite

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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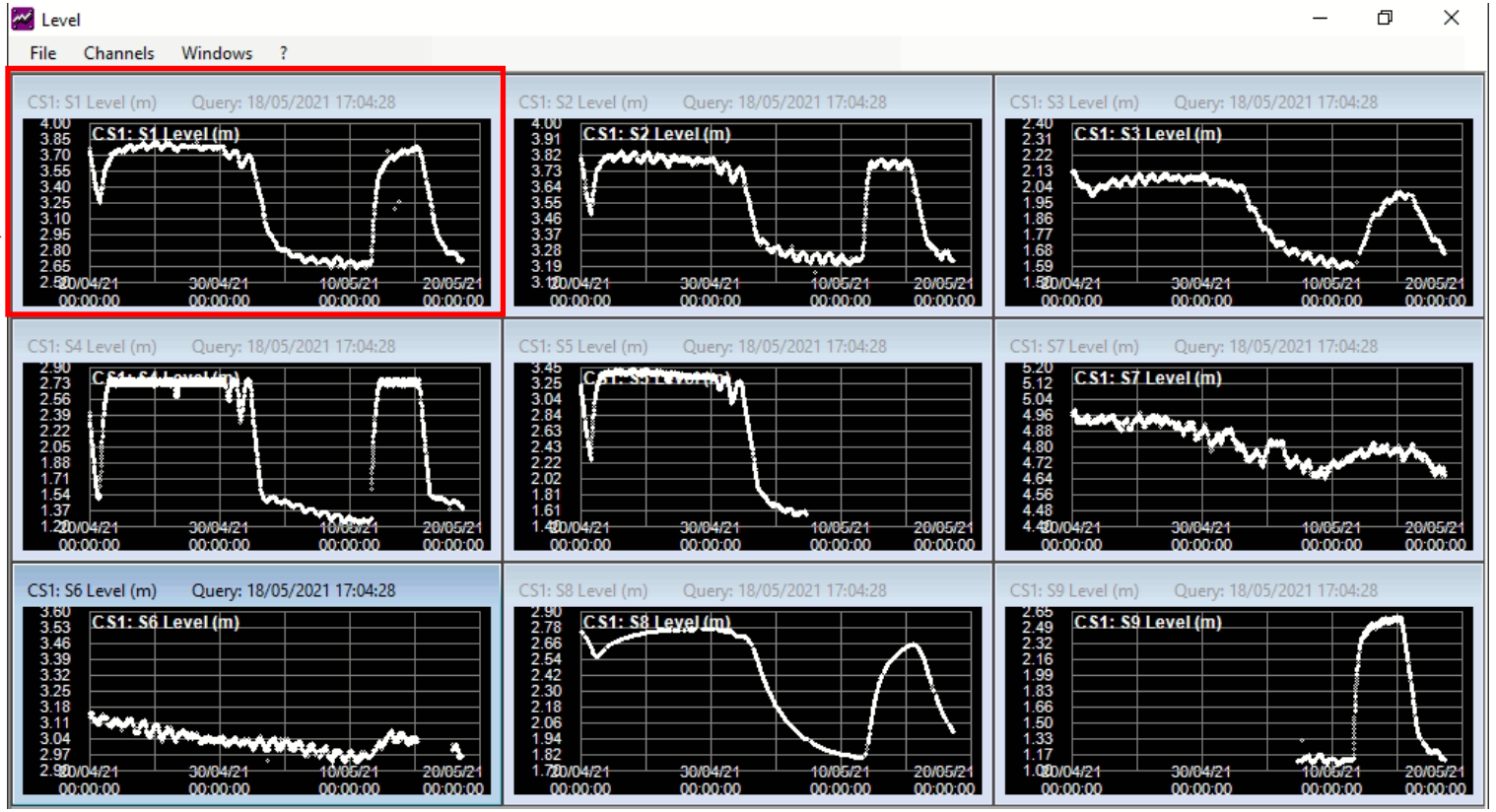
WS-SCADA monitor

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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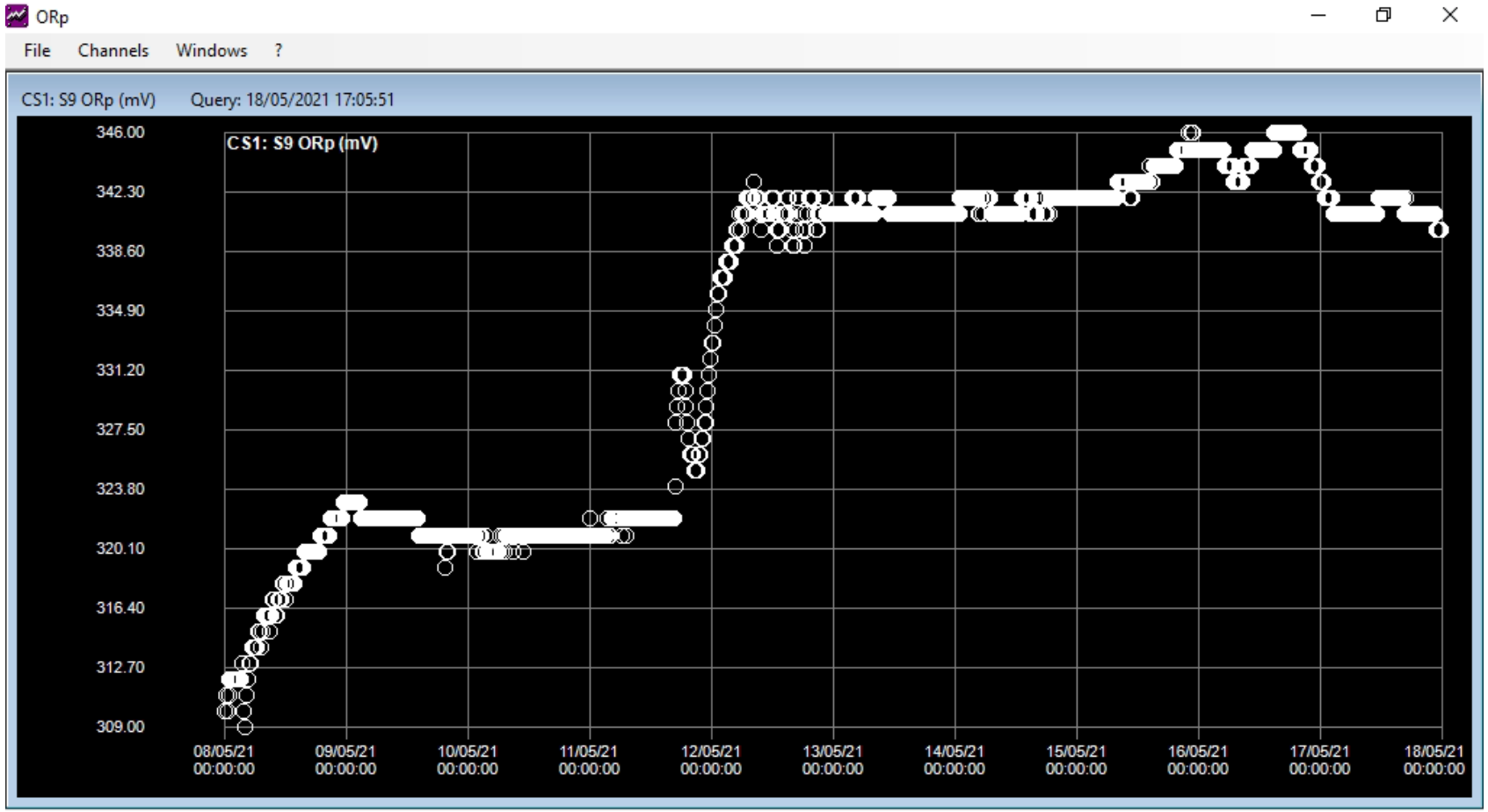
WS-SCADA monitor

Each dot on the plot represents the value of a single measurement stored in the database



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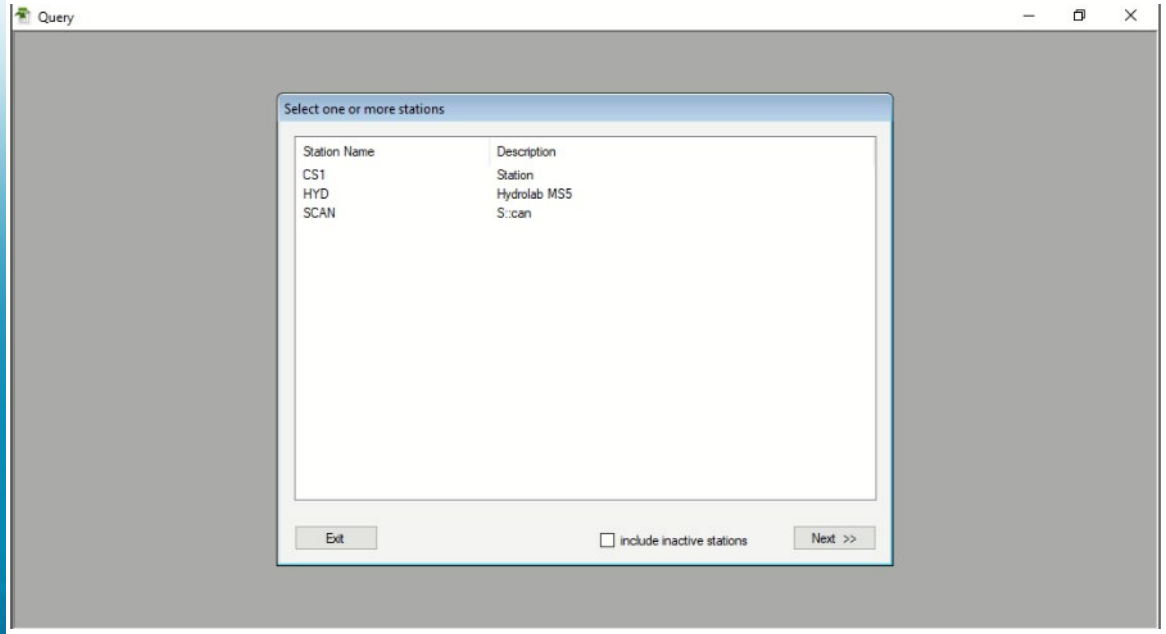
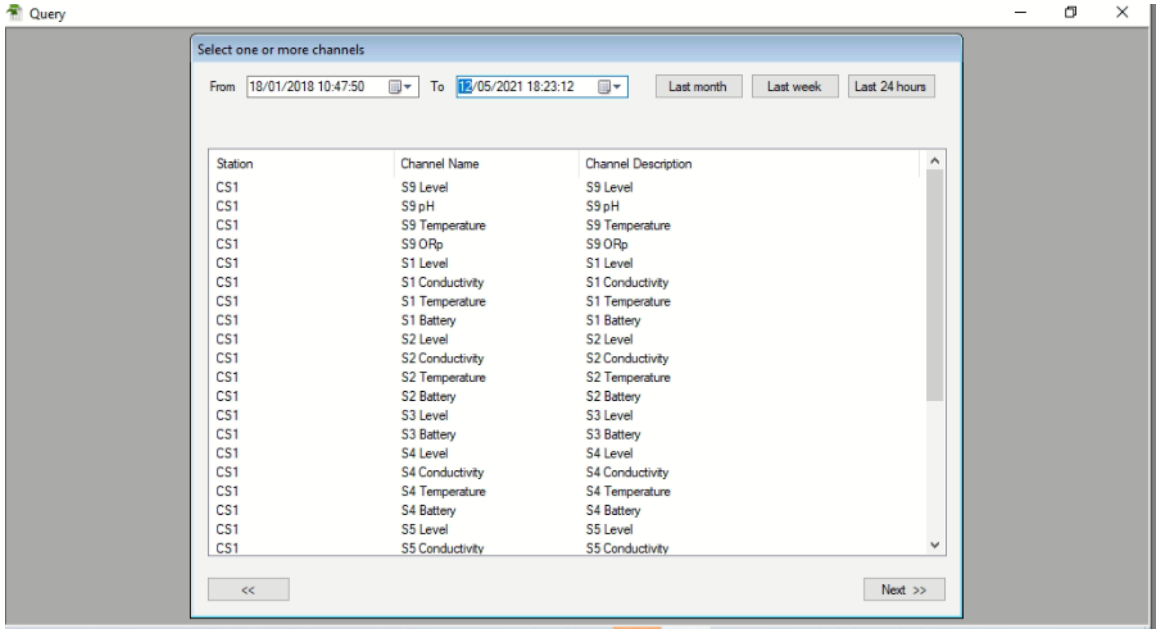
WS-SCADA query

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

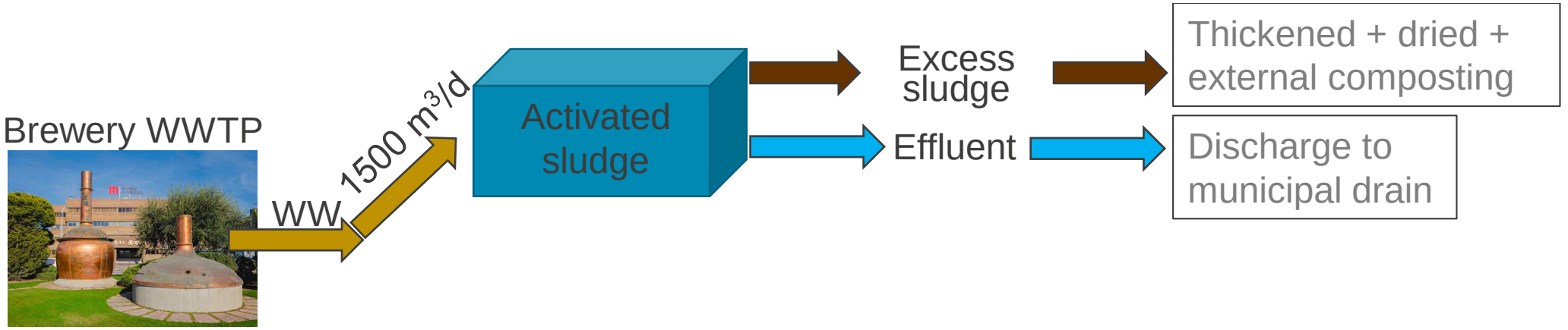
A. Giménez-Lorang

aqualia



20.05.2021 CS meeting on “Digitalization”

Case study nr. 5: baseline conditions



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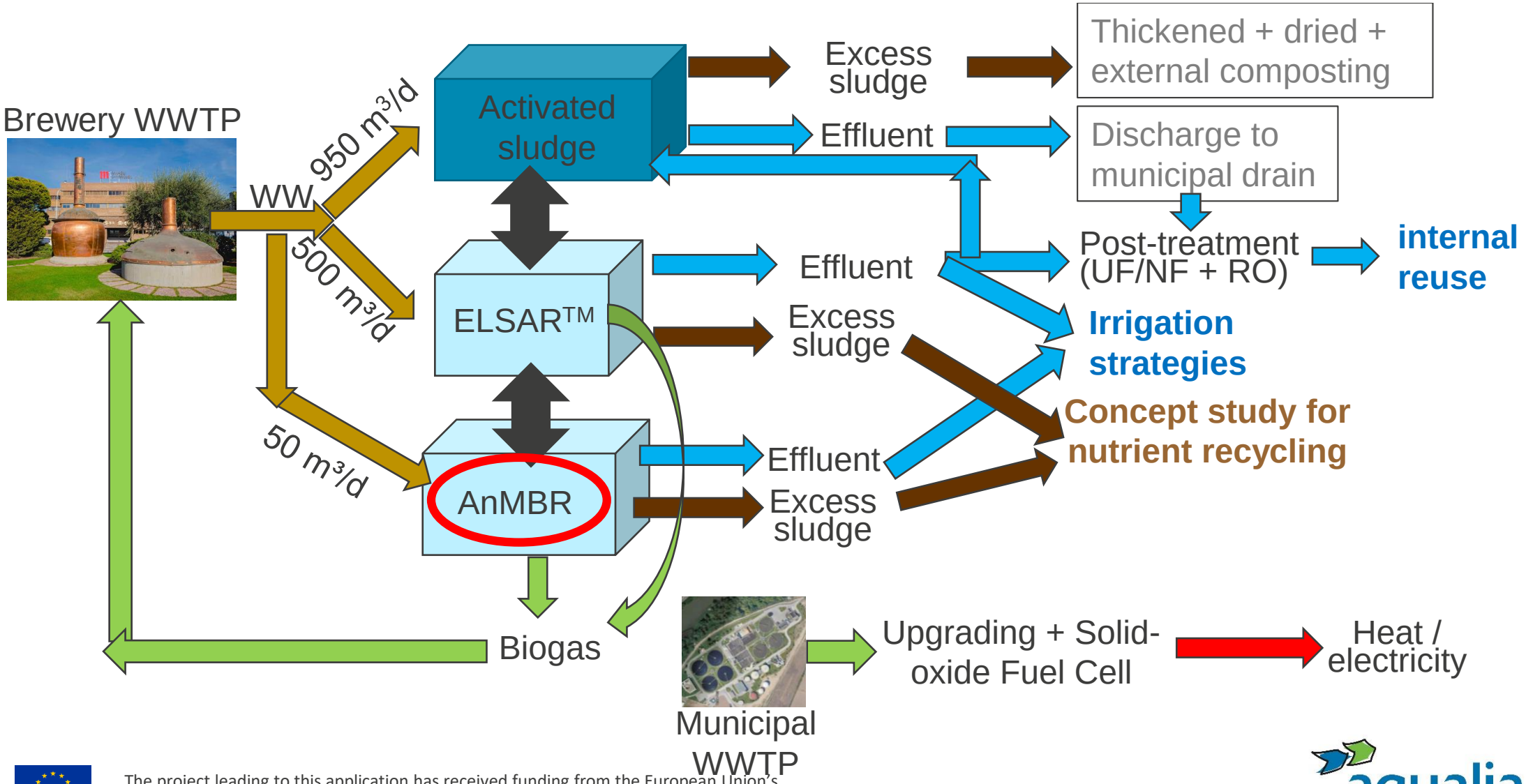
Case study nr. 5: ULTIMATE water-smart solution



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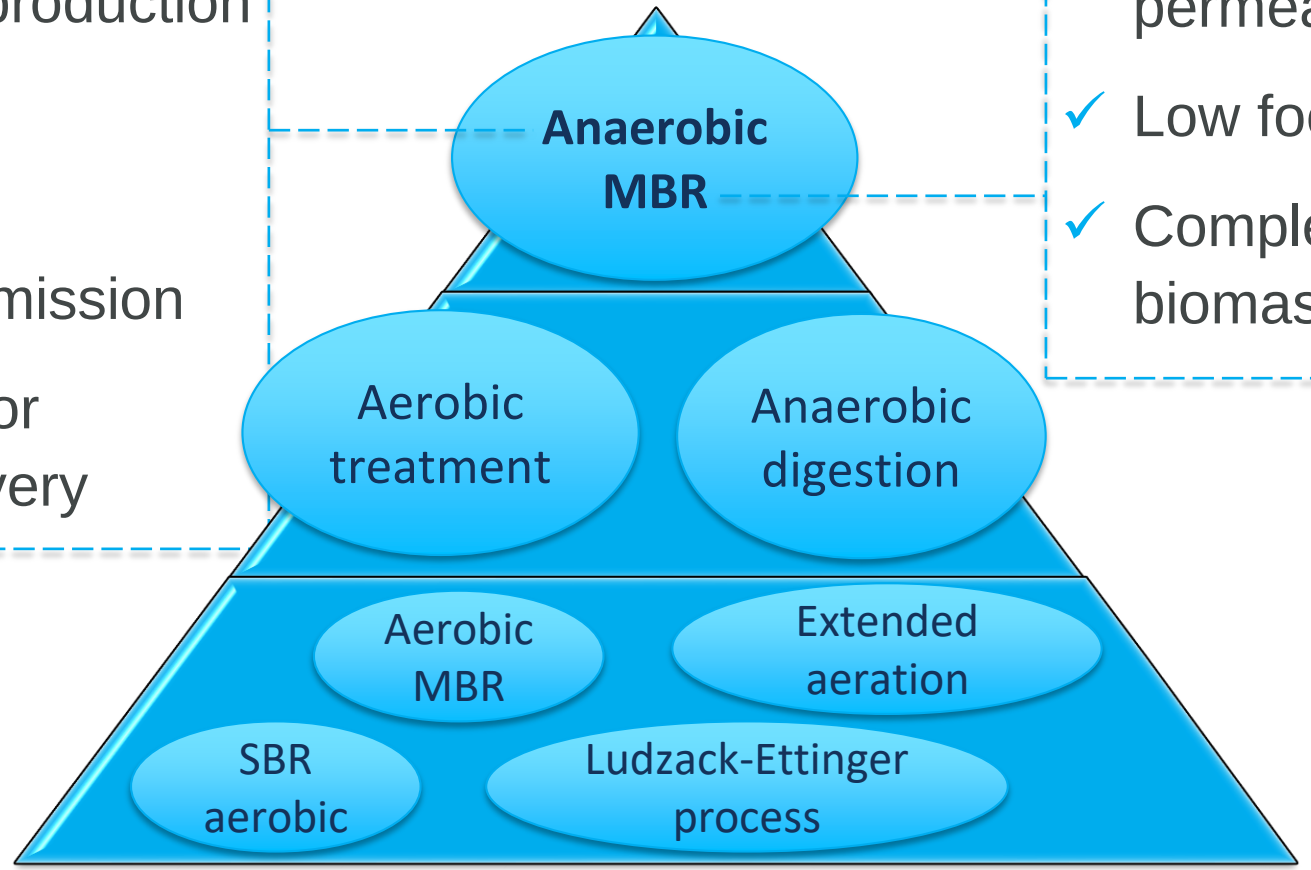
Why AnMBR?

- ✓ 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

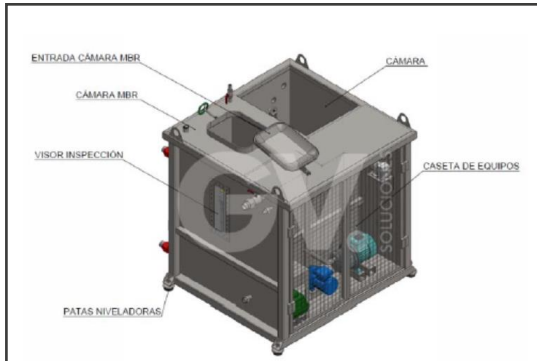
www.life-methamorphosis.eu



www.life-memory.eu



http://eranetbestf.eu/call/bestf2/project-results/biowamet/



www.run4life-project.eu



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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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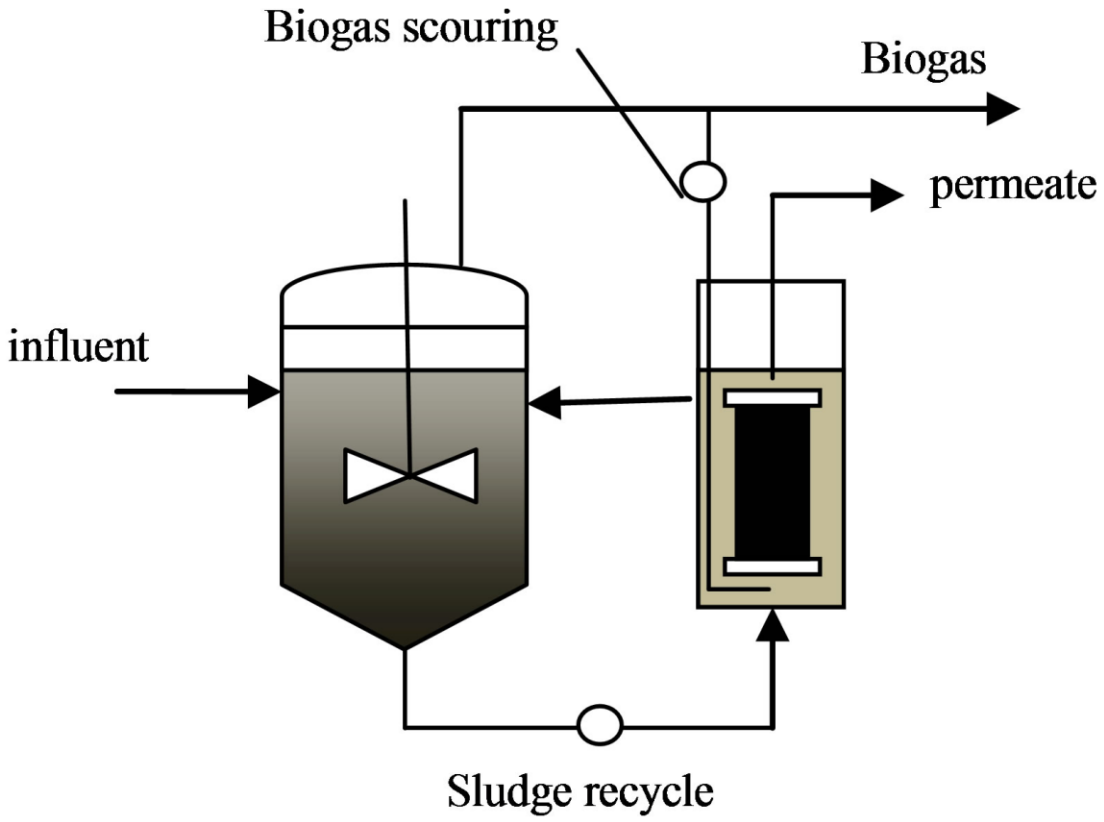
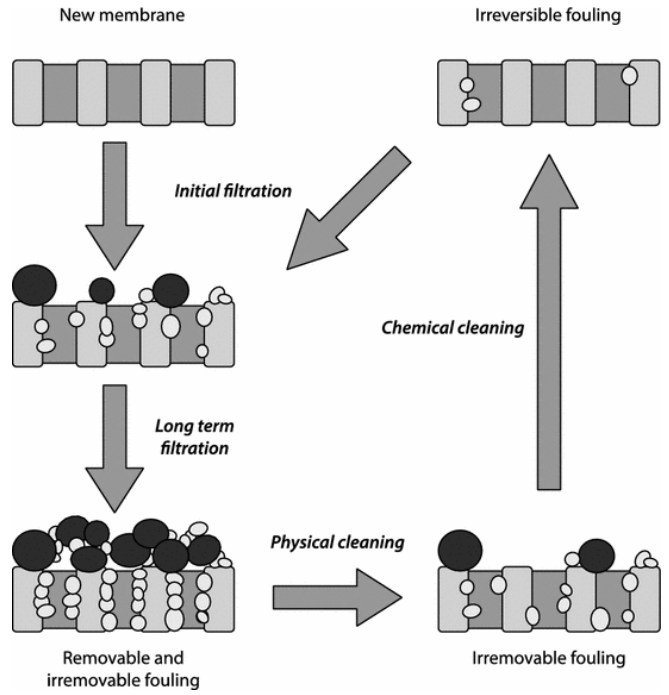
What we know from fouling… in a few words



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.



Advances in Chemical Engineering and Science
Vol.4 No.1(2014), Article ID:42423,6 pages DOI:10.4236/aces.2014.41008

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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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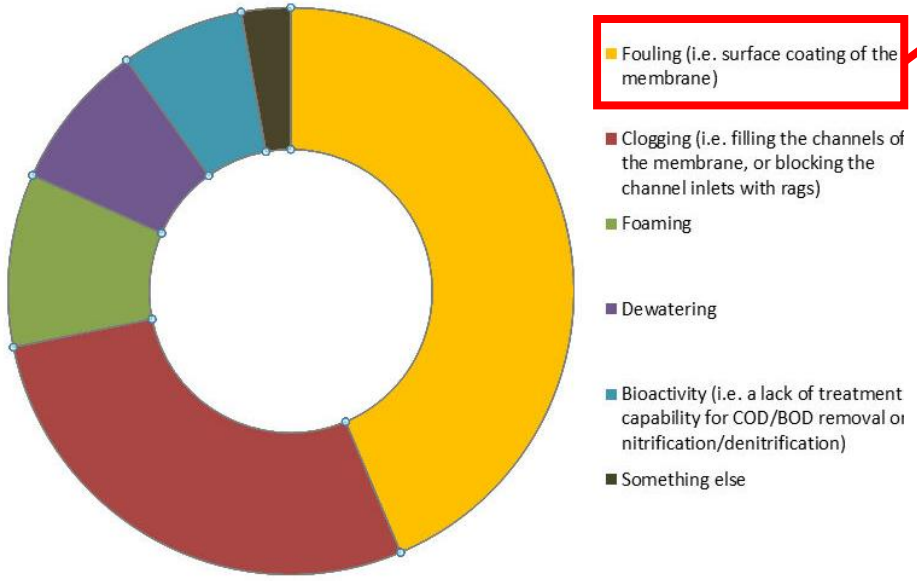
What's important about fouling (II)

- **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

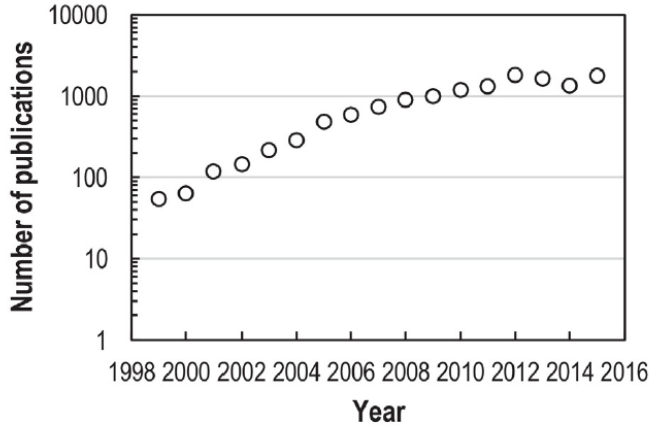


Fig. 1. The annual publications on MBR fouling (google scholar as literature database).

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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- **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.

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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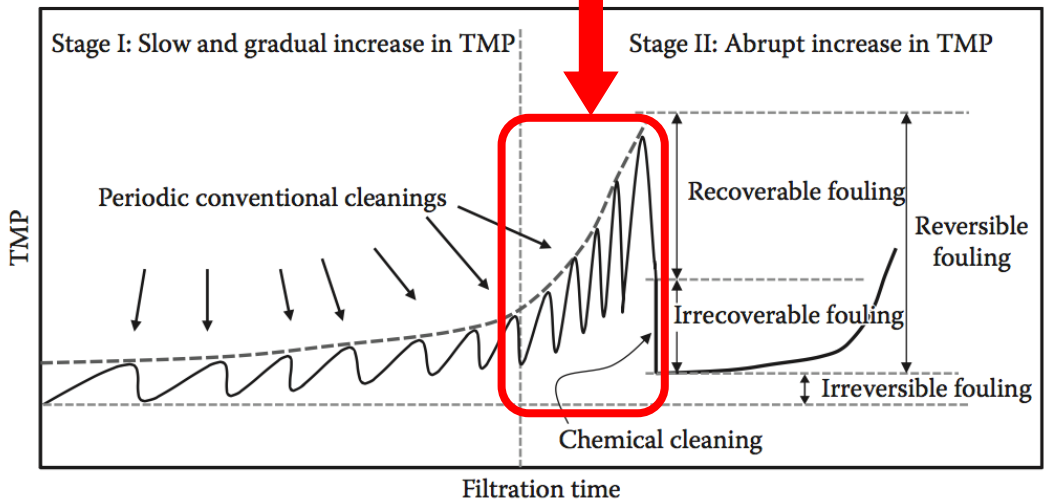
Advantages of monitoring sludge filterability (II)

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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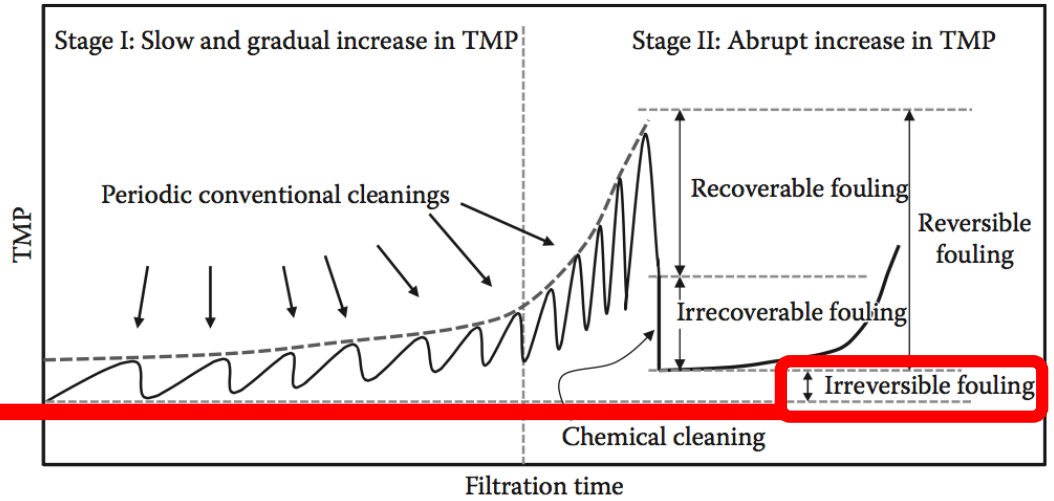
Advantages of monitoring sludge filterability (III)

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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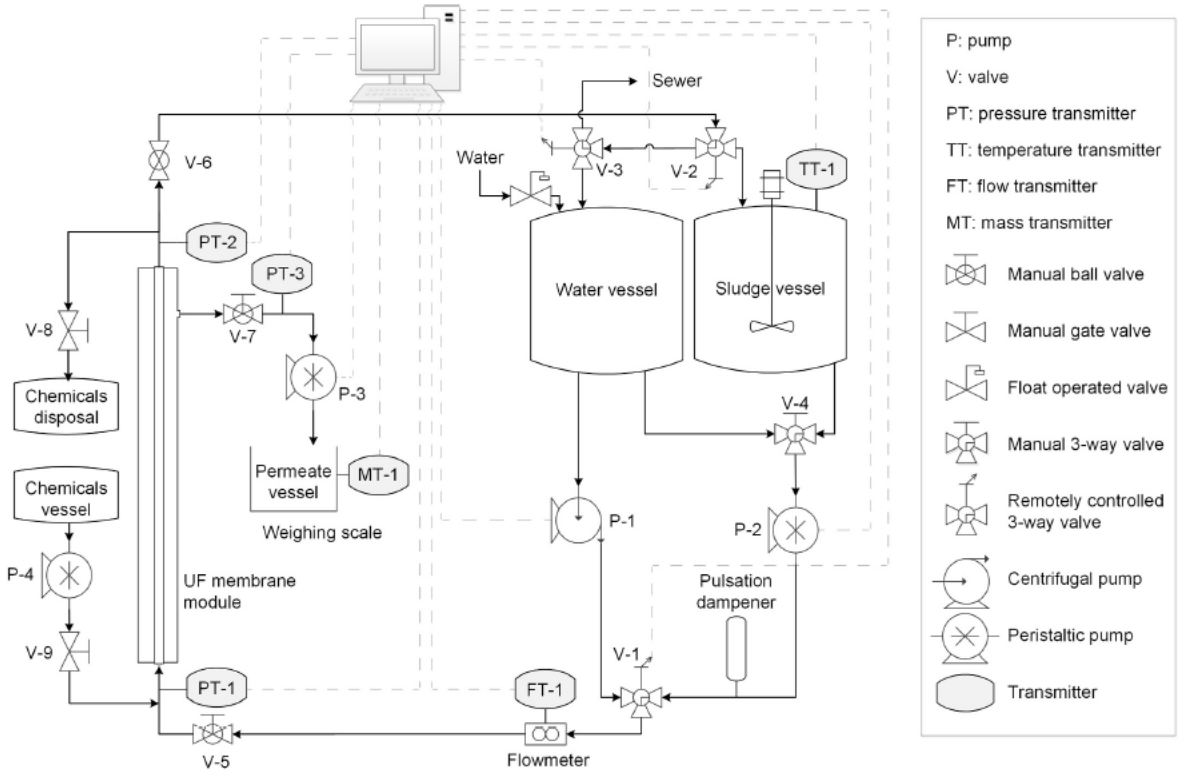
How we will do that? (I)

- Build & commissioning of the plant
  - Mobile (ex-situ), plug&play
  - Automatic
  - Integrable to SCADA

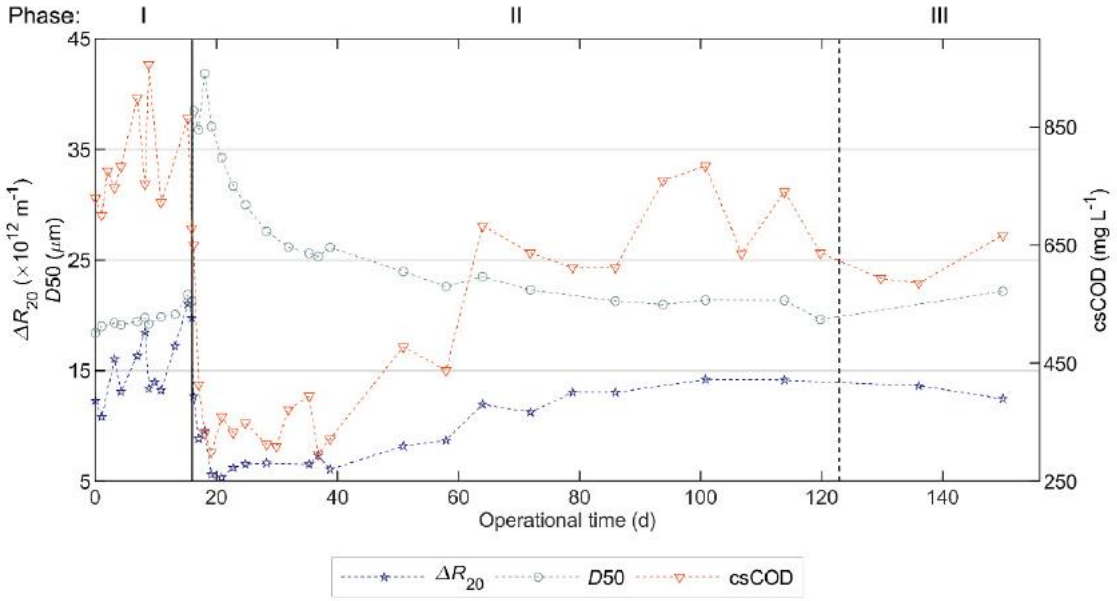


Odriozola M, Lousada-Ferreira M, Spanjers H, van Lier JB (2021). Effect of sludge characteristics on optimal required dosage of flux enhancer in anaerobic membrane bioreactors. Journal of Membrane Science 619 (2021) 118776

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

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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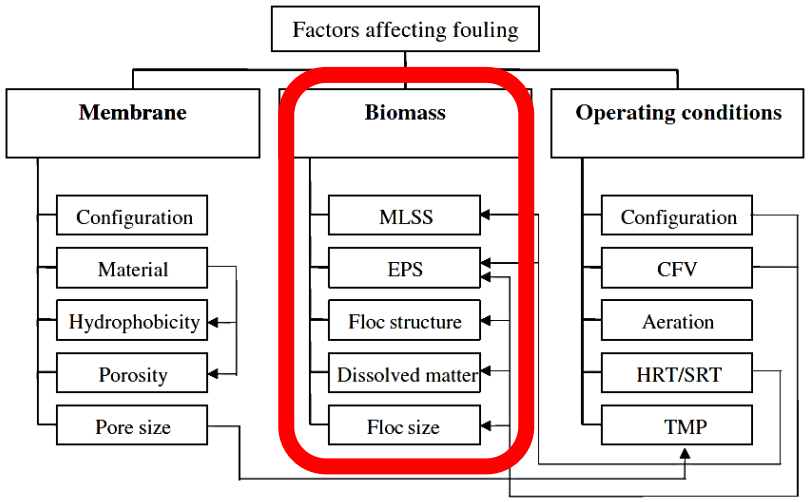
MBR + adsorbents → better filterability (I)

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)

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MBR + adsorbents → better filterability (II)

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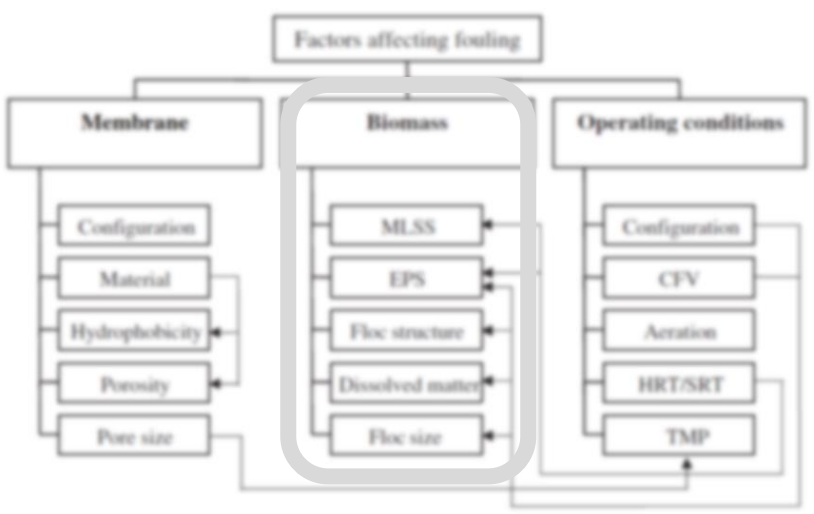
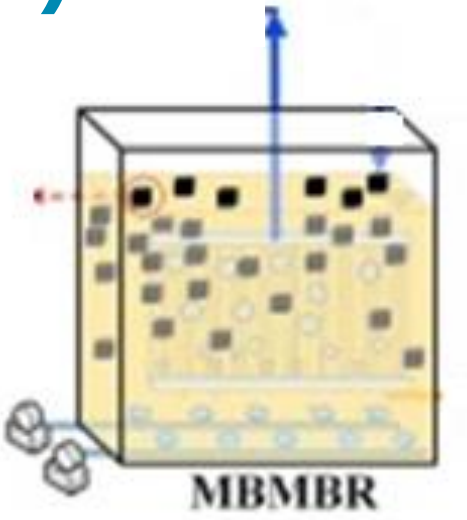


WHY ADD ACTIVATED CARBON IN A MBR?

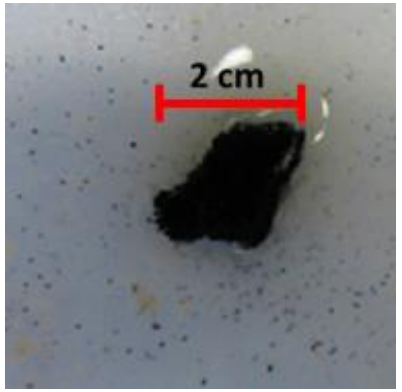
- Floc size increase
- Adsorption of soluble microbial products
- Micro-pollutant adsorption

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
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

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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”

ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

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)



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

CS9 in Kalundborg (Denmark)



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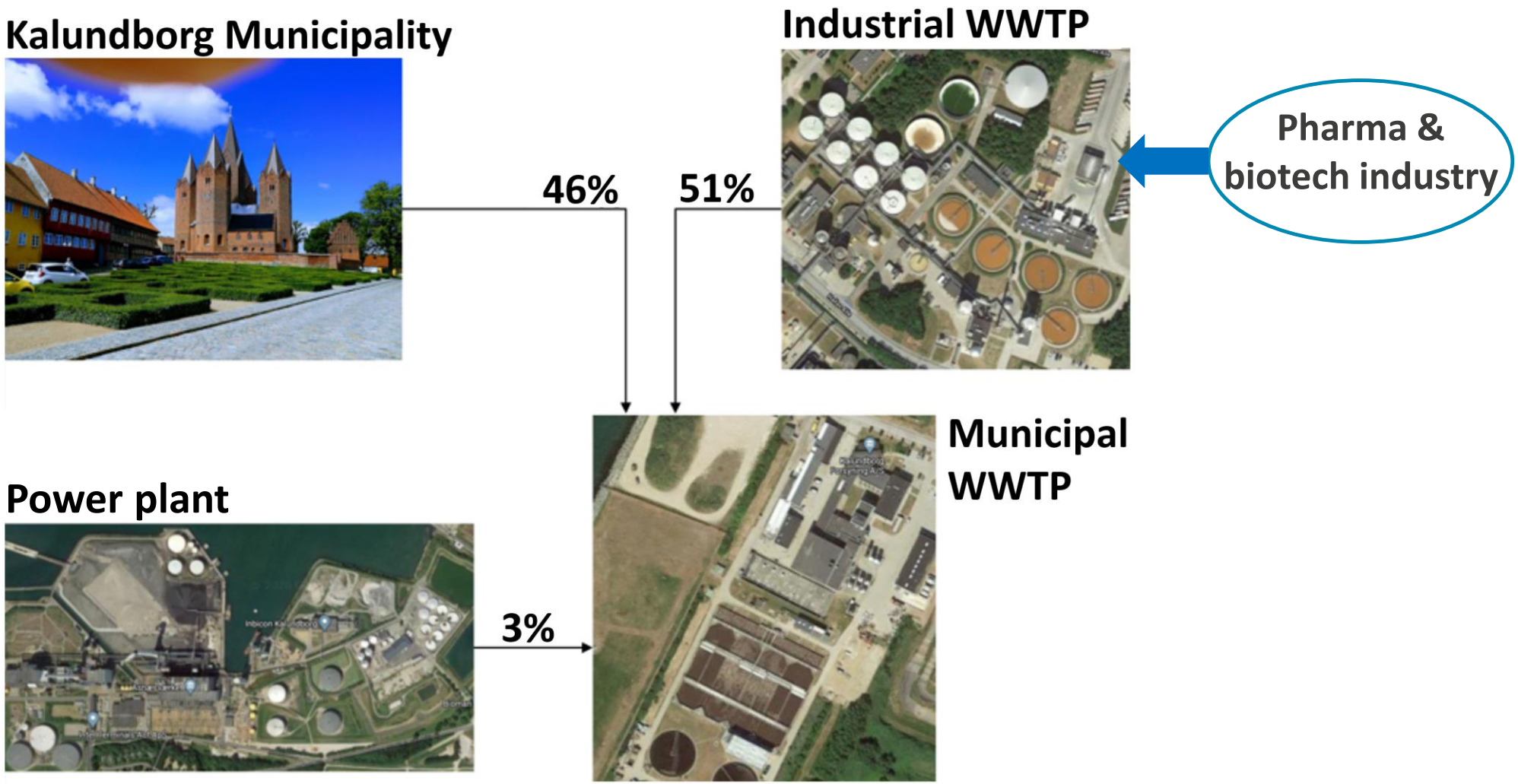
Situation at the start of Ultimate



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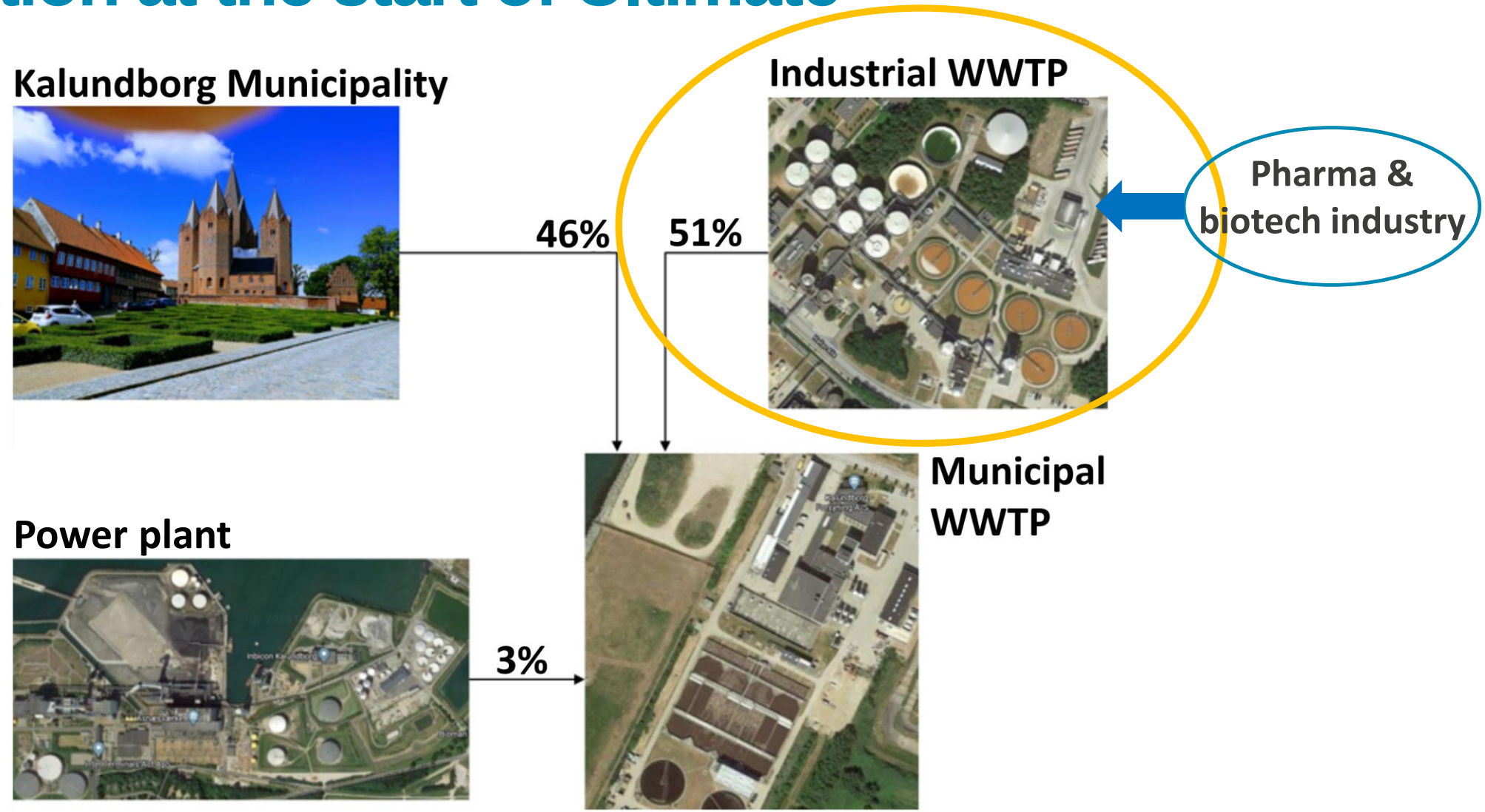
Situation at the start of Ultimate



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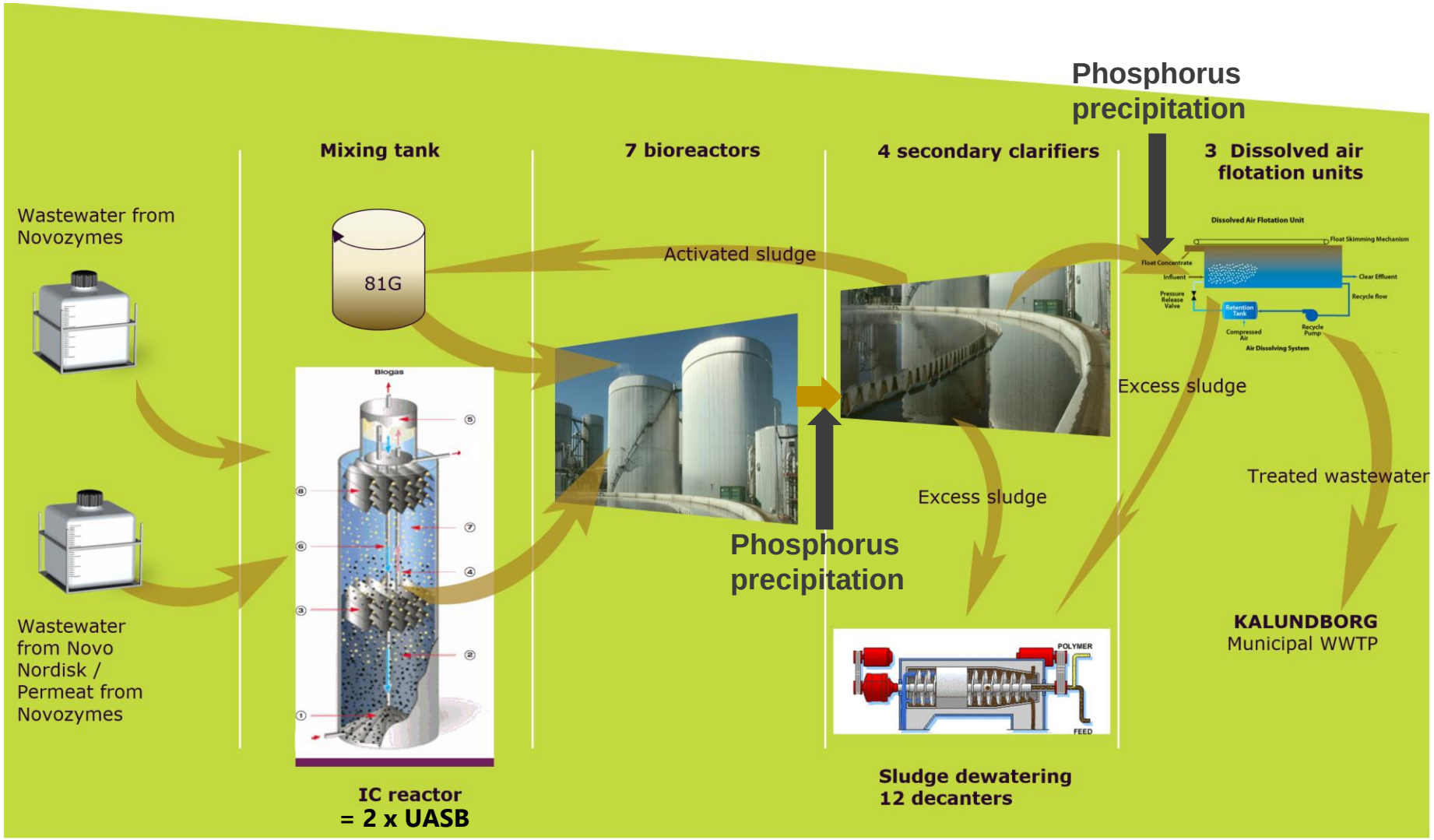
Industrial wastewater treatment plant:
own control system & chemical phosphorus removal



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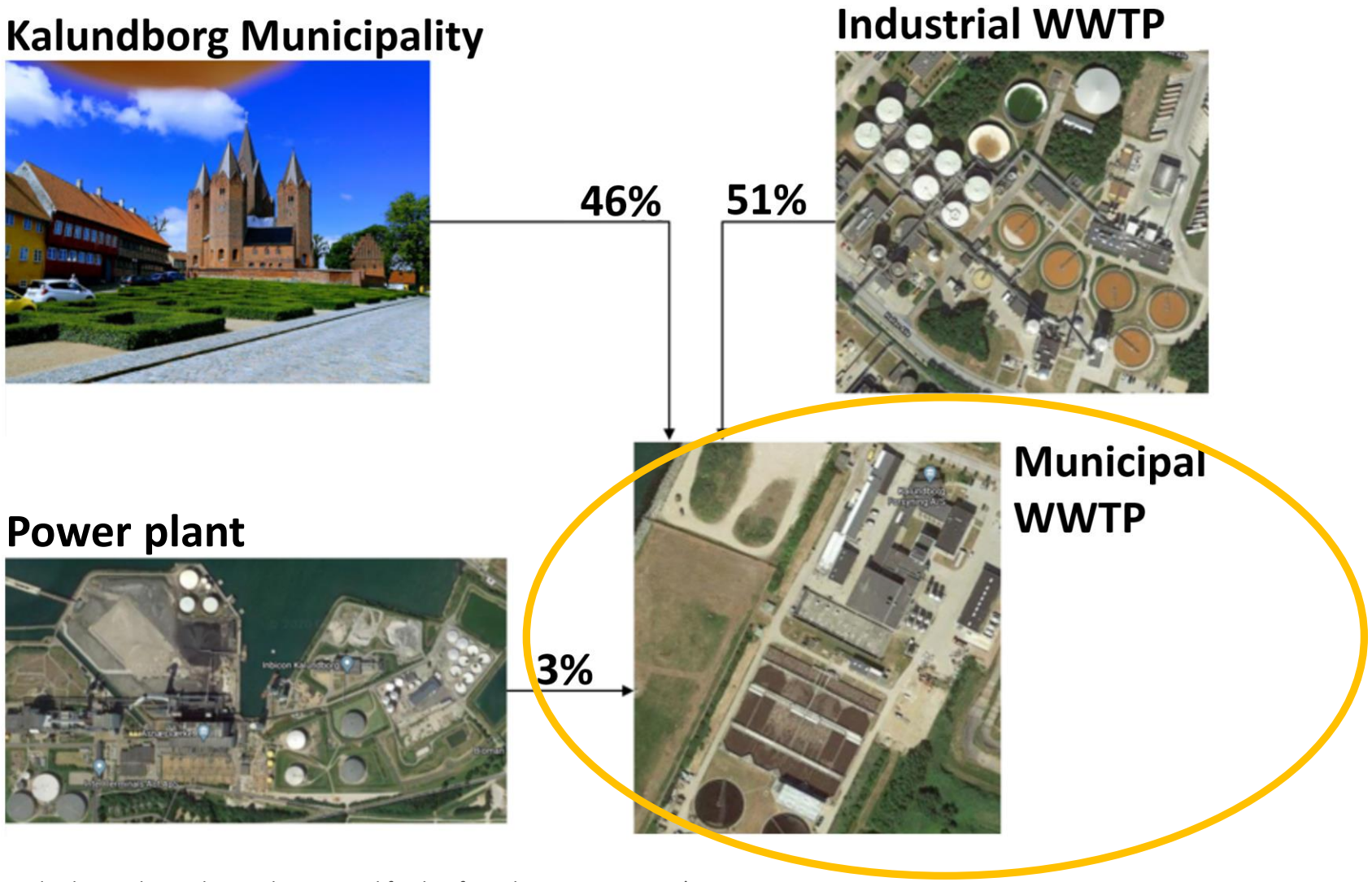

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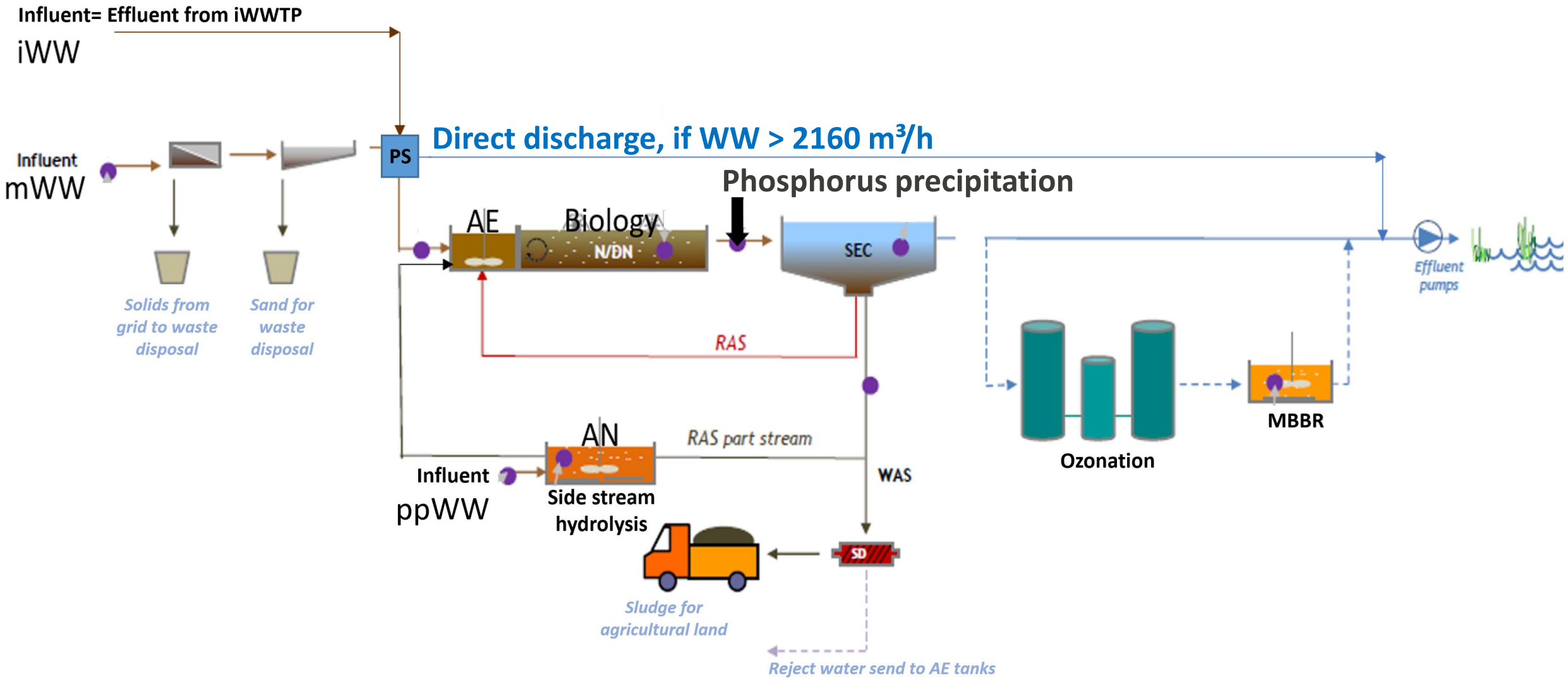
Municipal wastewater treatment plant:
own control system & chemical phosphorus removal



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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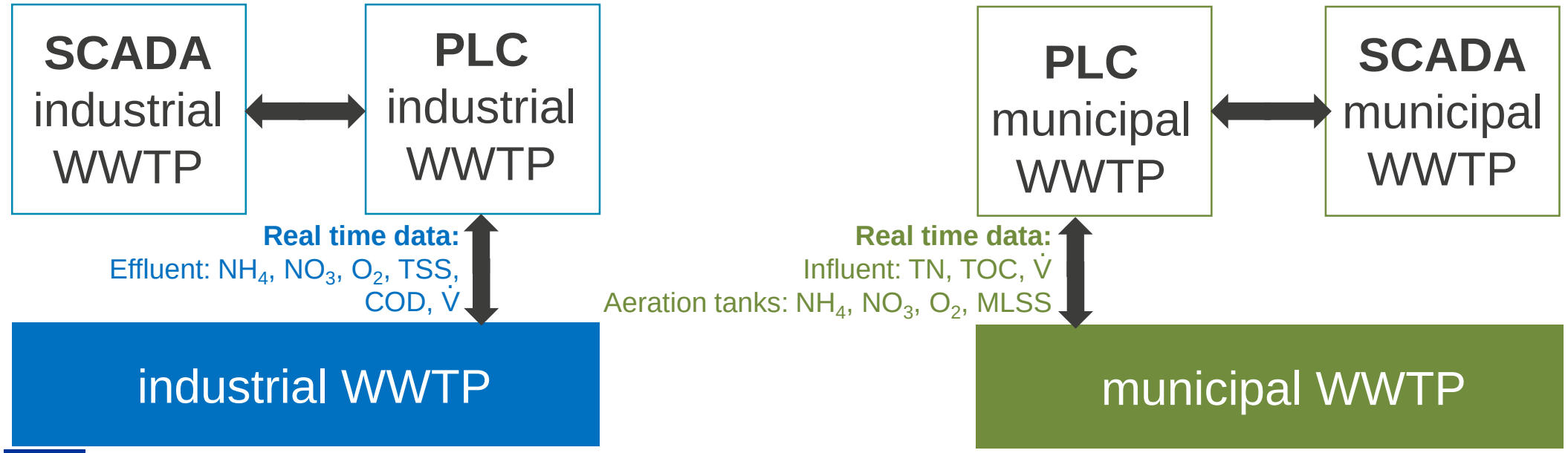
Joint Control System

SCADA	Supervisory Control and Data Acquisition
RTU	Remote Terminal Unit
PLC	Programmable Logic Controller
WWTP	Wastewater Treatment Plant



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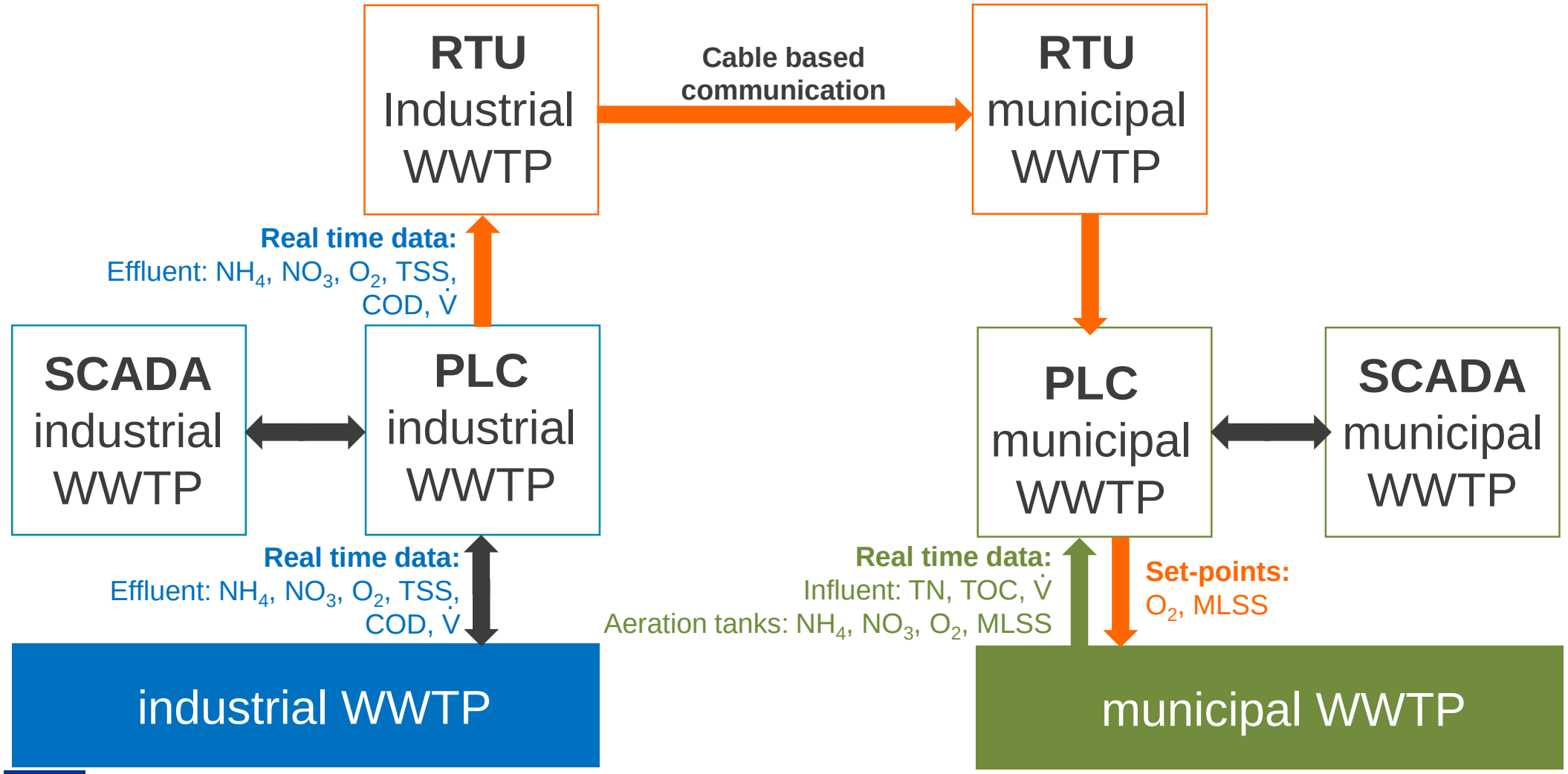

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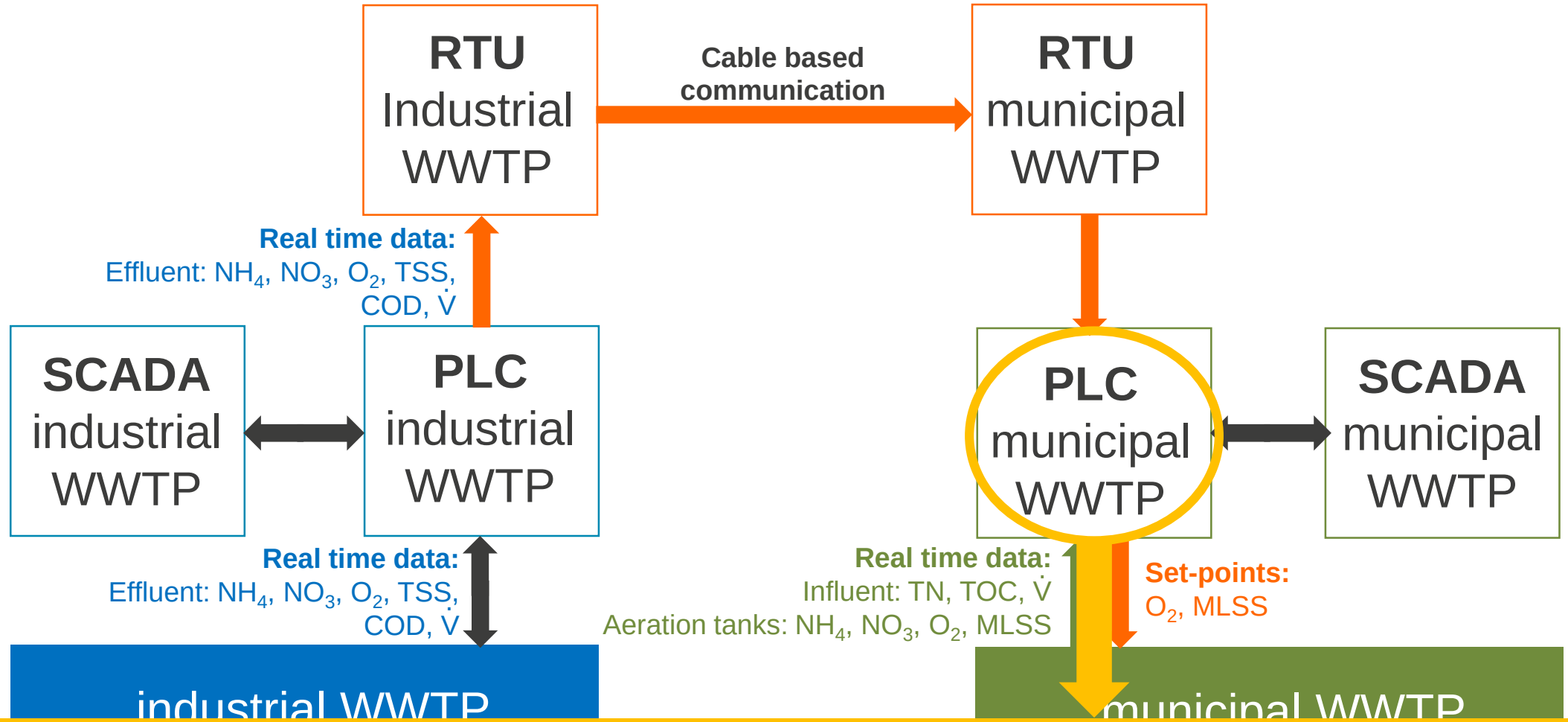

Which functions have to be implemented

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

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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, ✓
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- 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
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- Improved control-concept
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Digital twin

- Final set-up
- Improved model

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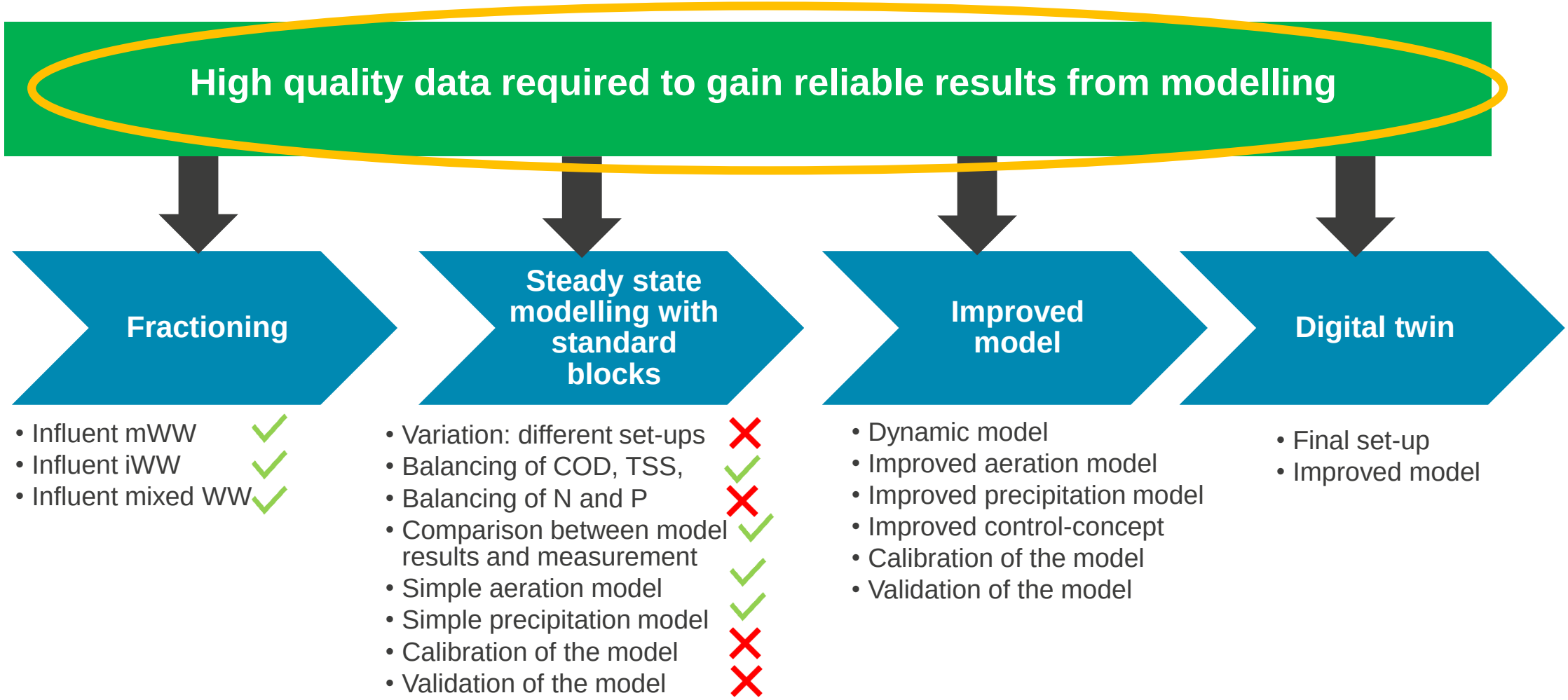
Development of digital twin:



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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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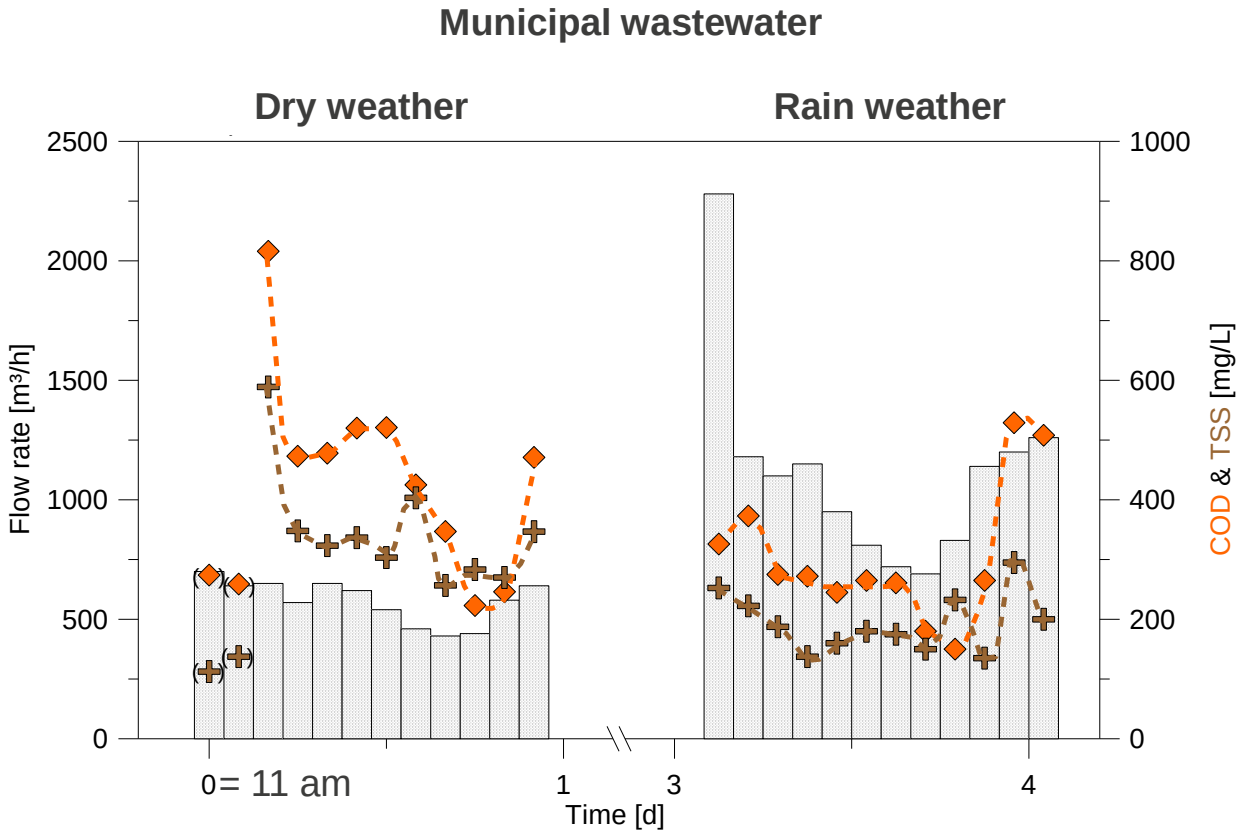
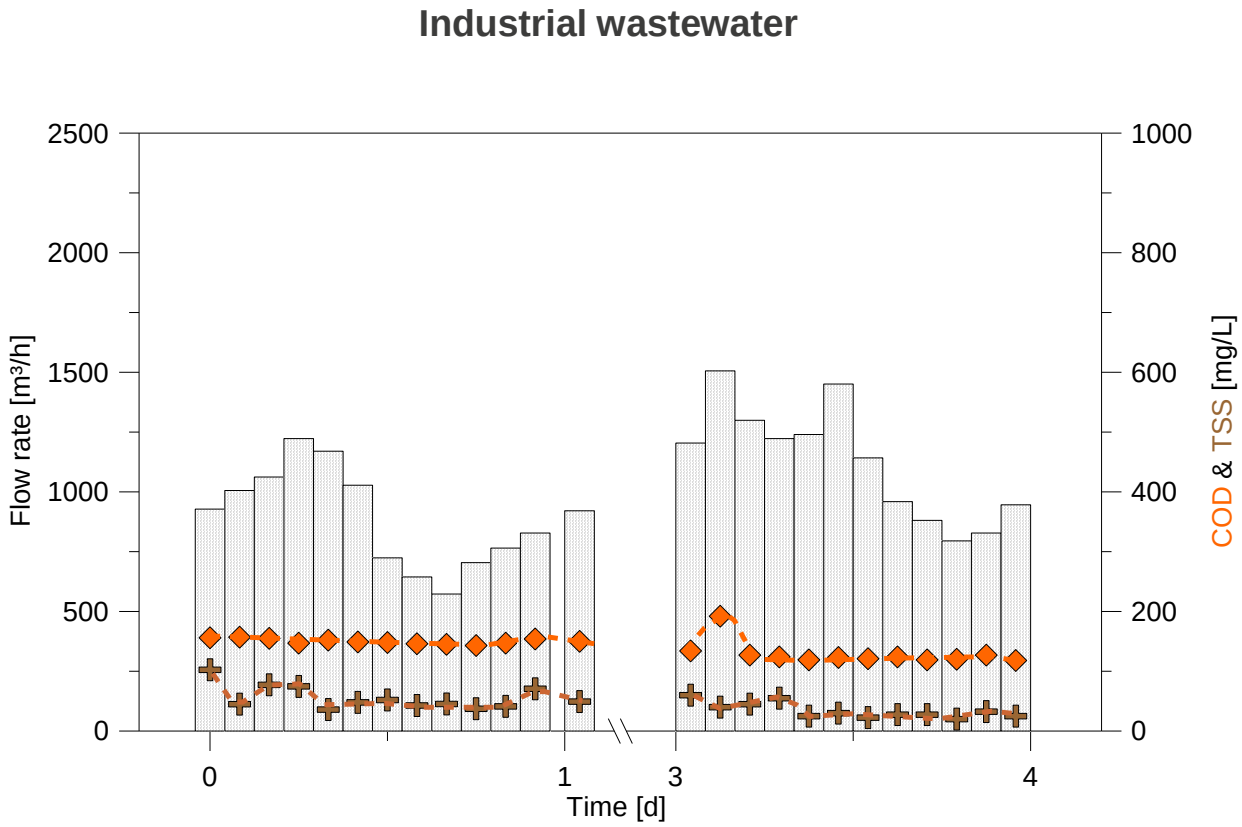
Measuring campaign to determine the diurnal variation Chemical oxygen demand & Total suspended solids





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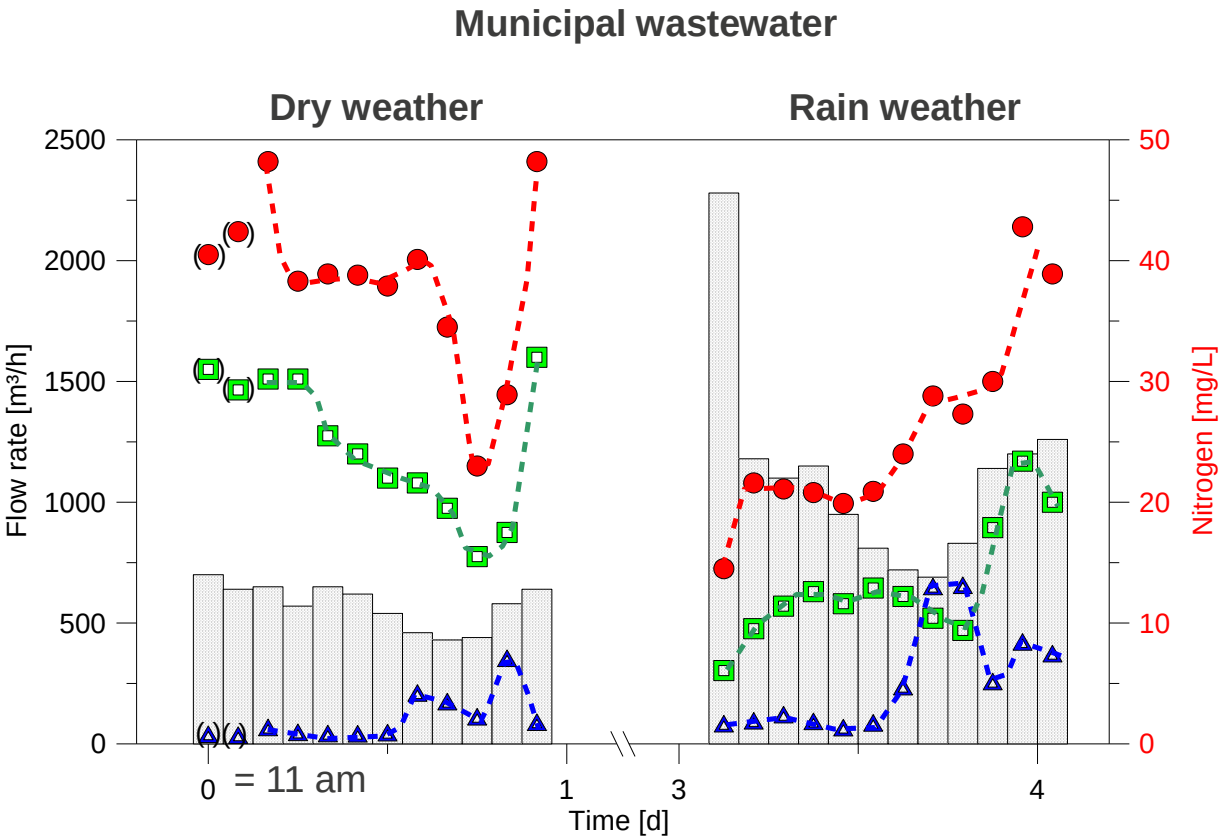
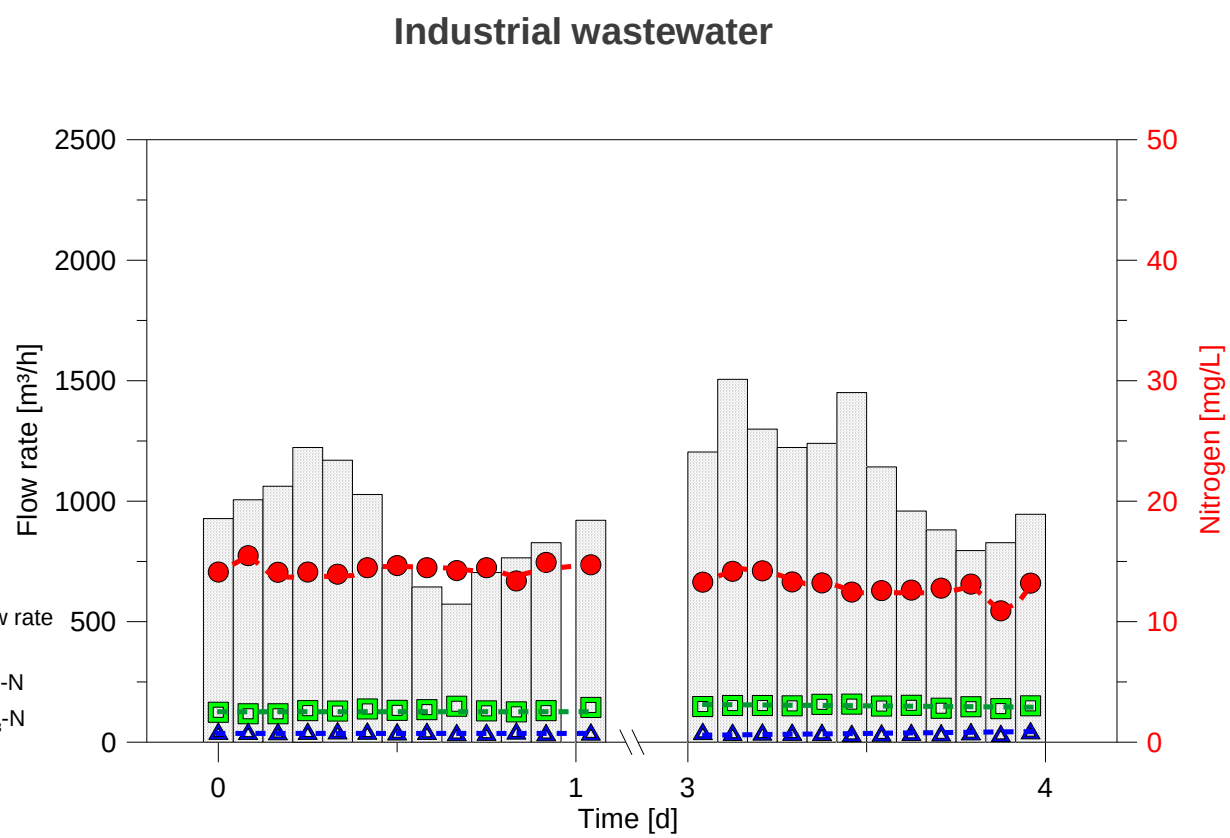
Measuring campaign to determine the diurnal variation
Total nitrogen, Ammonium, Nitrate





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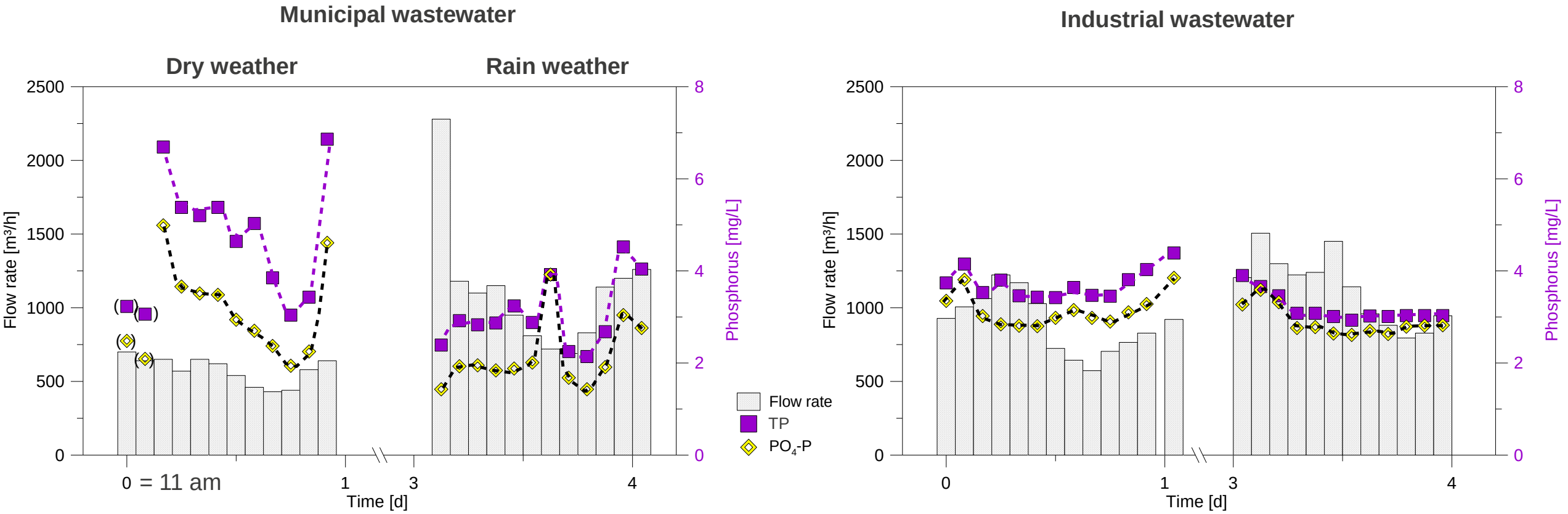
Measuring campaign to determine the diurnal variation Total phosphorus & Phosphate



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Development of digital twin:

High quality data required to gain reliable results from modelling

Fractioning

- Influent mWW ✓
- Influent iWW ✓
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Steady state modelling with standard blocks

- Variation: different set-ups ✗
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- Comparison between model results and measurement ✓
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- Simple precipitation model ✓
- Calibration of the model ✗
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Improved model

- Dynamic model
- Improved aeration model
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Digital twin

- Final set-up
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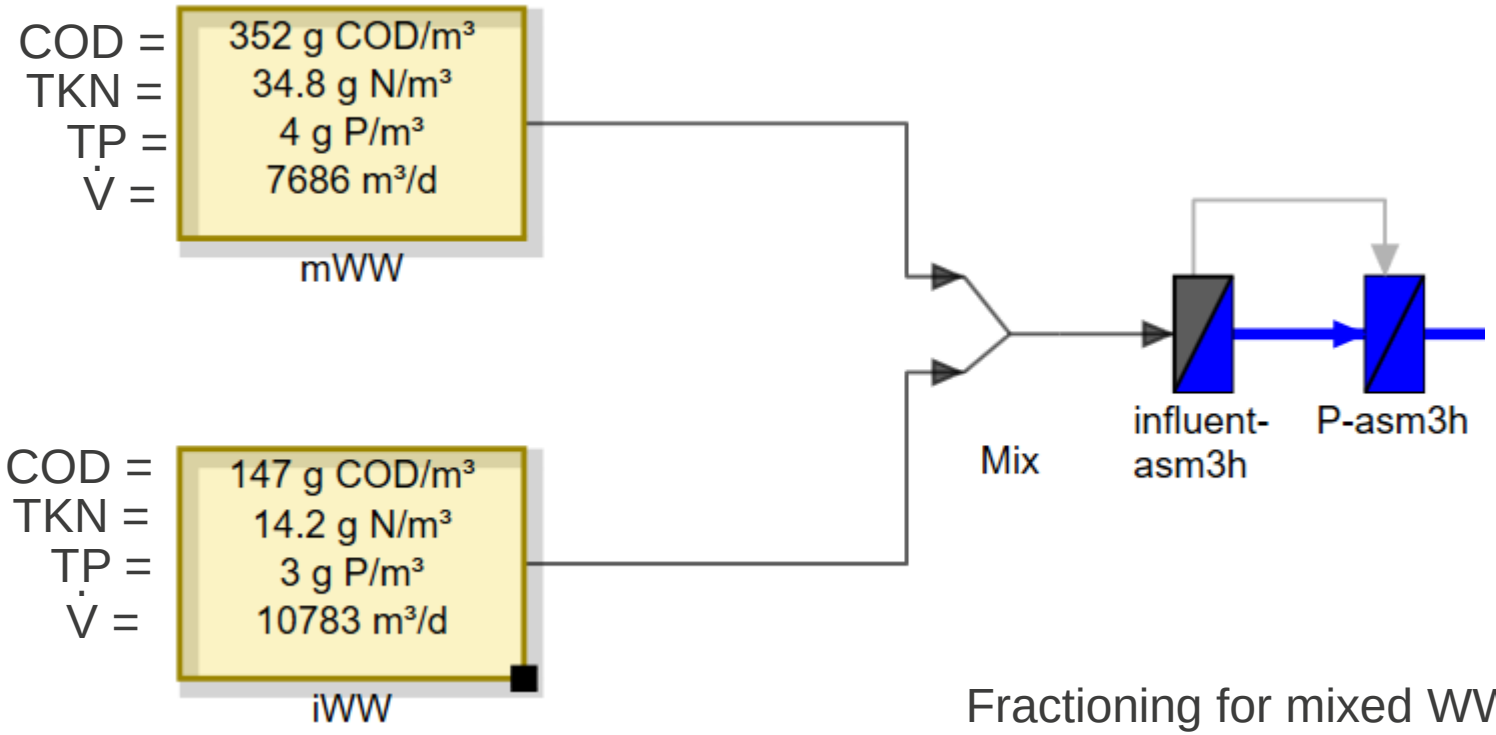
Modelling: Fractioning parameter



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:

f_S = 0.215

f_B = 0.265

f_A = 0.70

ratio of COD to VSS = **1.56** g COD /(g TSS)

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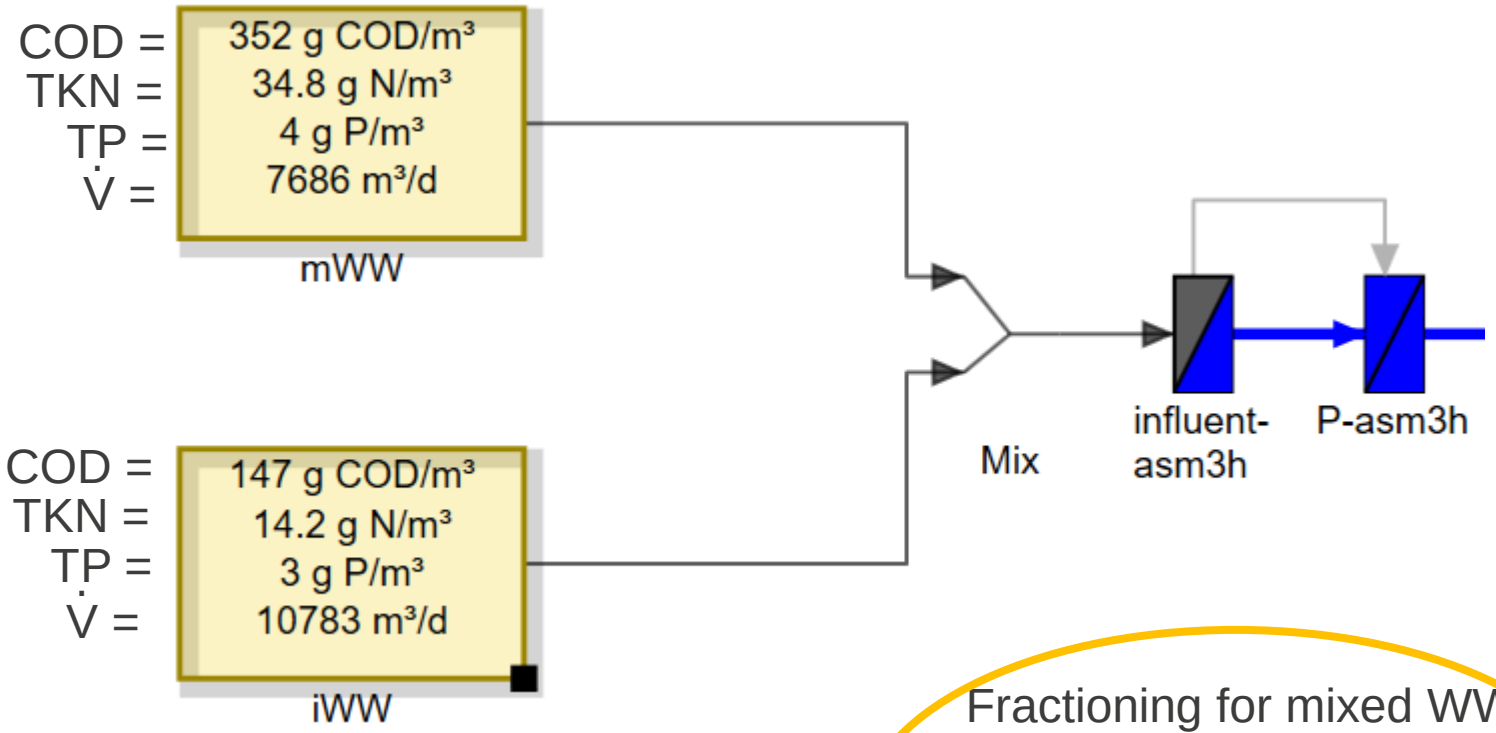
Modelling: Fractioning parameter



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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

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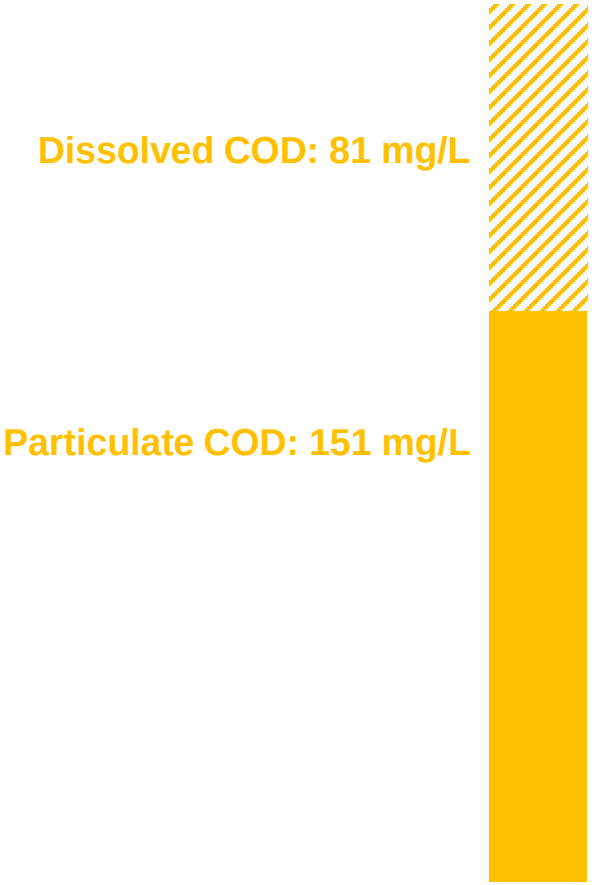

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25

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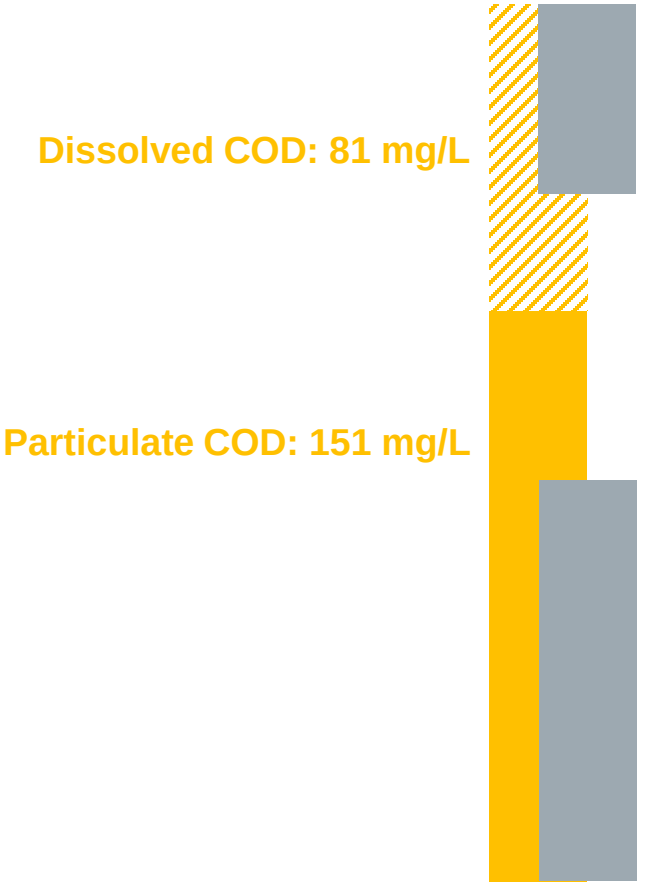

Dissolved inert COD: 50 mg/L
(f_S=0.215 of total COD)

Particulate inert COD: 106 mg/L
(f_A=0.7 of particulate COD)

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26

Fractioning of the influent mix: municipal & industrial WW

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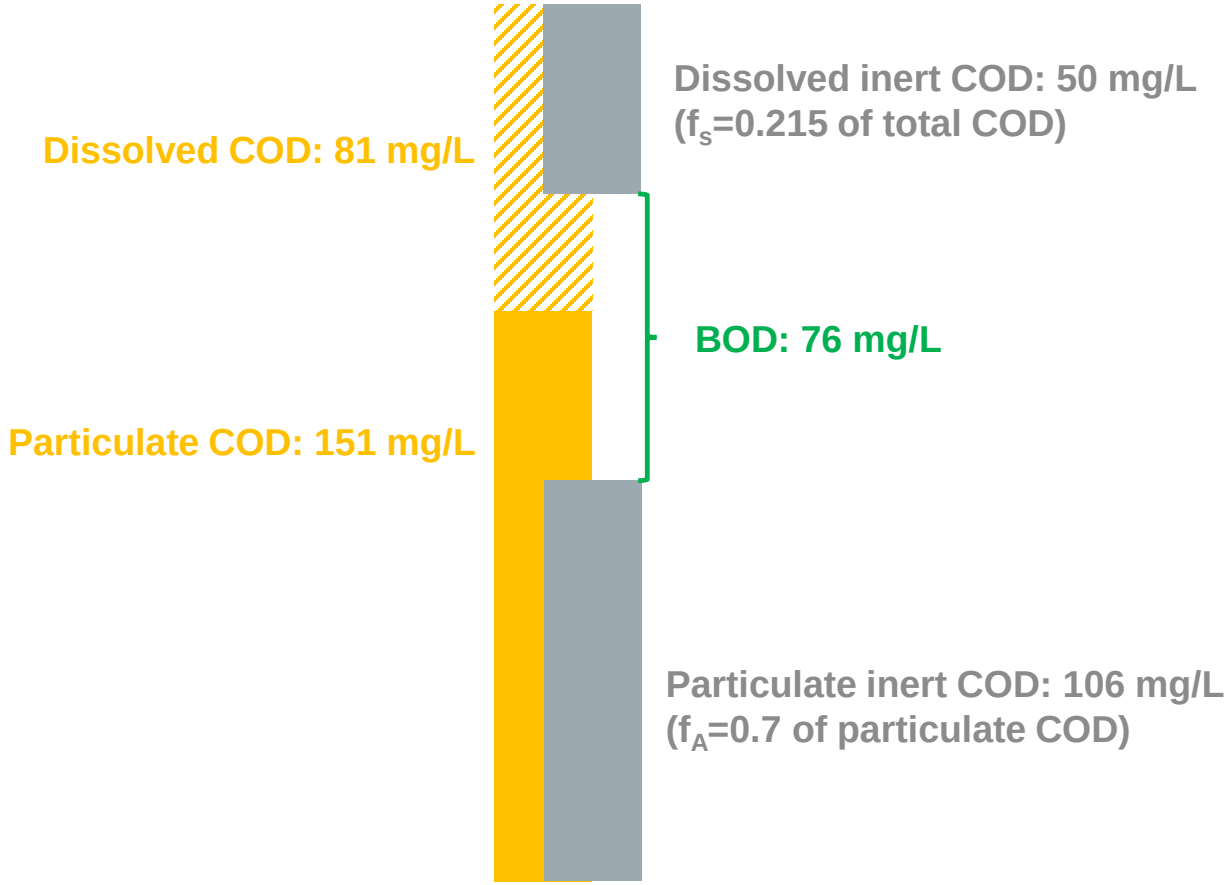

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27

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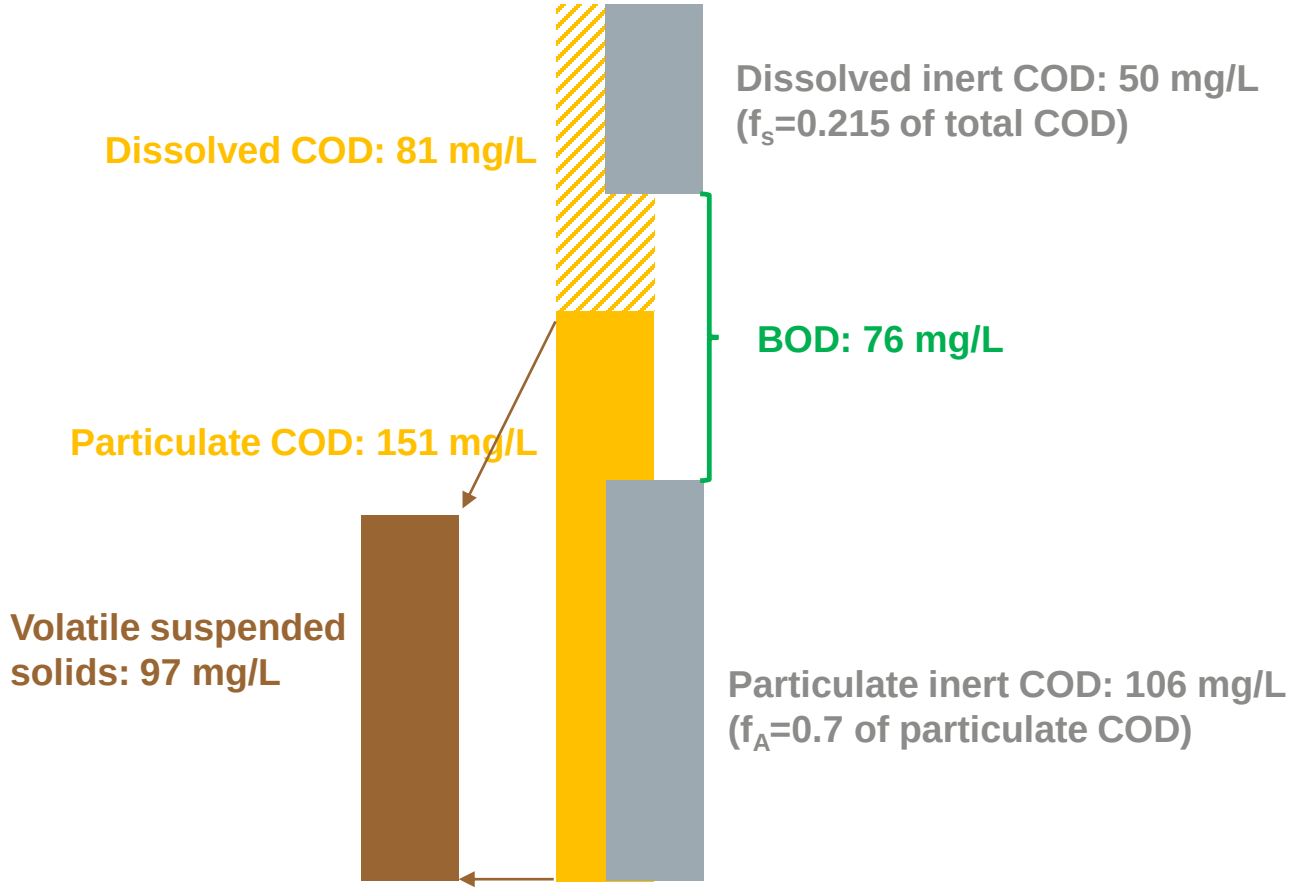

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28

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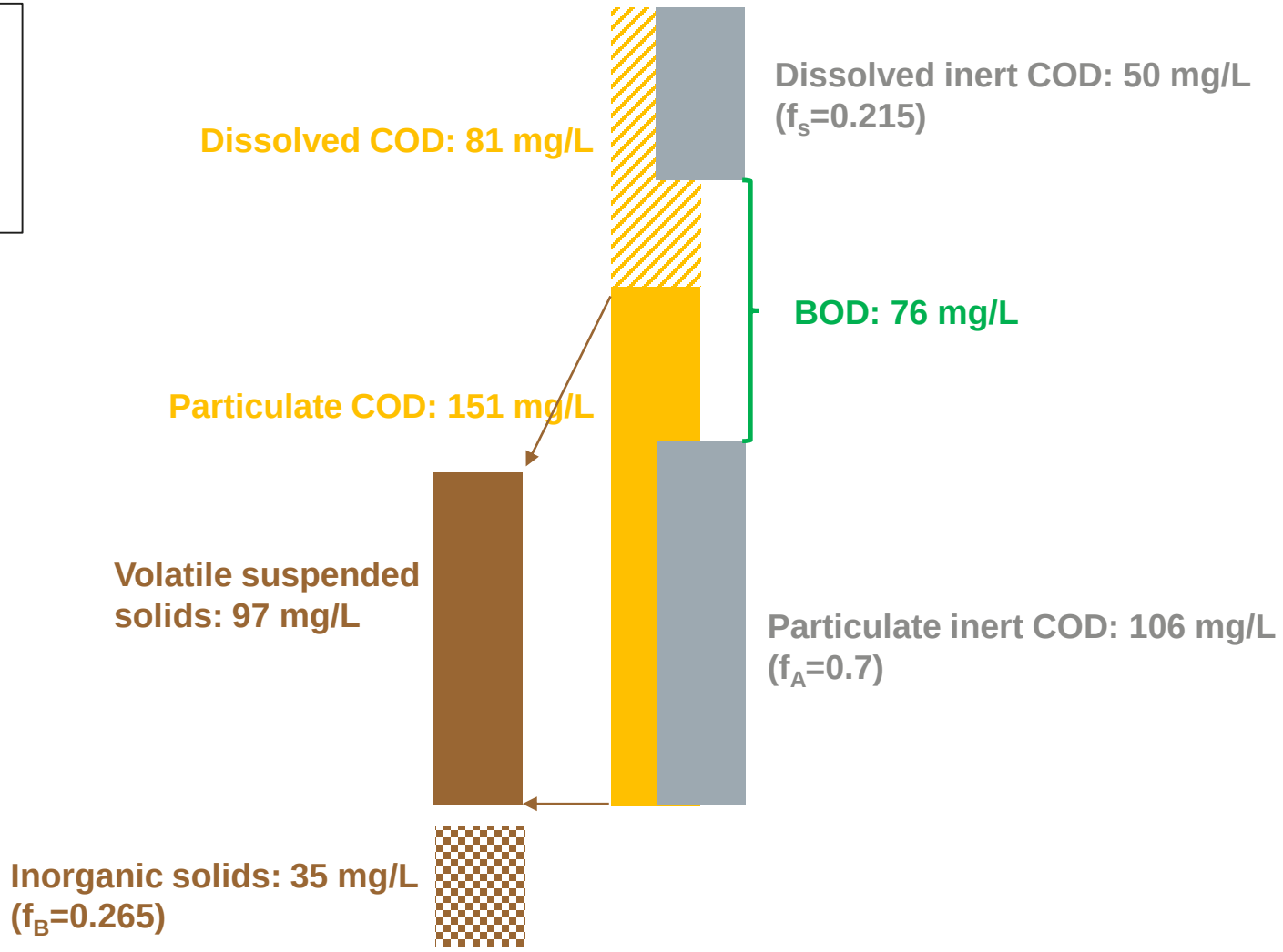

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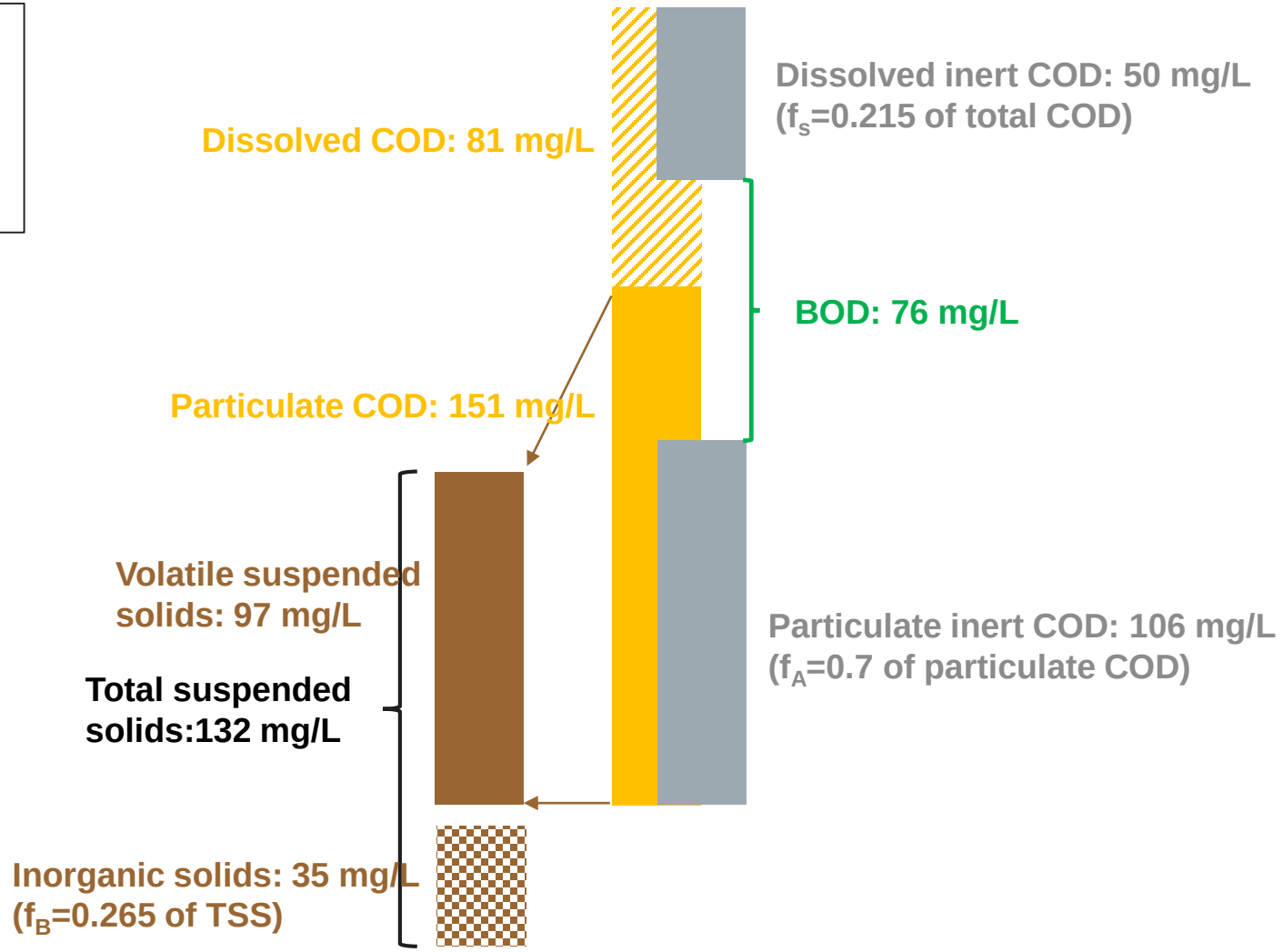

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30

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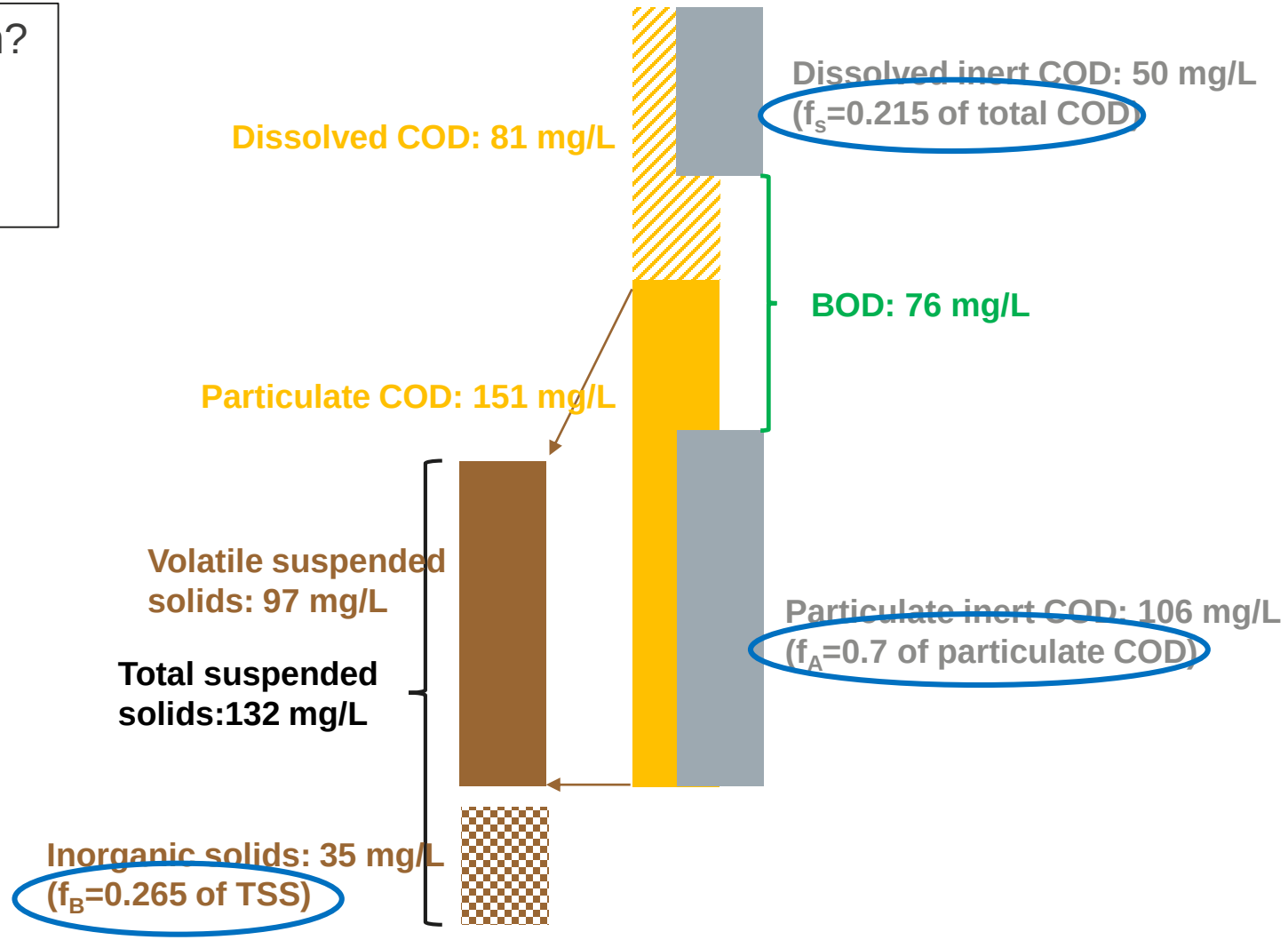

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31

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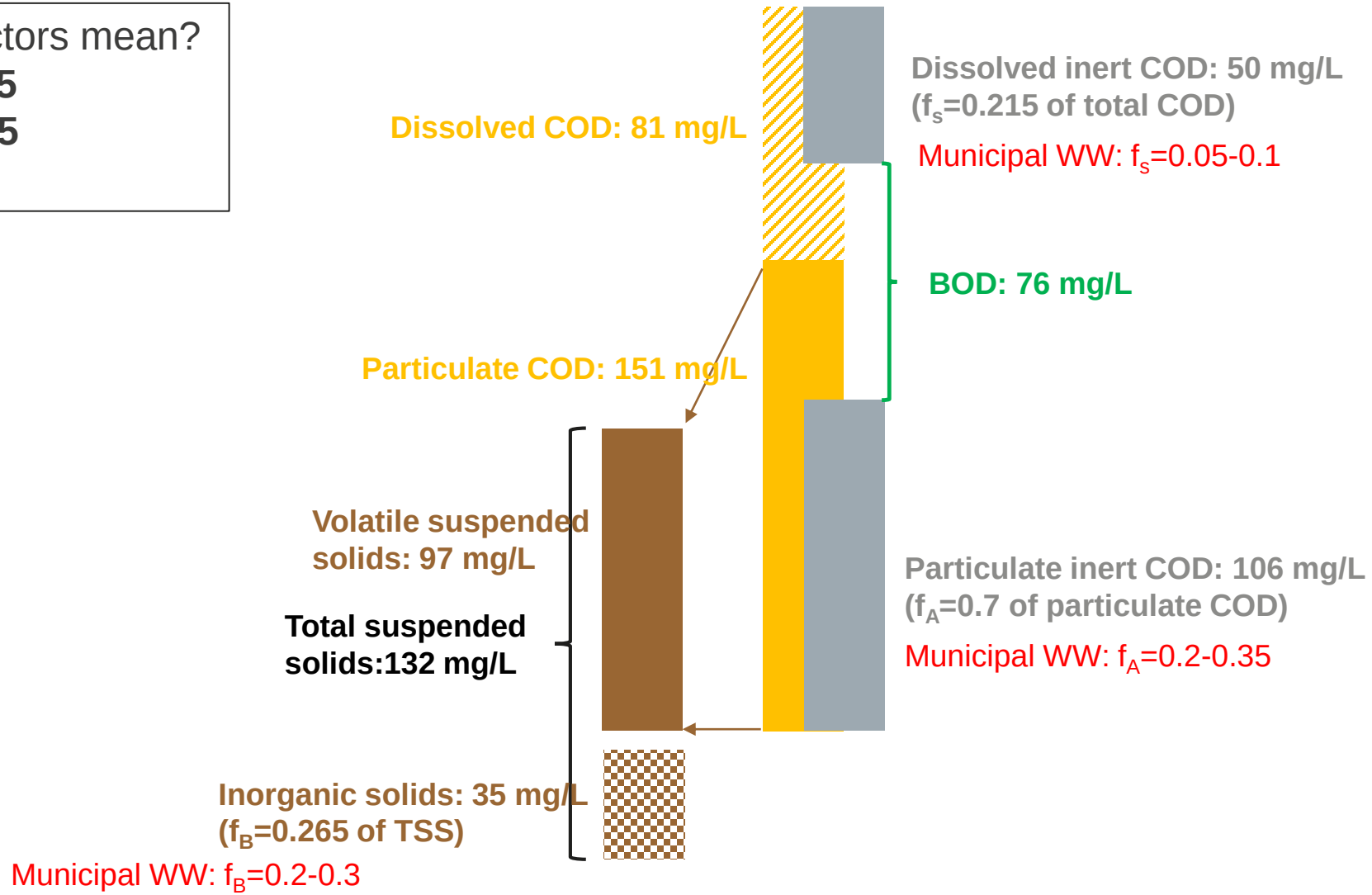

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Development of digital twin:

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 ✗
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Improved model

- Dynamic model
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Digital twin

- Final set-up
- Improved model

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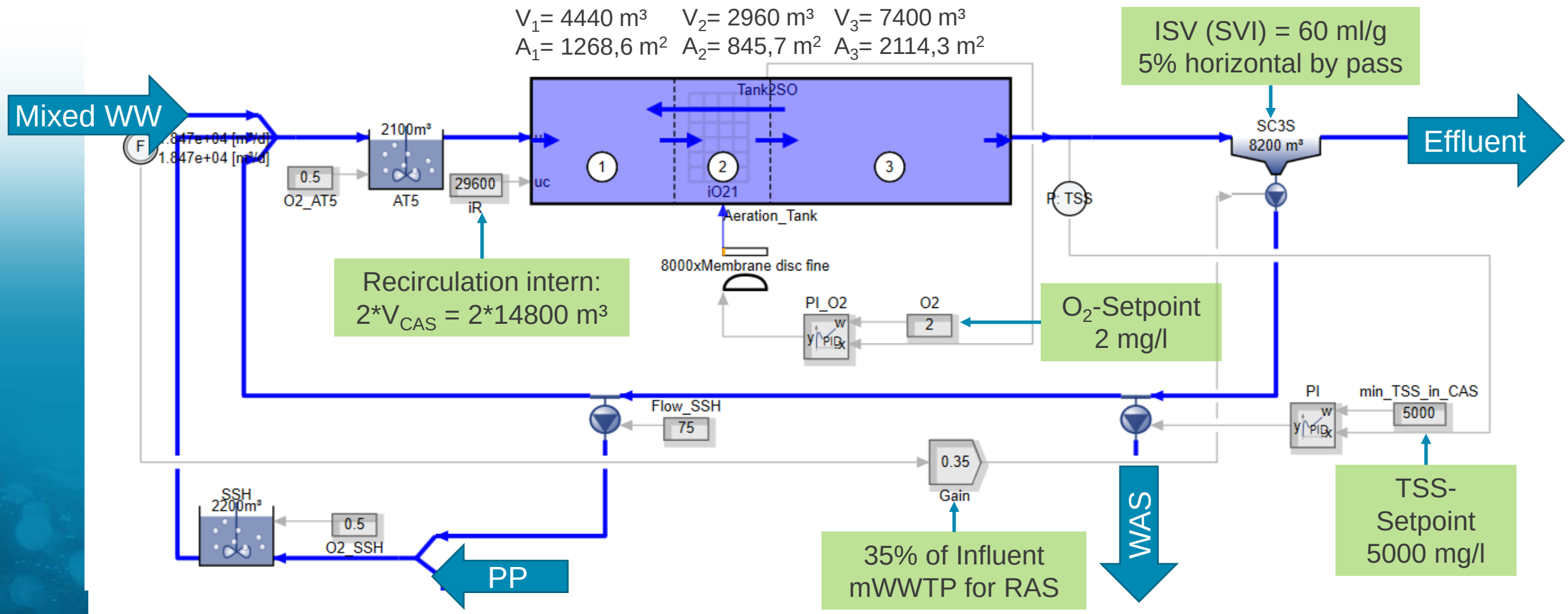
Modelling: #SIMBA Model-Overview Basic Set-UP 1



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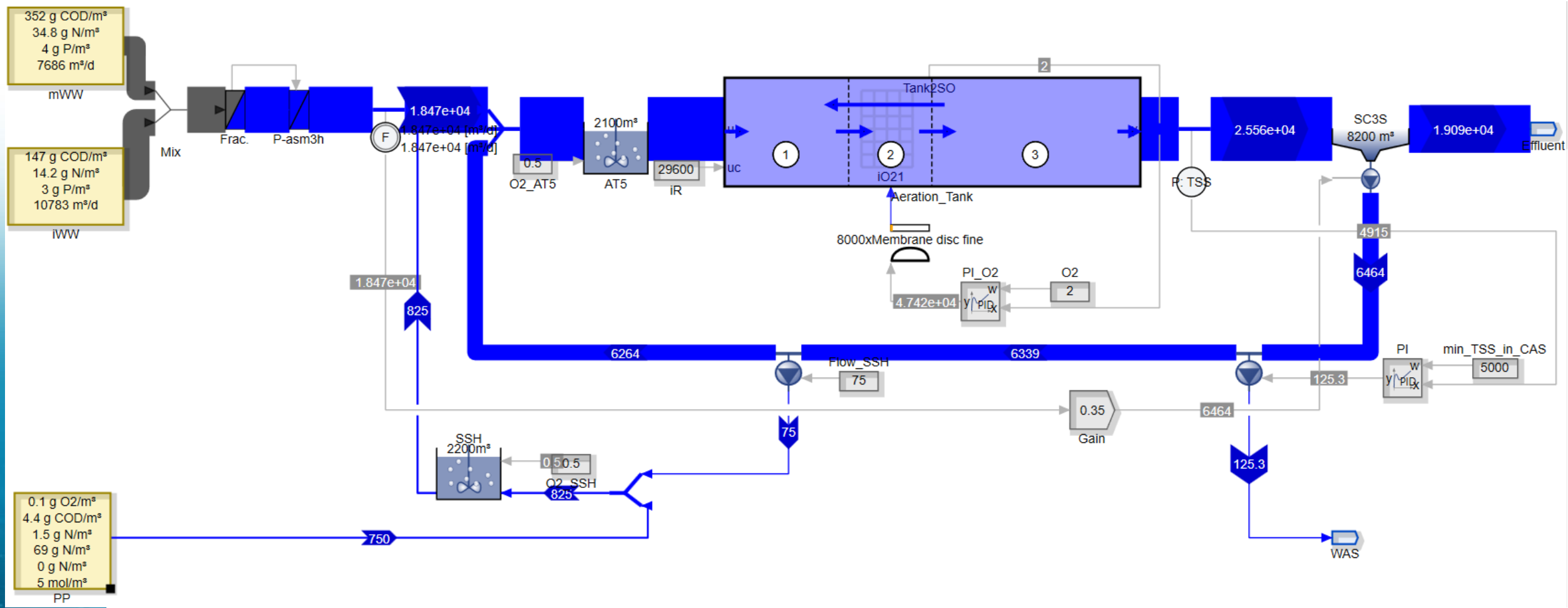
Modelling: #SIMBA - Flow [m³/d]



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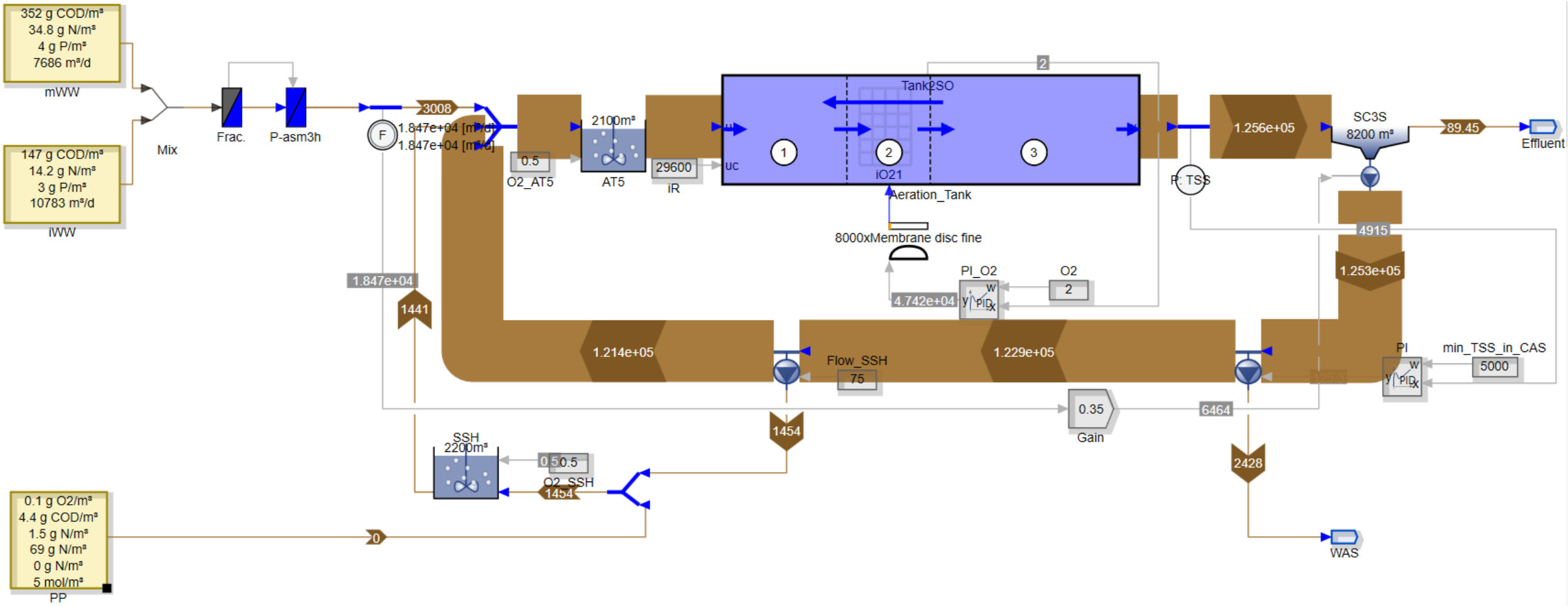
Modelling: #SIMBA - Total suspended solids [g/d]



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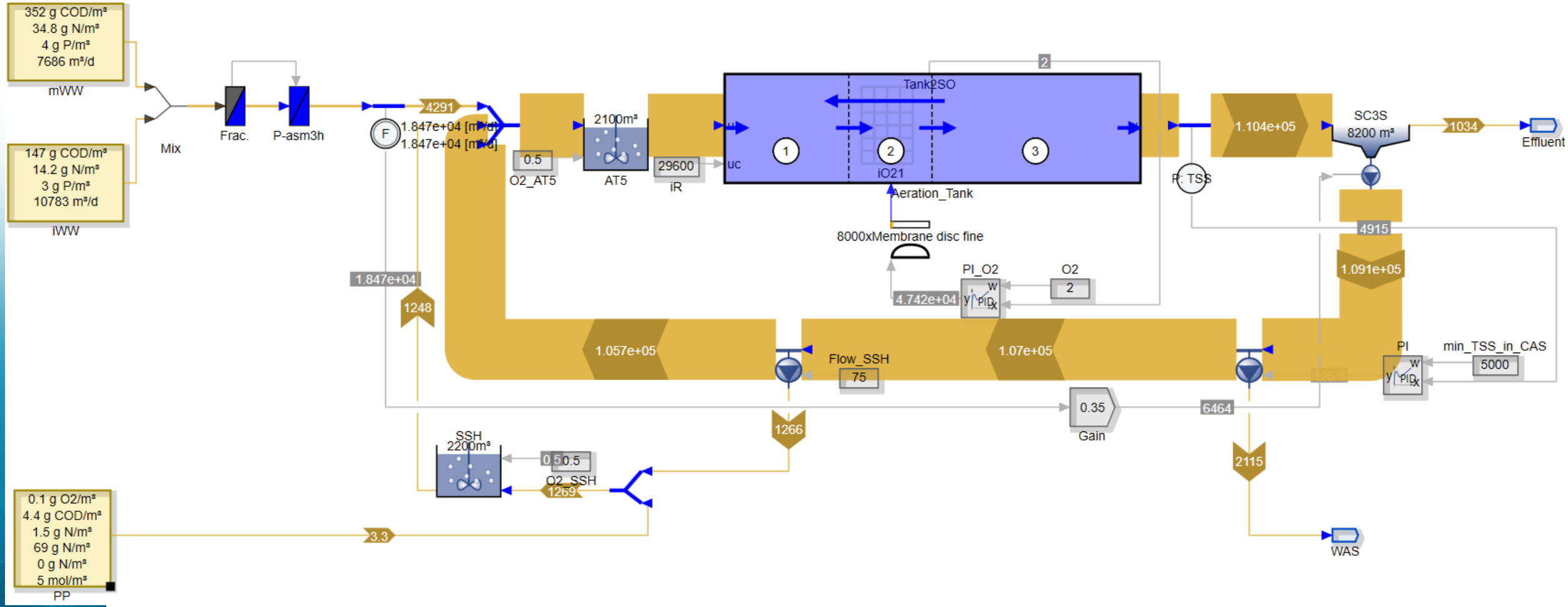
Modelling: #SIMBA – Chemical oxygen demand [g/d]



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Development of digital twin:

High quality data required to gain reliable results from modelling

Fractioning

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Steady state modelling with standard blocks

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Digital twin

- Final set-up
- Improved model

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ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

Thank you for your attention!

Contact:

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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

digital-water.city

Leading urban water management to its digital future

H2020 innovation action | 5 M€ funding

2019-2022

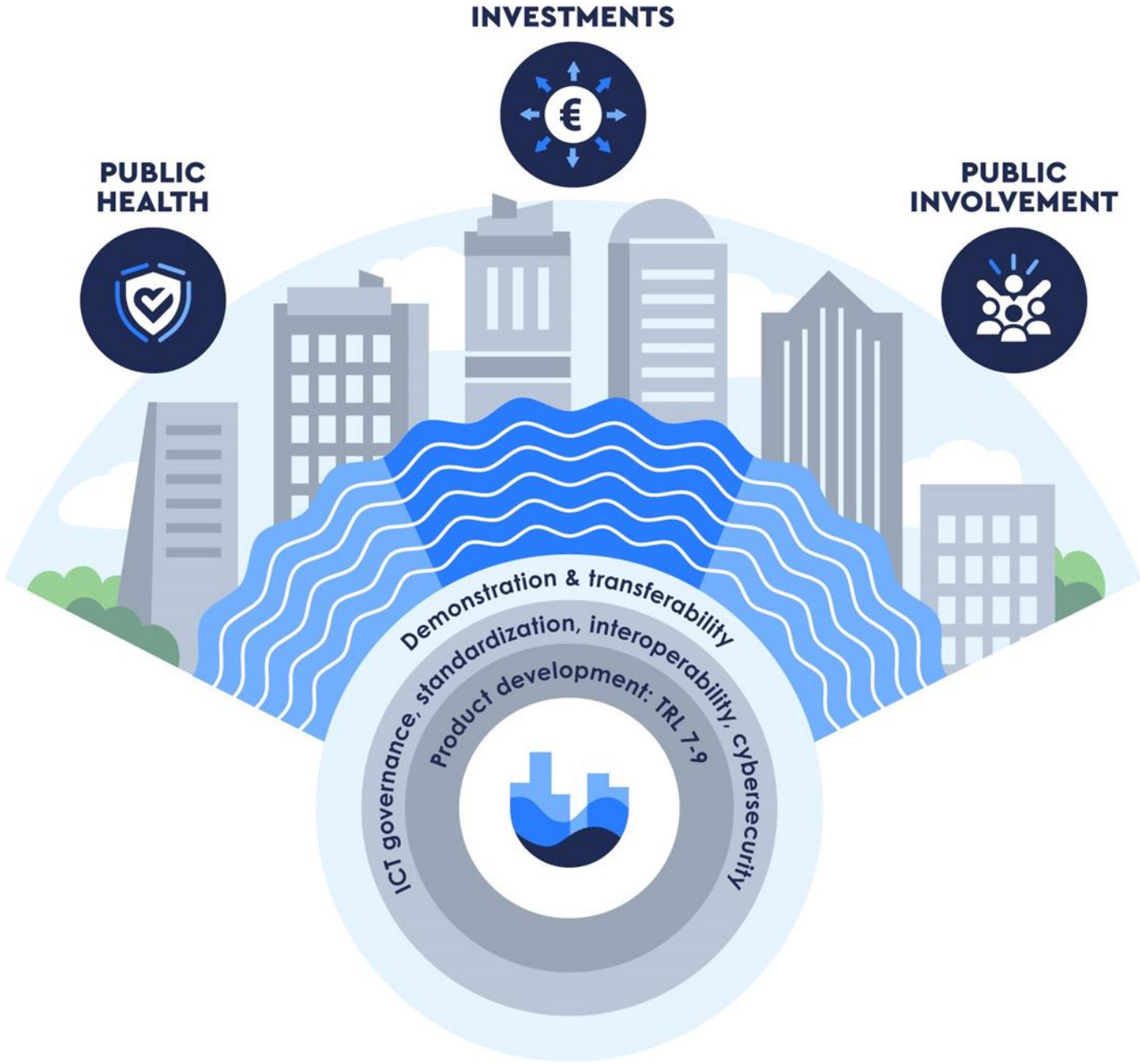
Nico Caradot

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

Berliner Wasserbetriebe

Sofiyska Voda

SIAAP
Service public de l'assainissement francilien

GRUPPO CAP

BIOFOS

R&D

UNIVERSITÀ POLITECNICA DELLE MARCHE

UNIVERSITÀ DEGLI STUDI DI MILANO

SINTEF

irstea

SORBONNE UNIVERSITÉ

DHI

eco logic

ISTITVTO SVPERIORE DI SANITÀ

Companies and SME

ICRA
Institut Català de Recerca de l'Aigua

PARTNERS4URBANWATER
Langeveld | Liefting | Schilperoort | De Haan | Post

IPEK

ICATALIST

fluidion
fluidic intelligence

GIMENO grupo

kando

Vragments

Strane Innovation

Arctik
Communication for sustainability

digital-water.city
digitalwater_eu

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

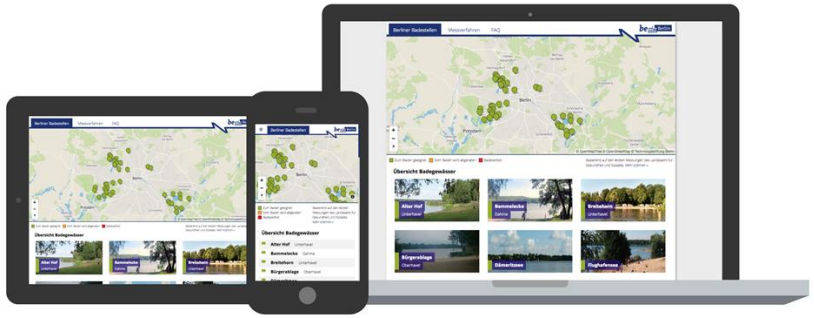
Safe water-reuse

#Sofia

ROI and operational costs

Bathing water

Early warning system to forecast bathing water quality and communicate with the public



Mockup: Technologiestiftung Berlin



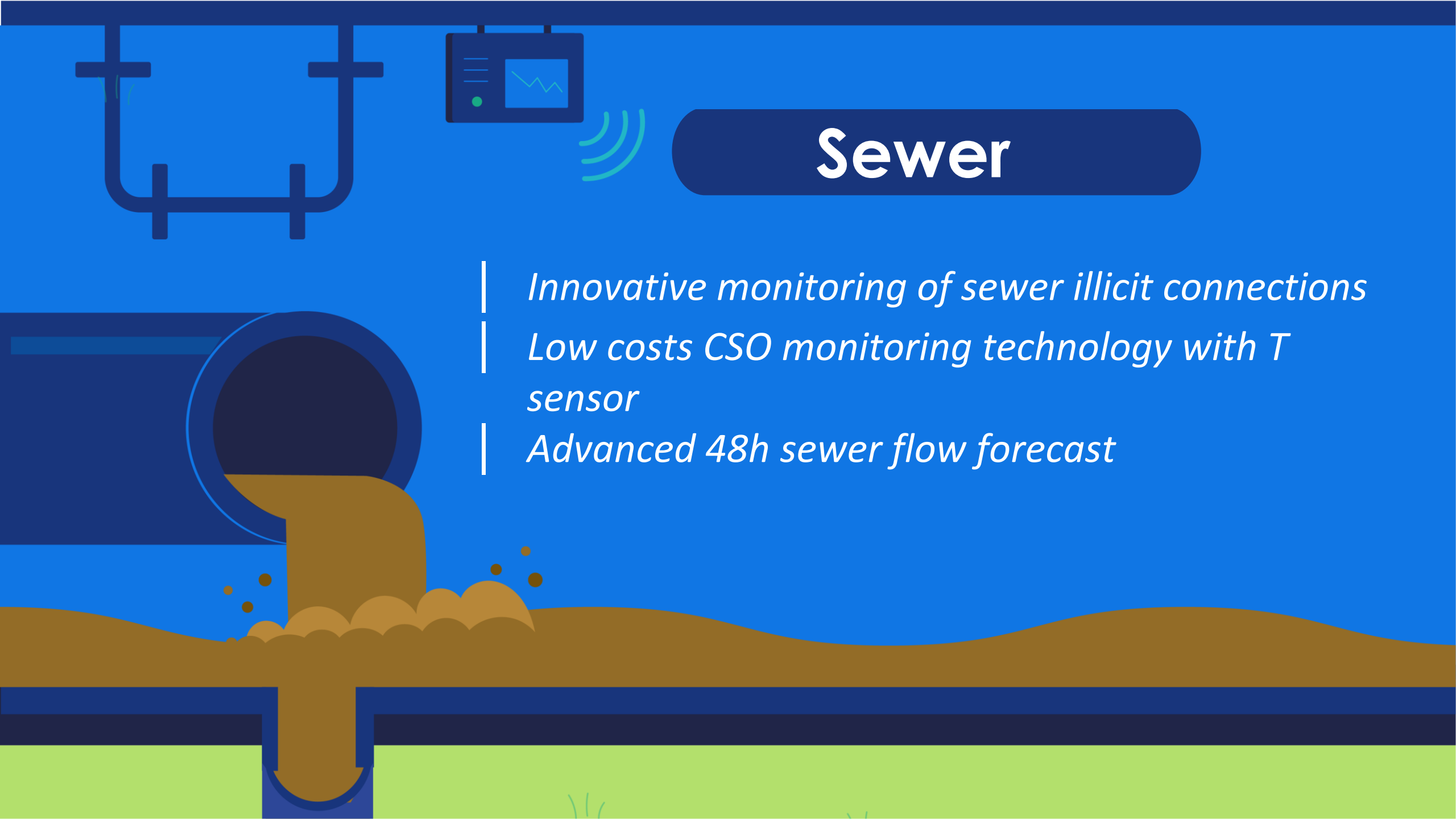
Real-time measurement of bacterial contamination



Drinking water

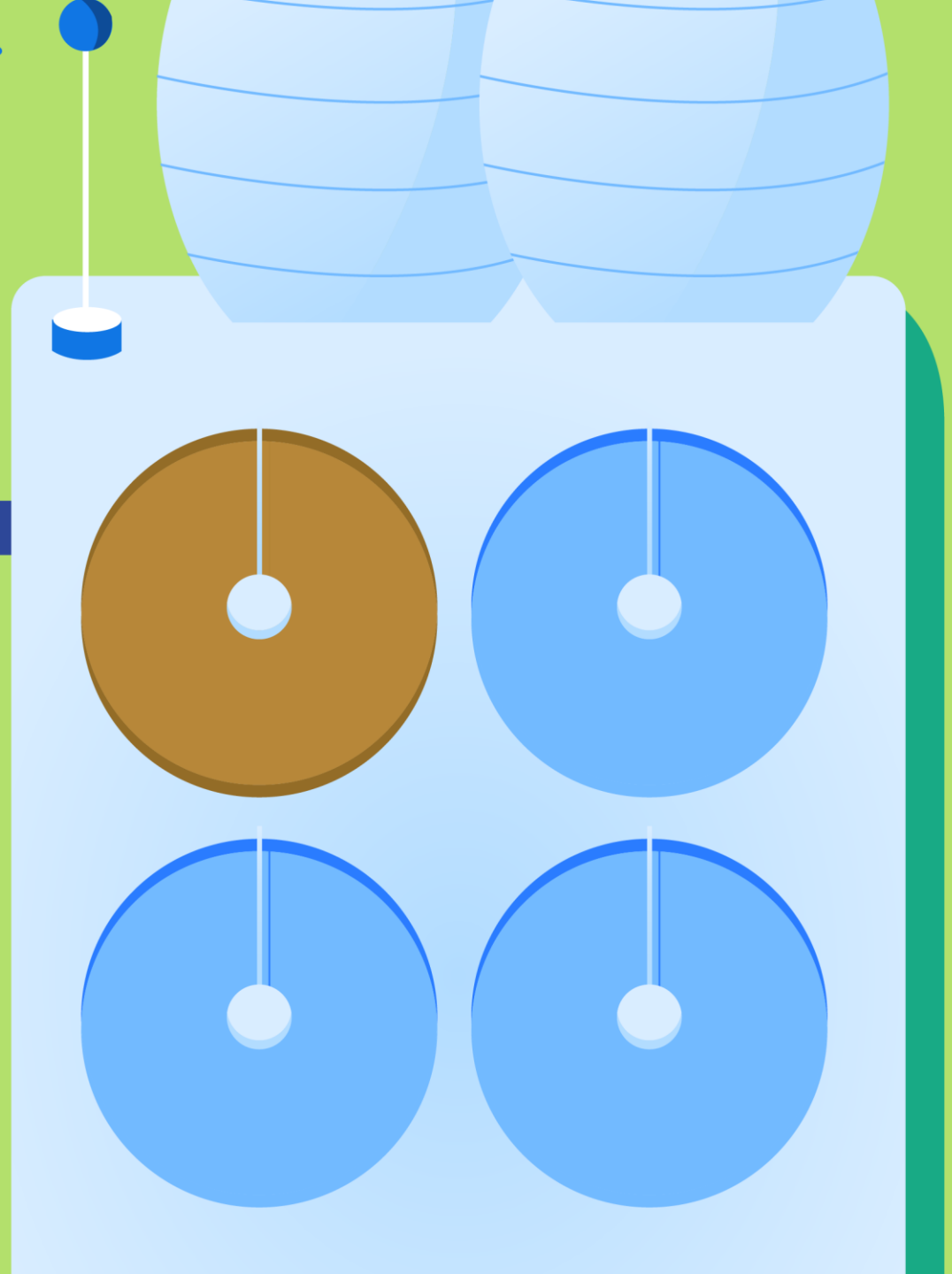
Predictive asset management of drinking water wells




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



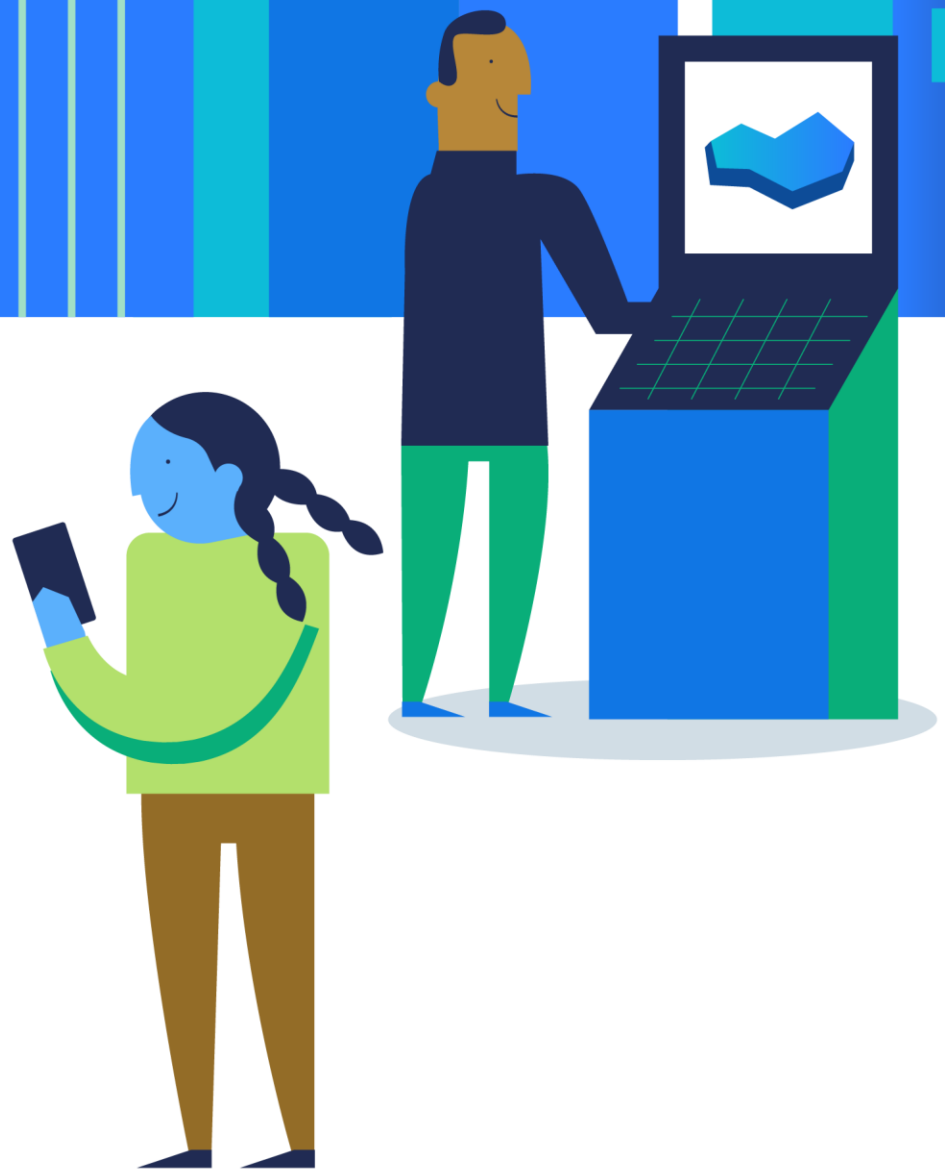
Remote monitoring of water stress

Match making platform to support water allocation

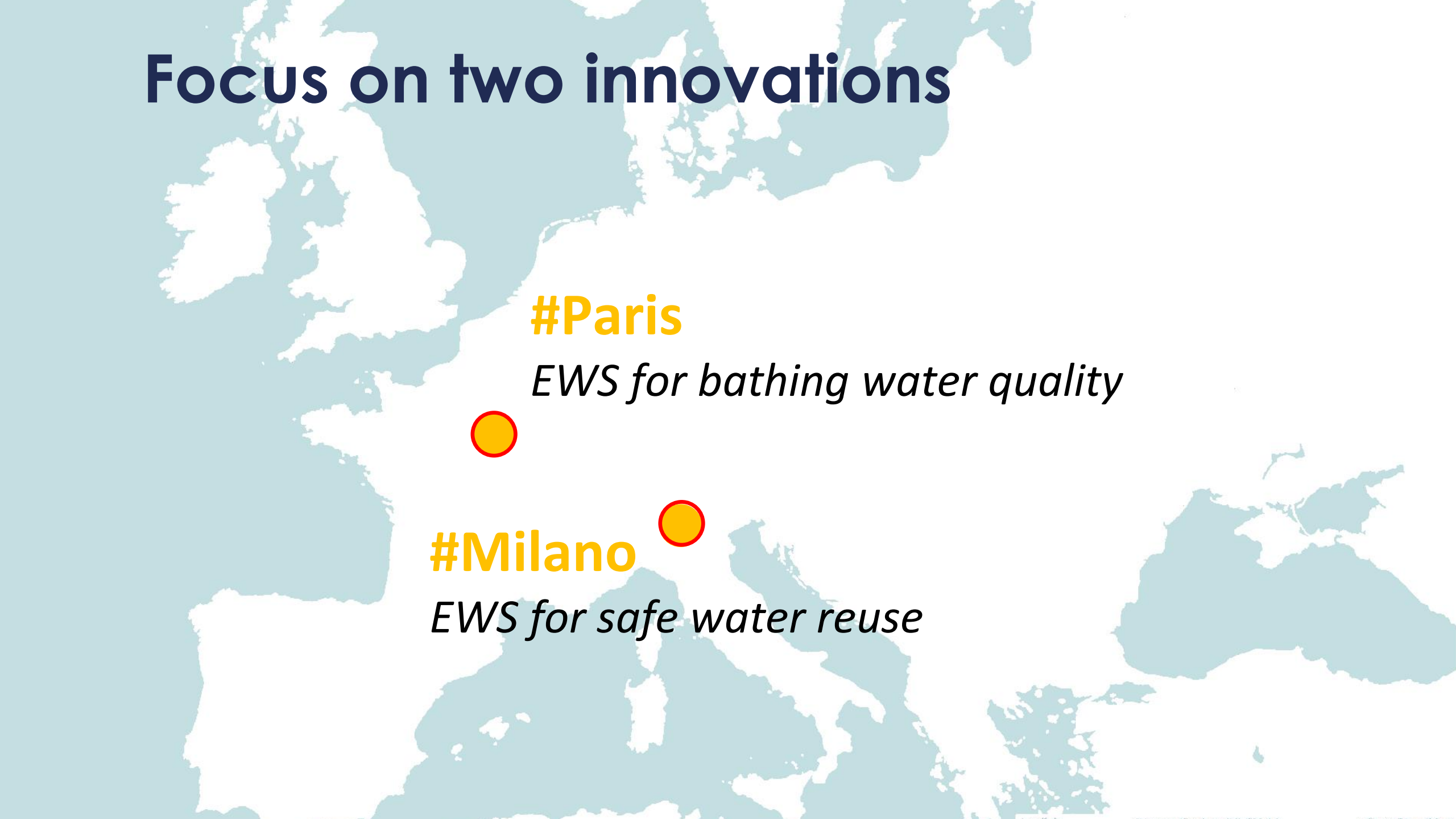
Public involvement

- *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

EWS for bathing water quality

#Milano

EWS for safe water reuse

#Paris

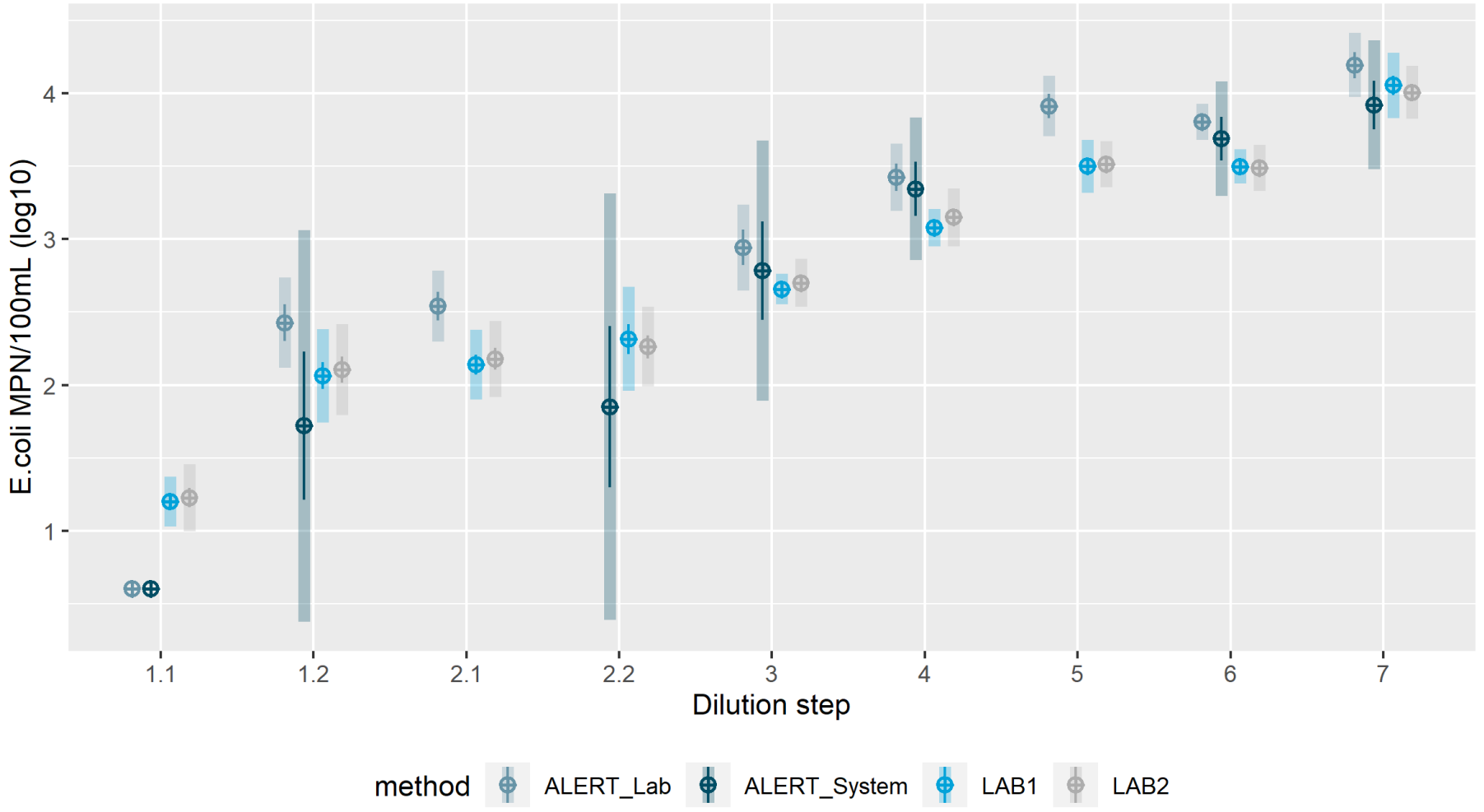
Improve bathing water management in the river Seine
for the Olympic games of 2024

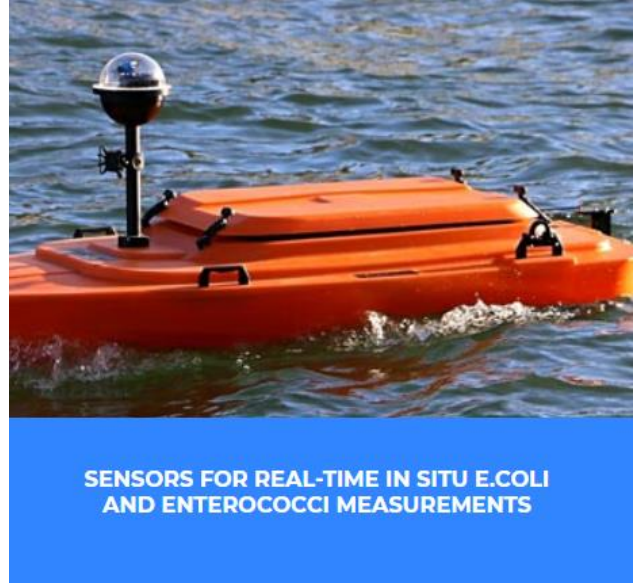


© Pixabay

Comparison of laboratories and ALERT devices

Errorbars show 95% prediction intervals (shaded thick outer line) and 95% confindence interval (inner solid line)



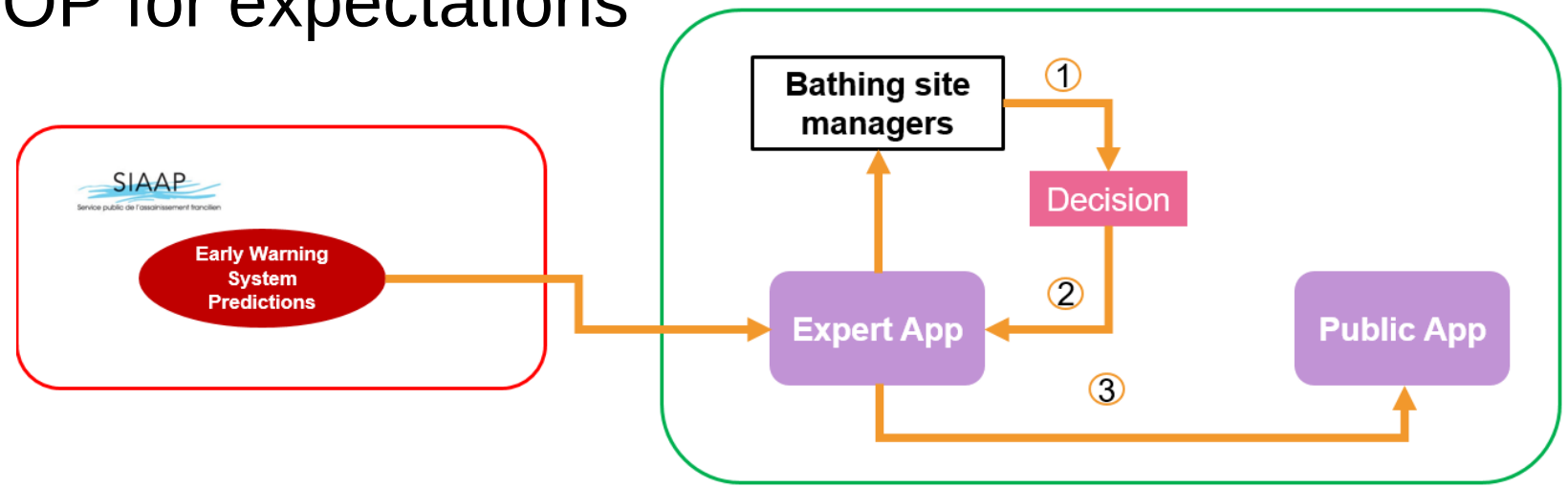


digital-water.city has received funding from the European Union's H2020 Research and Innovation Programme under Grant Agreement No. 820954.

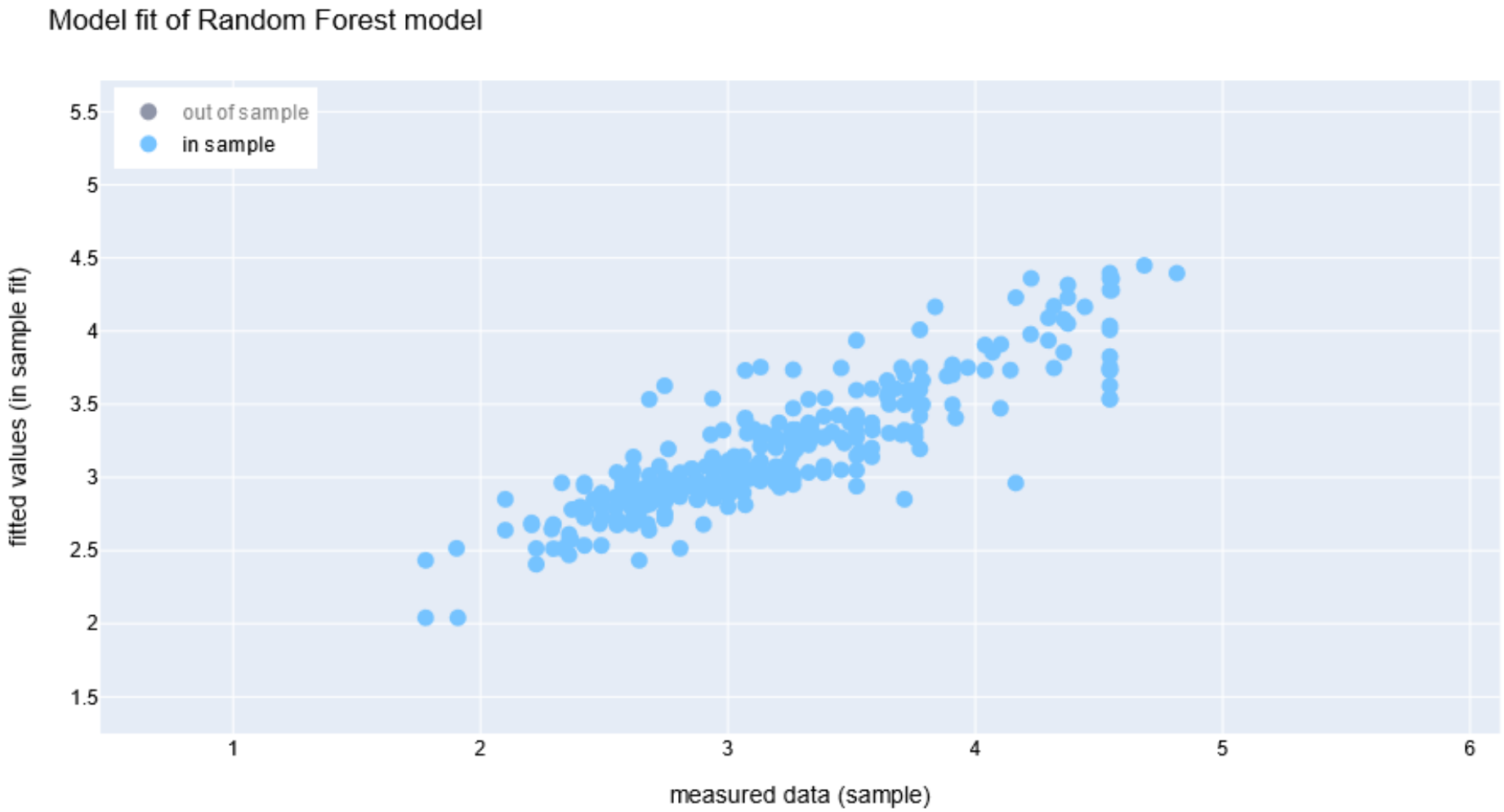
Early warning system for bathing water quality



- → 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

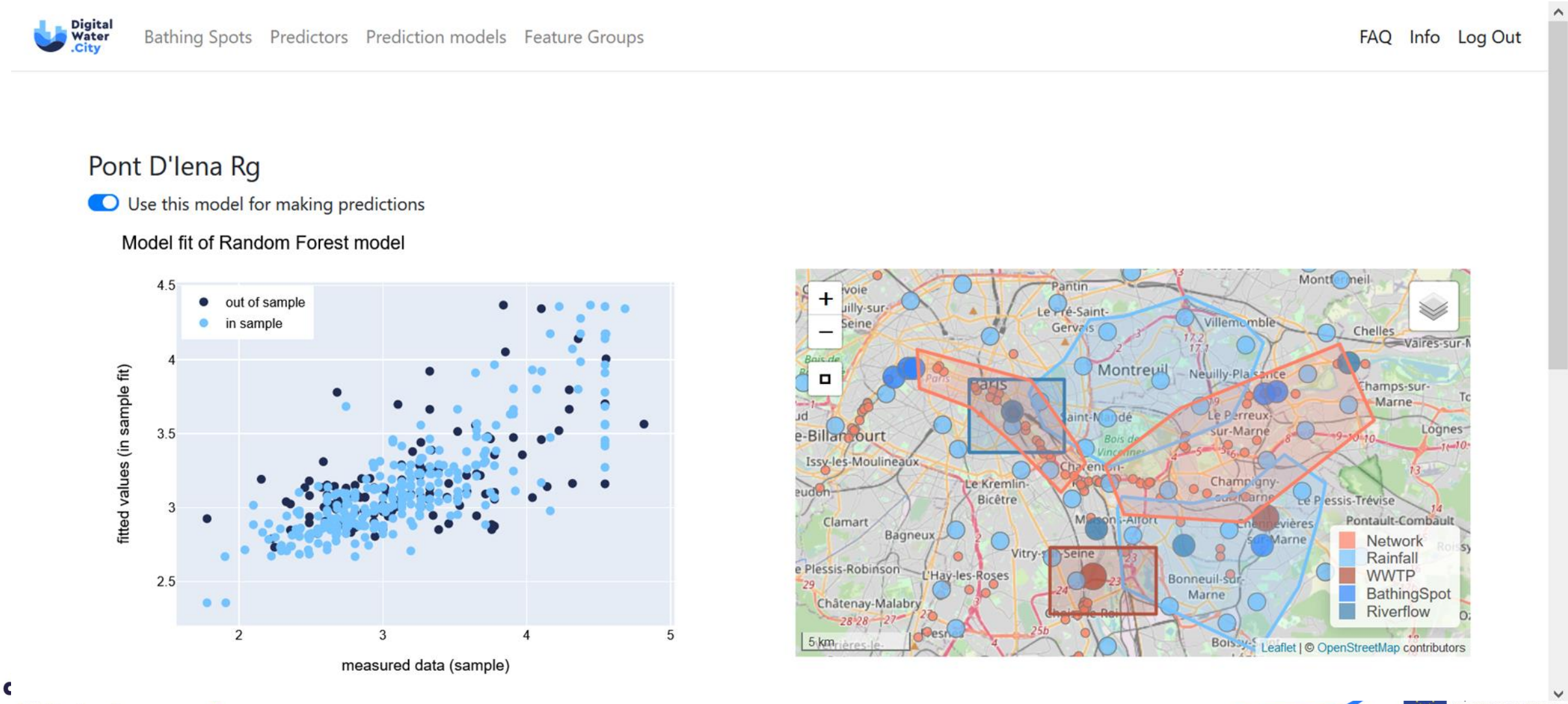


First model runs (24h-Random Forest)



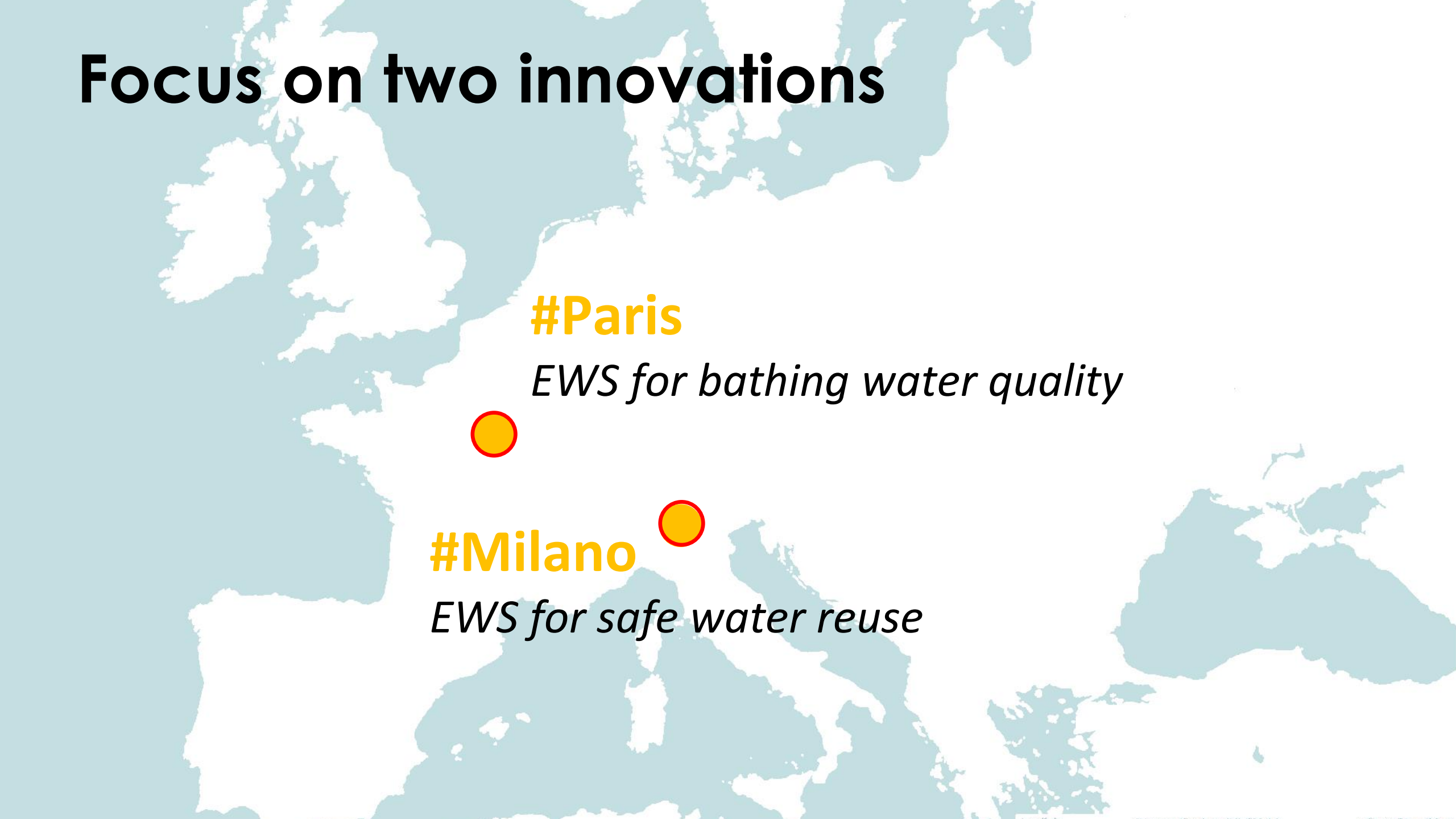
digital-water.city has received funding from the European Union's H2020 Research and Innovation Programme under Grant Agreement No. 820954.

First software architecture



Programme under Grant Agreement No. 820954.

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

- 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

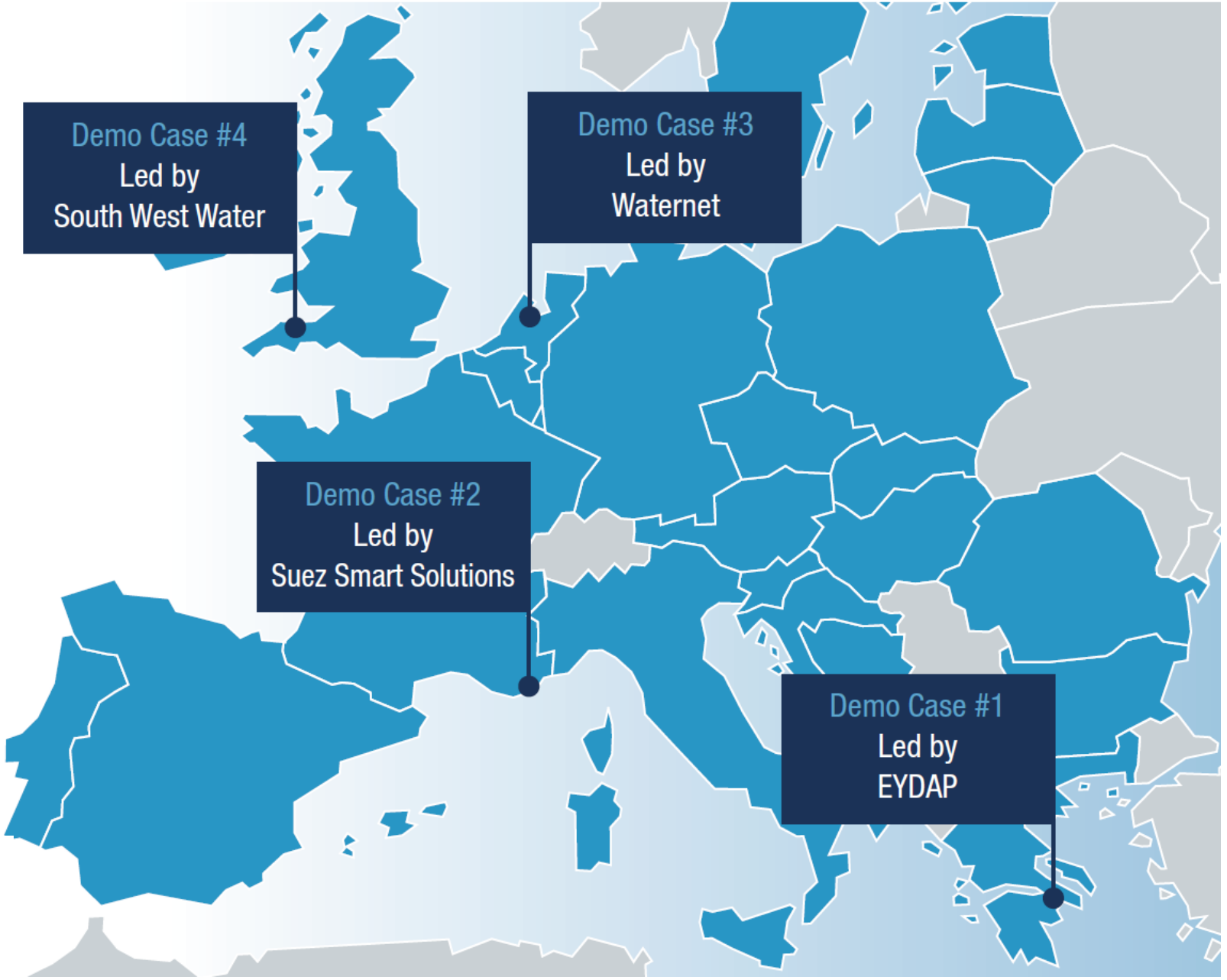
Cannes • Improving the Water
Supply System

Demo Case #3 • Netherlands

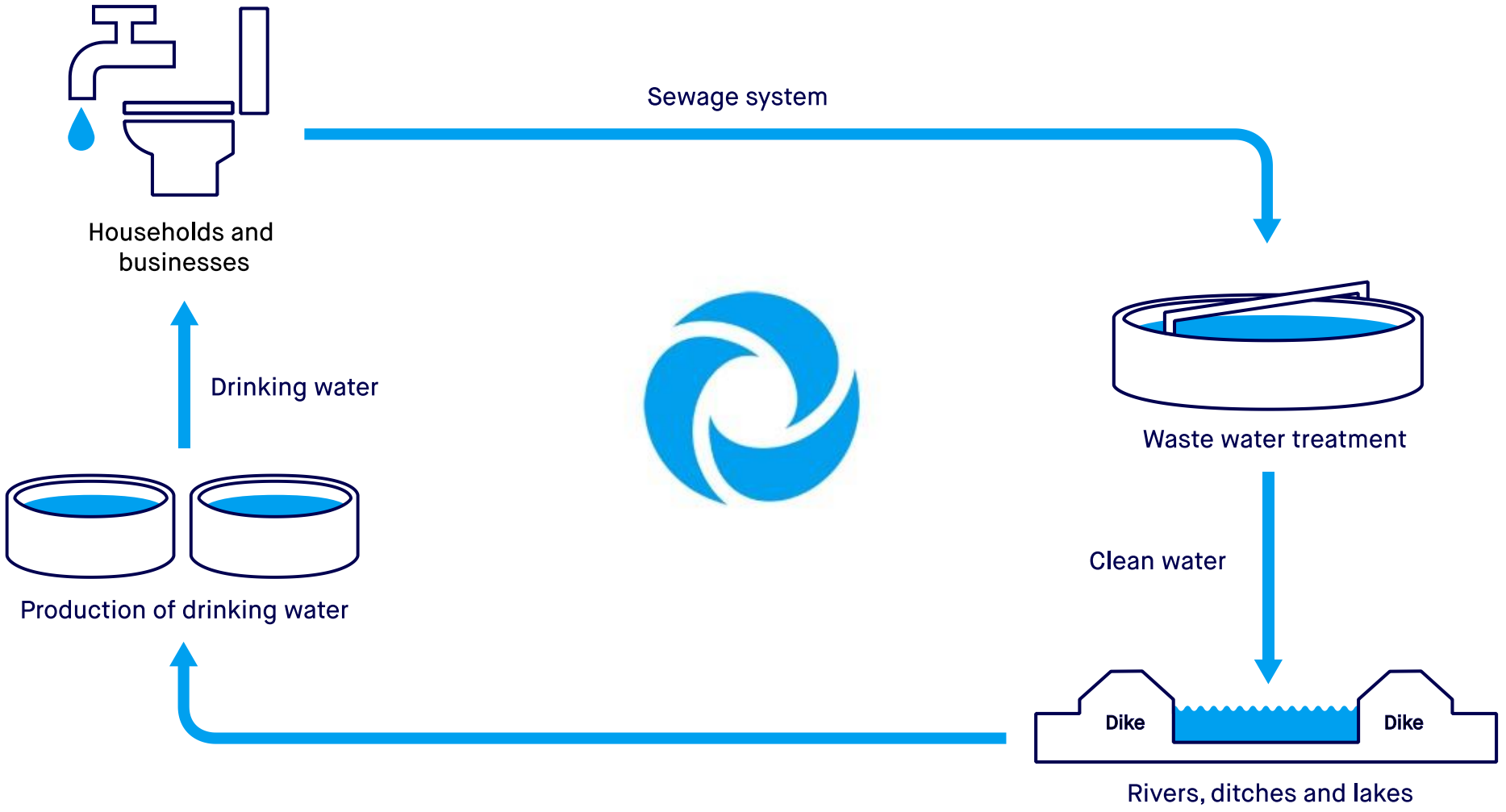
Amsterdam • Intelligent control
for wastewater treatment

Demo Case #4 • United Kingdom

Great Torrington • Smart Meters
and Customers



Waternet water cycle utility of Amsterdam



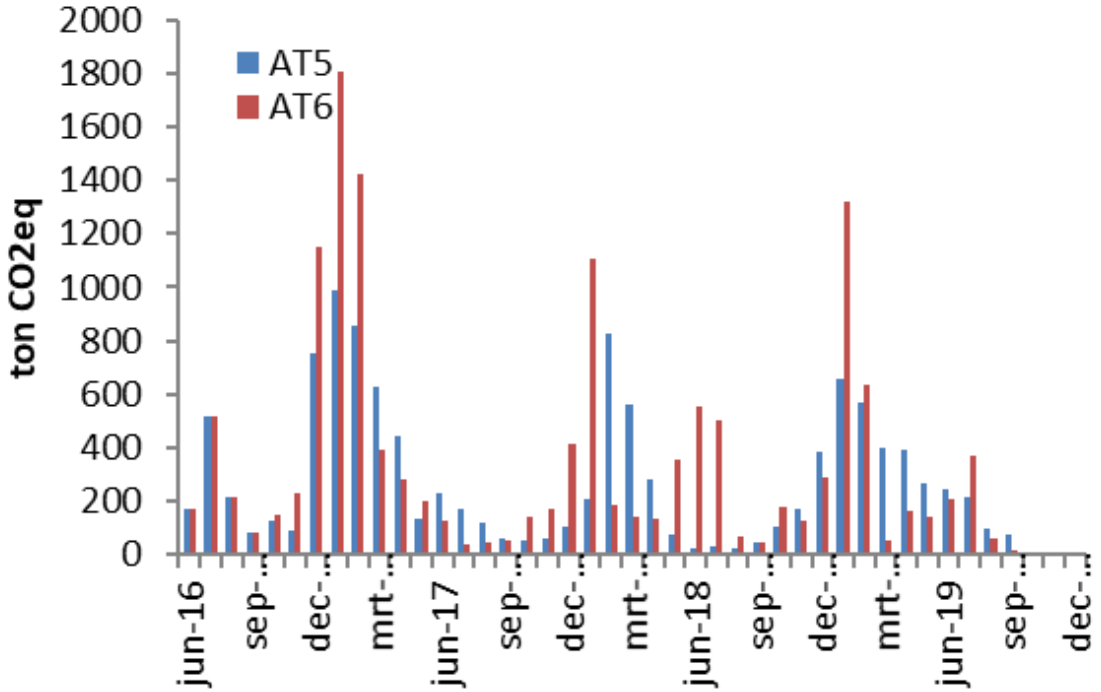
Wastewater treatment plant Amsterdam West



Nitrous oxide (N2O) gas emissions

Real-time measurement in off-gas aeration tanks (ATs) of WWTP Amsterdam West starting 2016:

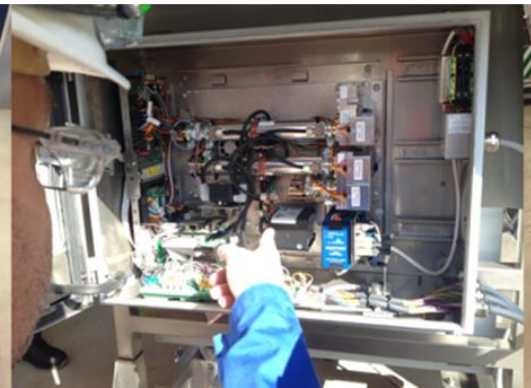
15 – 28 kton/year CO_2-eq











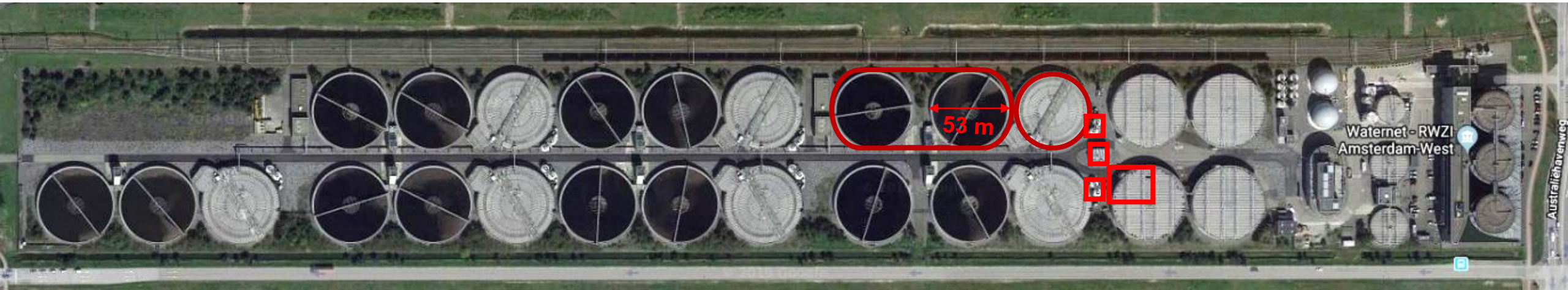


Full-scale research lane

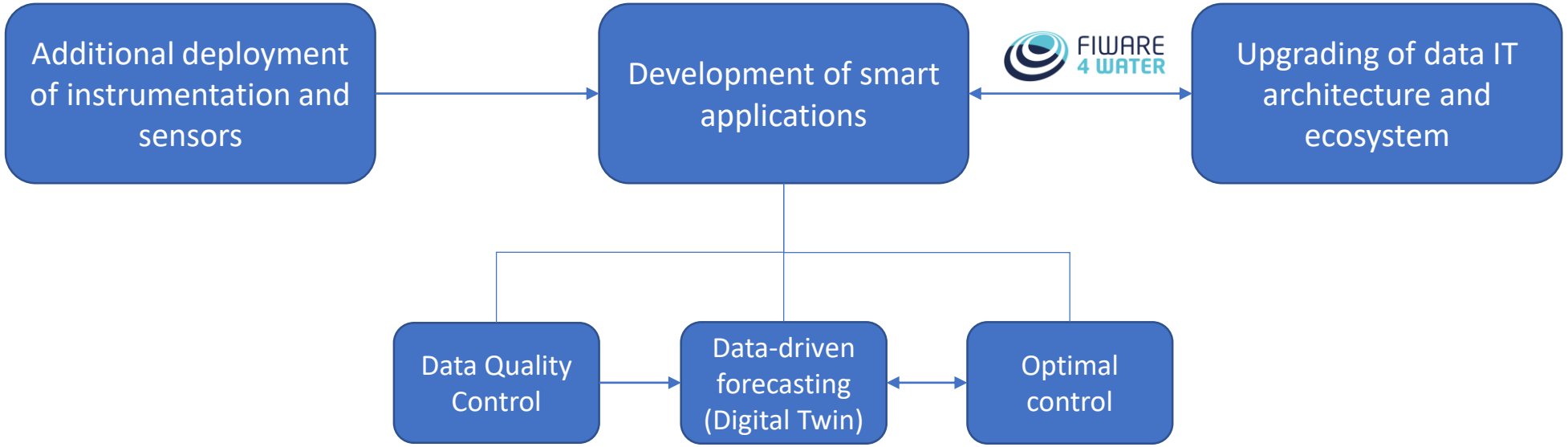
Objective: Reduction of nitrous oxide emission and electricity use aeration

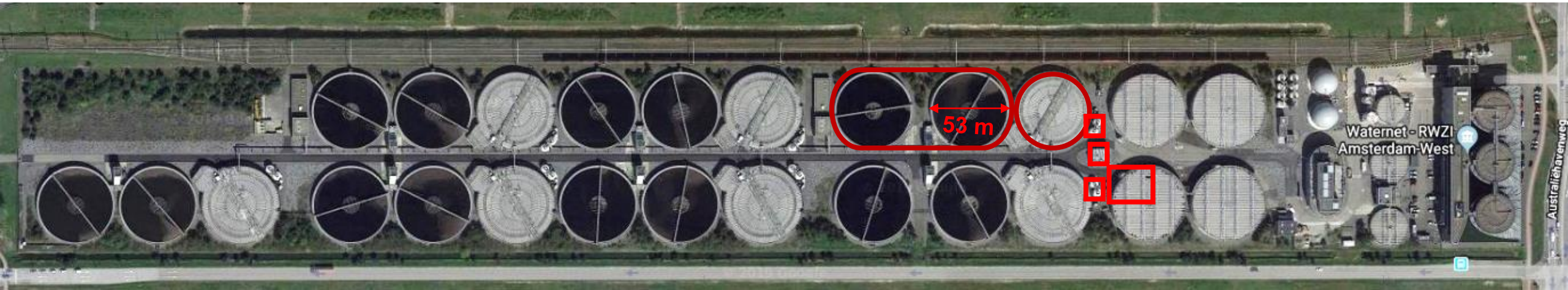
Installing additional sensors

Treatment optimisation with Artificial Intelligence



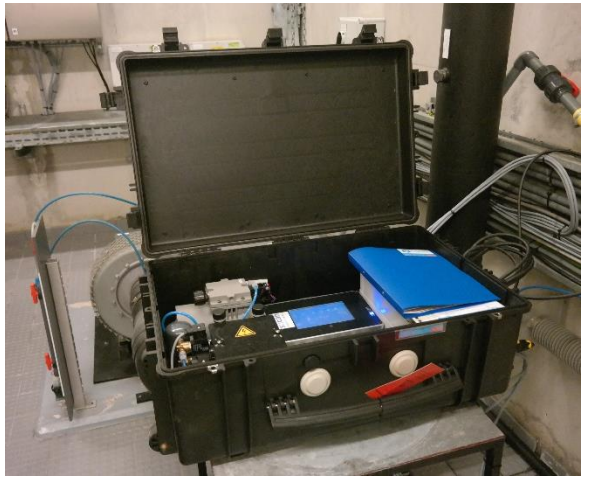
Building Blocks for Digitalization of WWTP





Sensor deployment and research facility

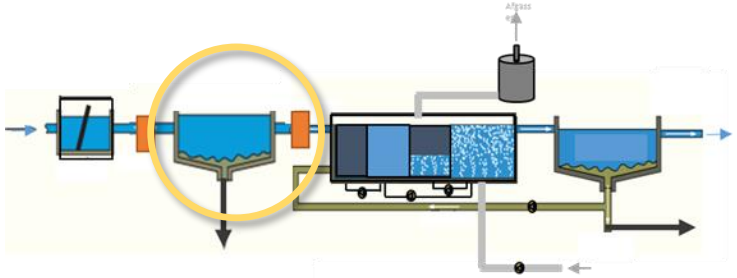








Primary settler

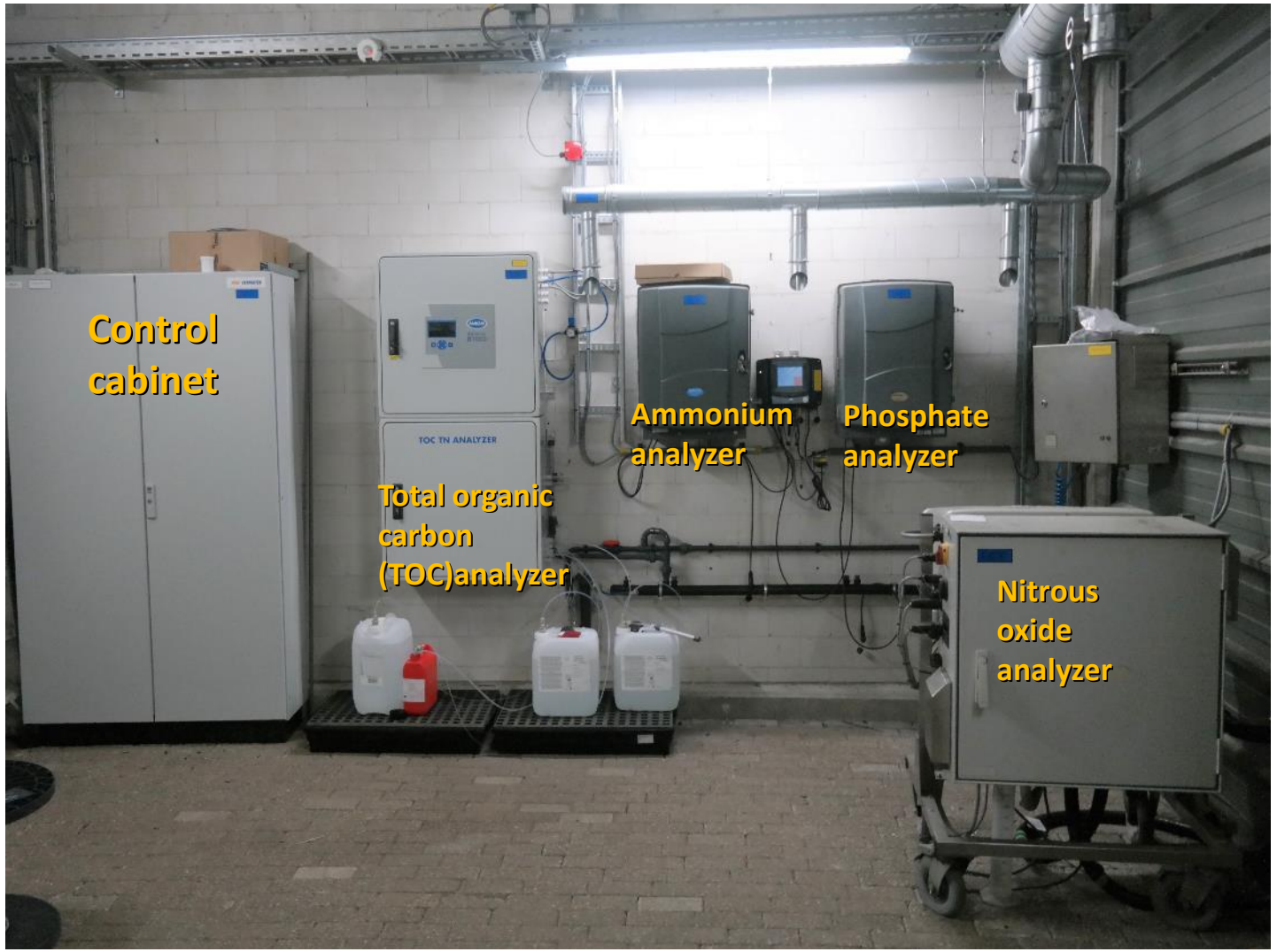






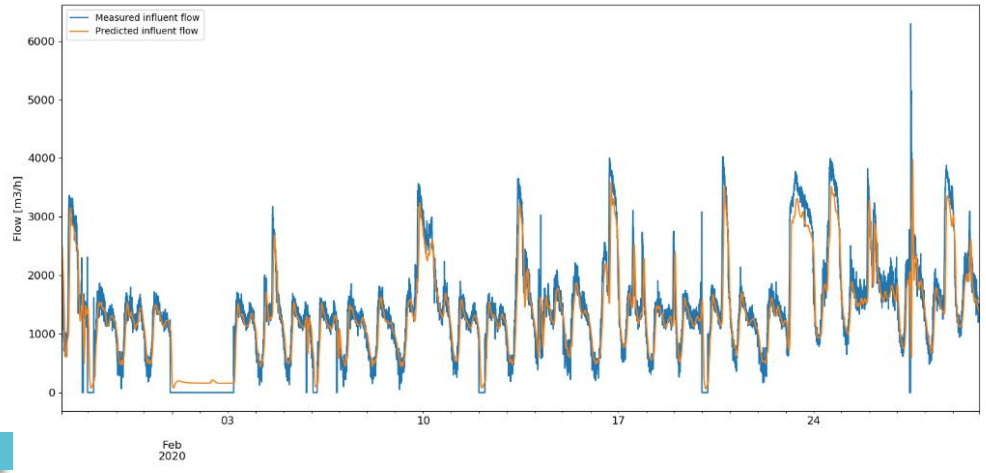




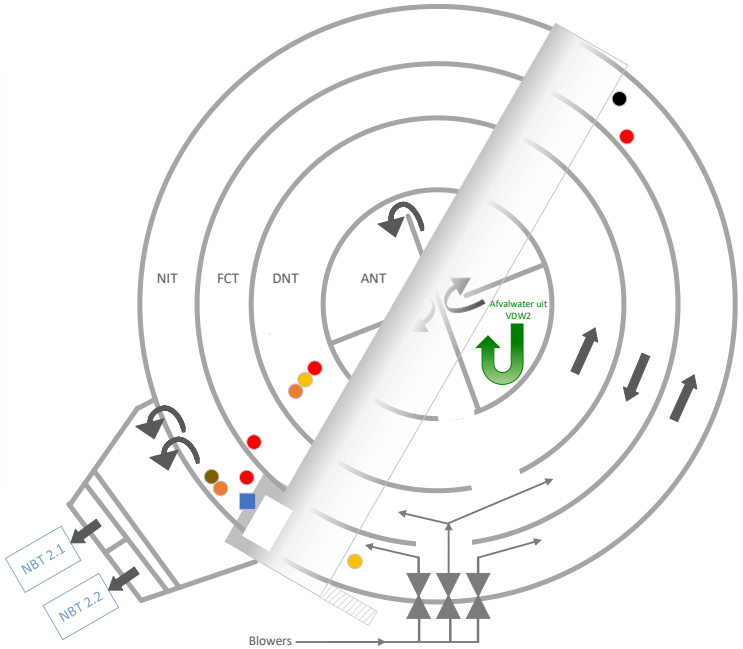


AI models for aeration optimisation

Influent model
"How much wastewater is coming?"



Digital twin model
"What happens if …?"



Control model
"What is the best action?"

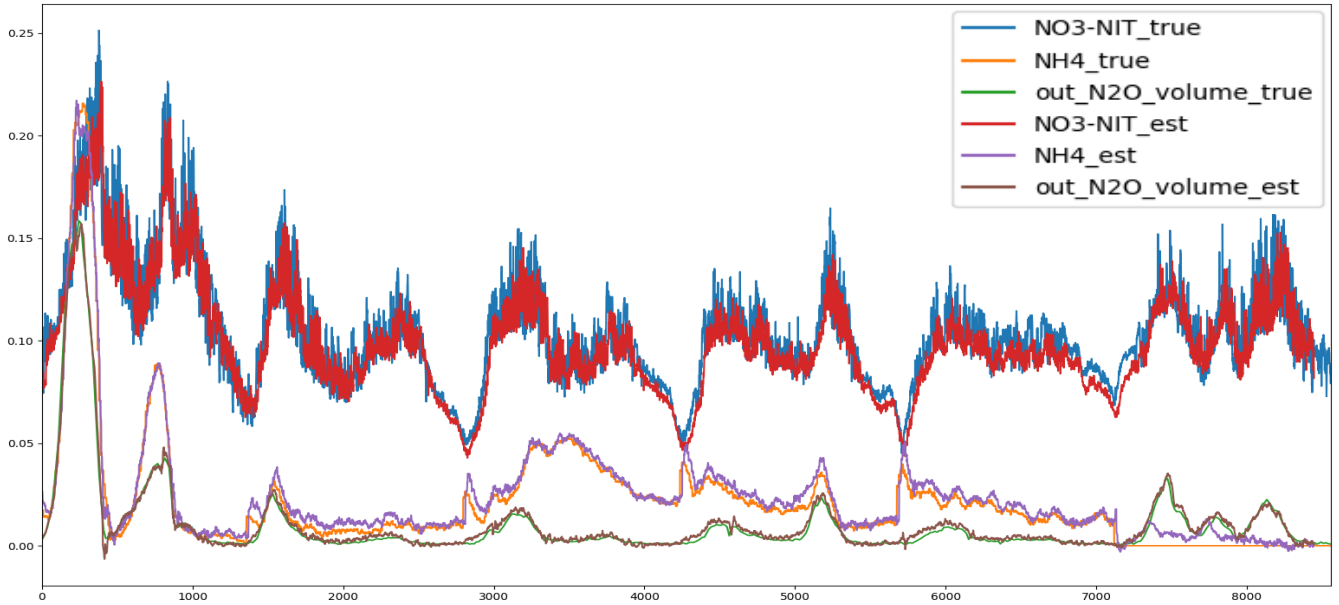


Objective:
- Low N_2O
- Low kWh

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	



$[x_1^{t0}, x_2^{t0}, \ldots, x_n^{t0}]$
$[x_1^{t-1}, x_2^{t-1}, \ldots, x_n^{t-1}]$
…
$[x_1^{t-95}, x_2^{t-95}, \ldots, x_n^{t-95}]$

Deep Q-Learning Model

$[y_1^{t+1}, y_2^{t+1}, \ldots, y_n^{t+1}]$

A reinforcement learning agent



Simulator (environment)

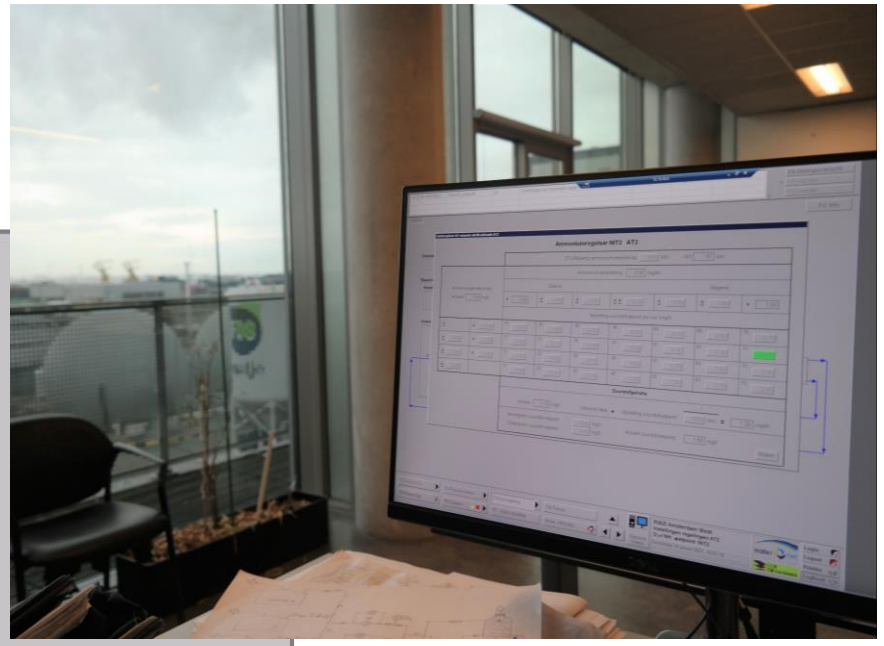
Actions
(control signals)

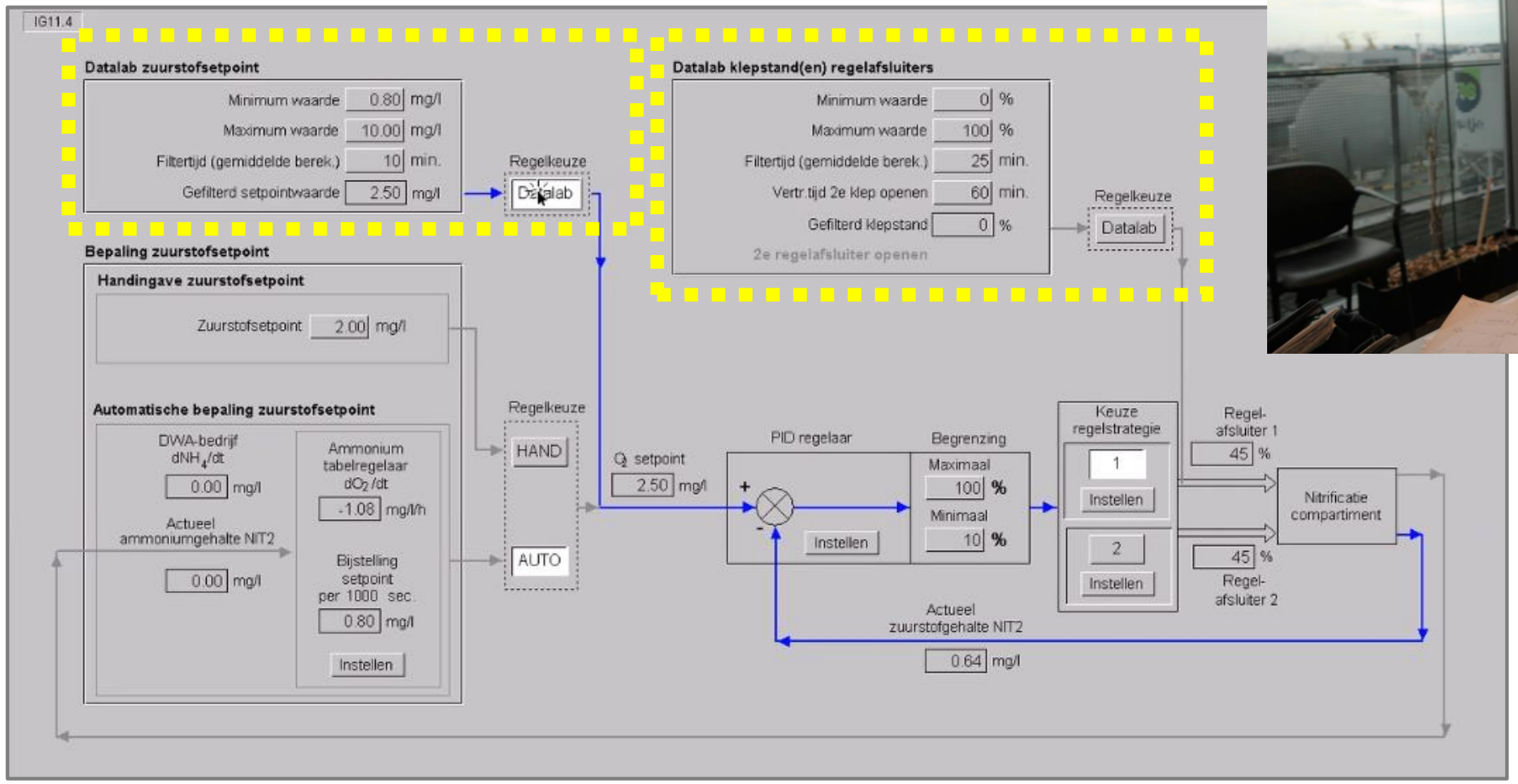
Observations
+
Reward



Agent

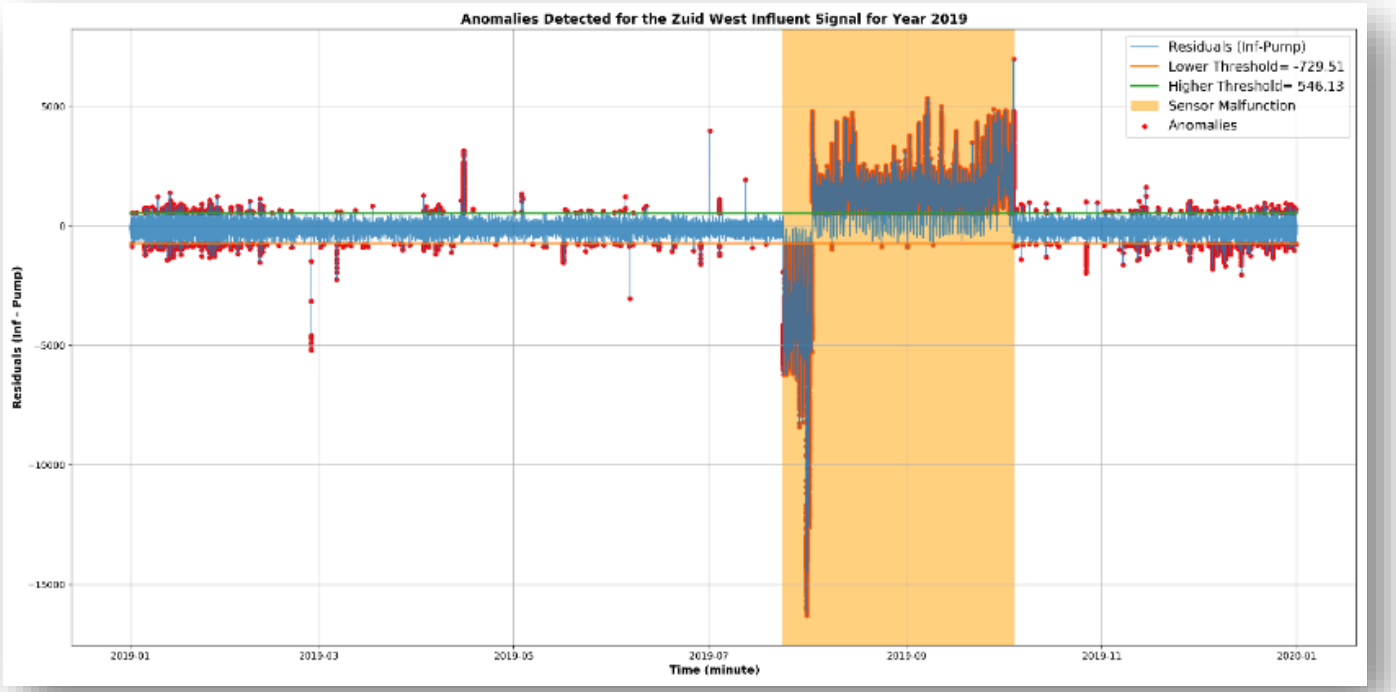
AI control implementation





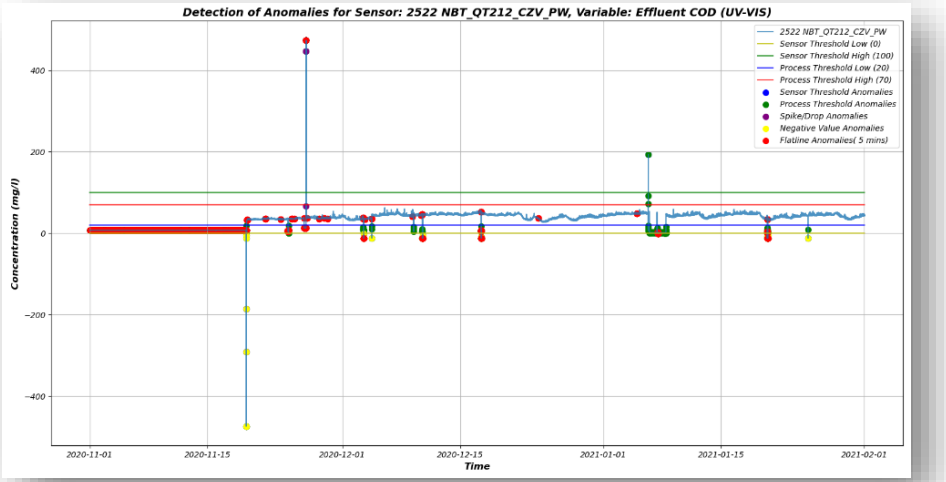
Automatic Data Validation and Data Quality Control

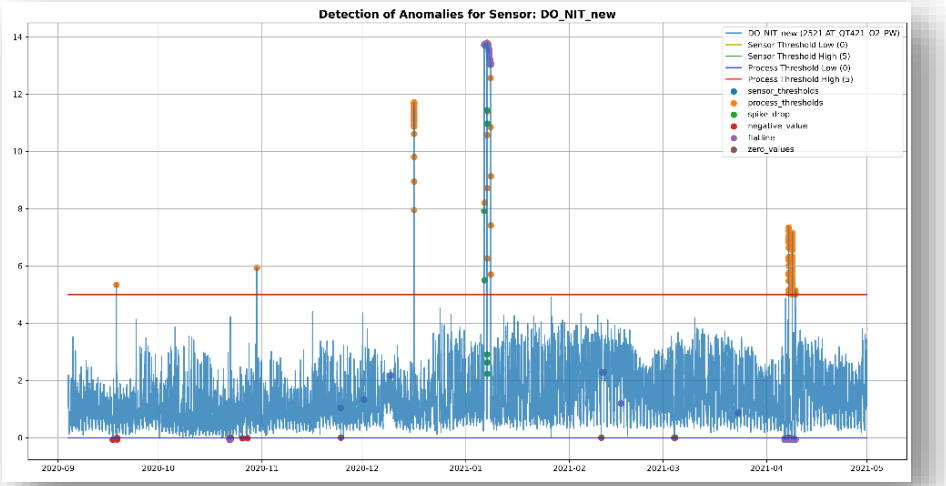
- Data quality can be impacted by sensor faults, (sensor) calibration issues, fouling, connectivity problems during transfer of data between the sensors/actuators and PIMS.
- Manual detection and correction can be labour intensive, particularly for signals used for simulation by AI models.
- Development of an automated data validation framework to screen raw data signals prior to model simulations and visualization.



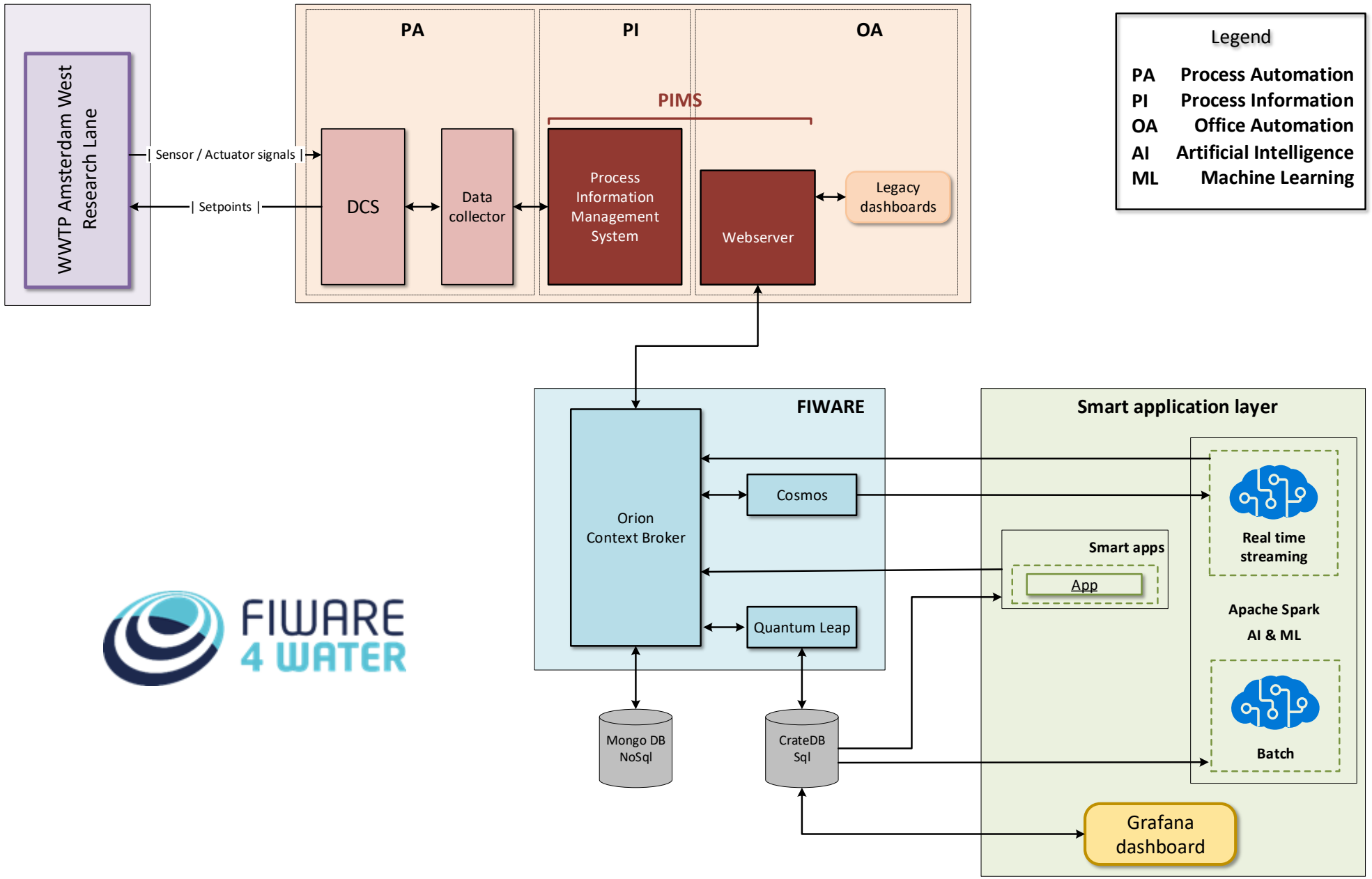
Automatic Data Validation and Data Quality Control

- 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.





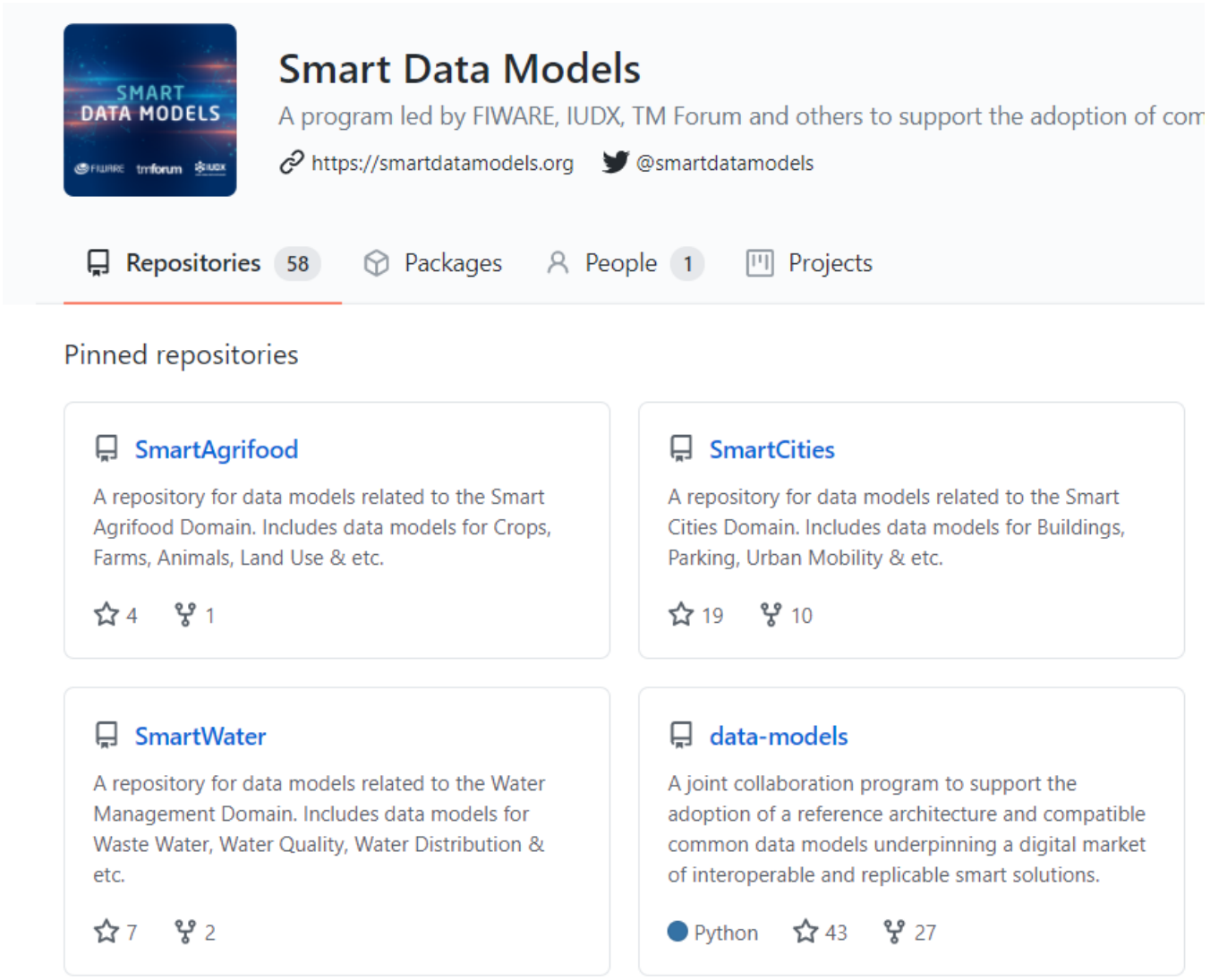
Integration of FIWARE To Legacy System



Data Integration Layer

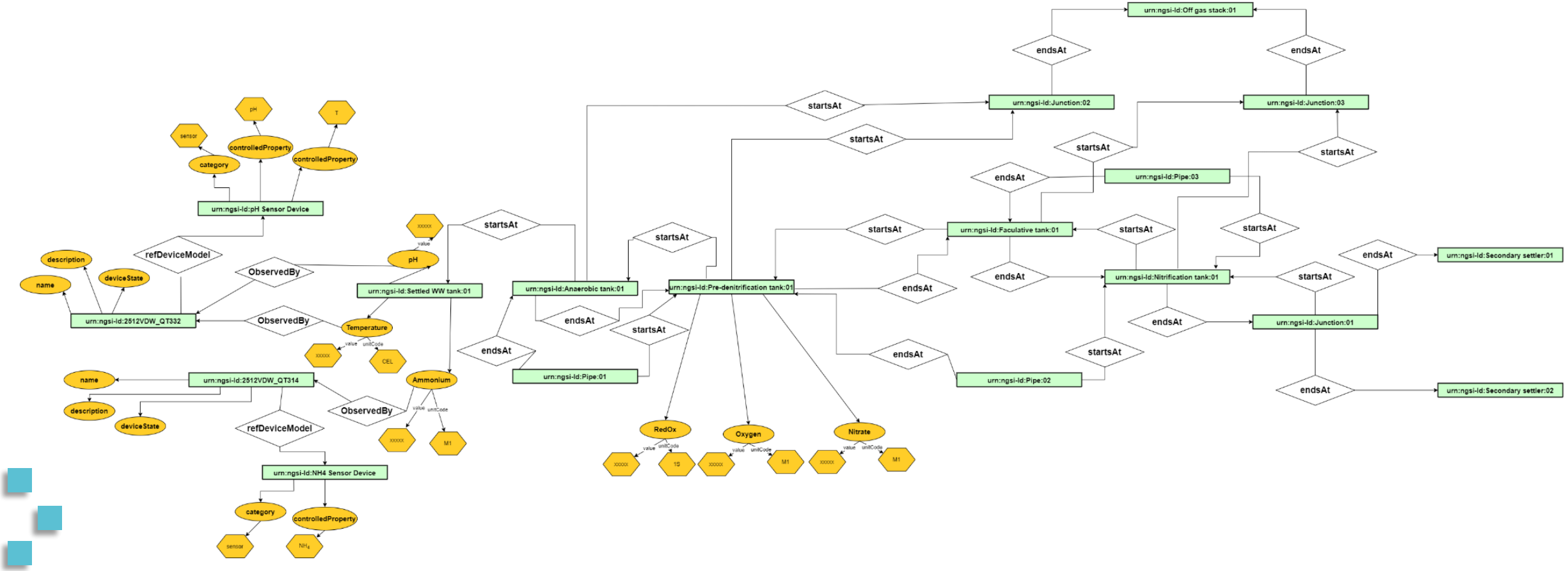
NGSI-LD Data Models Describing the ‘As-built’ Digital Twin

- 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

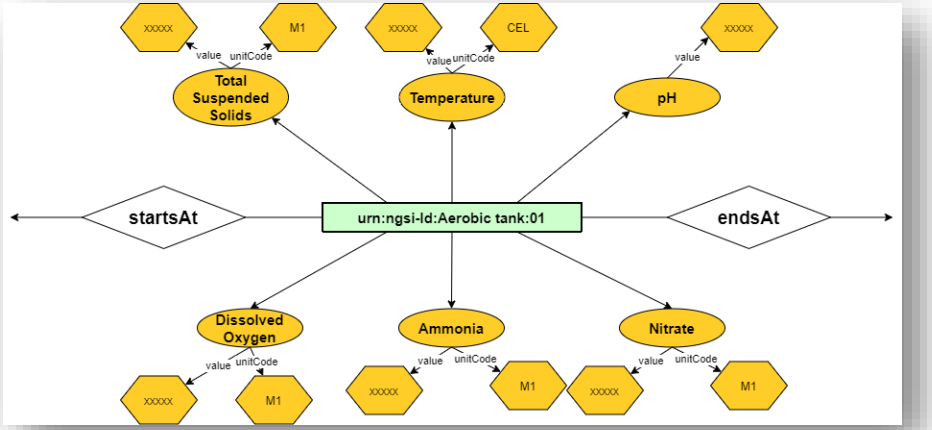
WasteWaterTreatment Data Models

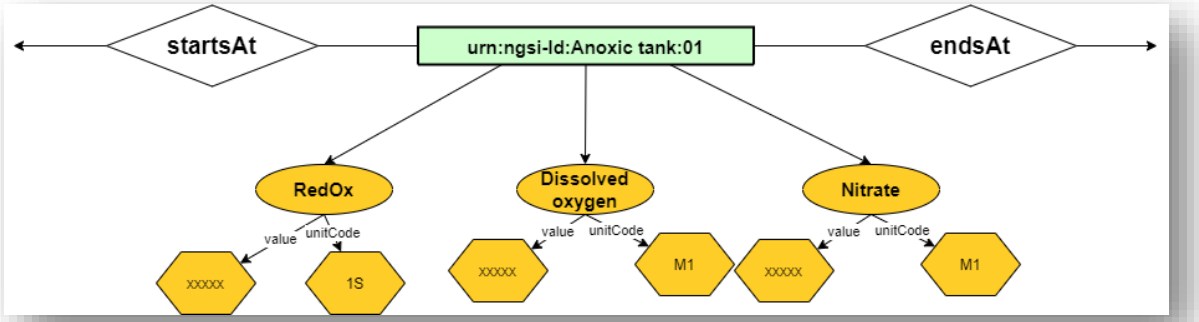
- Following entity types have been developed:
  - WasteWaterTank
  - WasteWaterJunction
  - Blower
  - OffGasStack

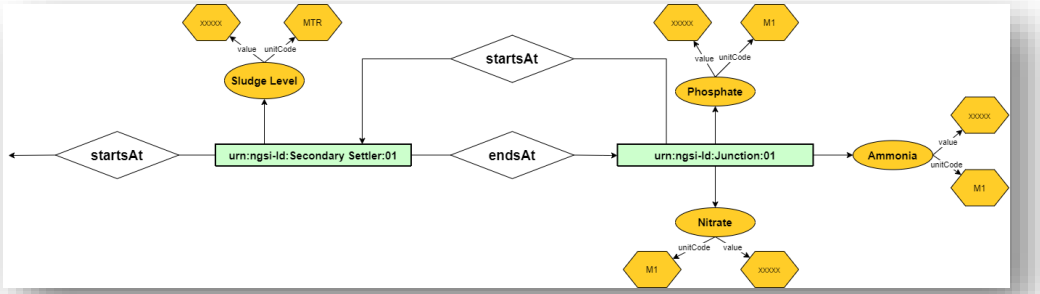
- Models can be found here - *https://github.com/smart-data-models/dataModel.WasteWater*

- 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.

ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

What is the secret of successful water smart industrial symbioses?

A. Kleyböcker and A. Perkis

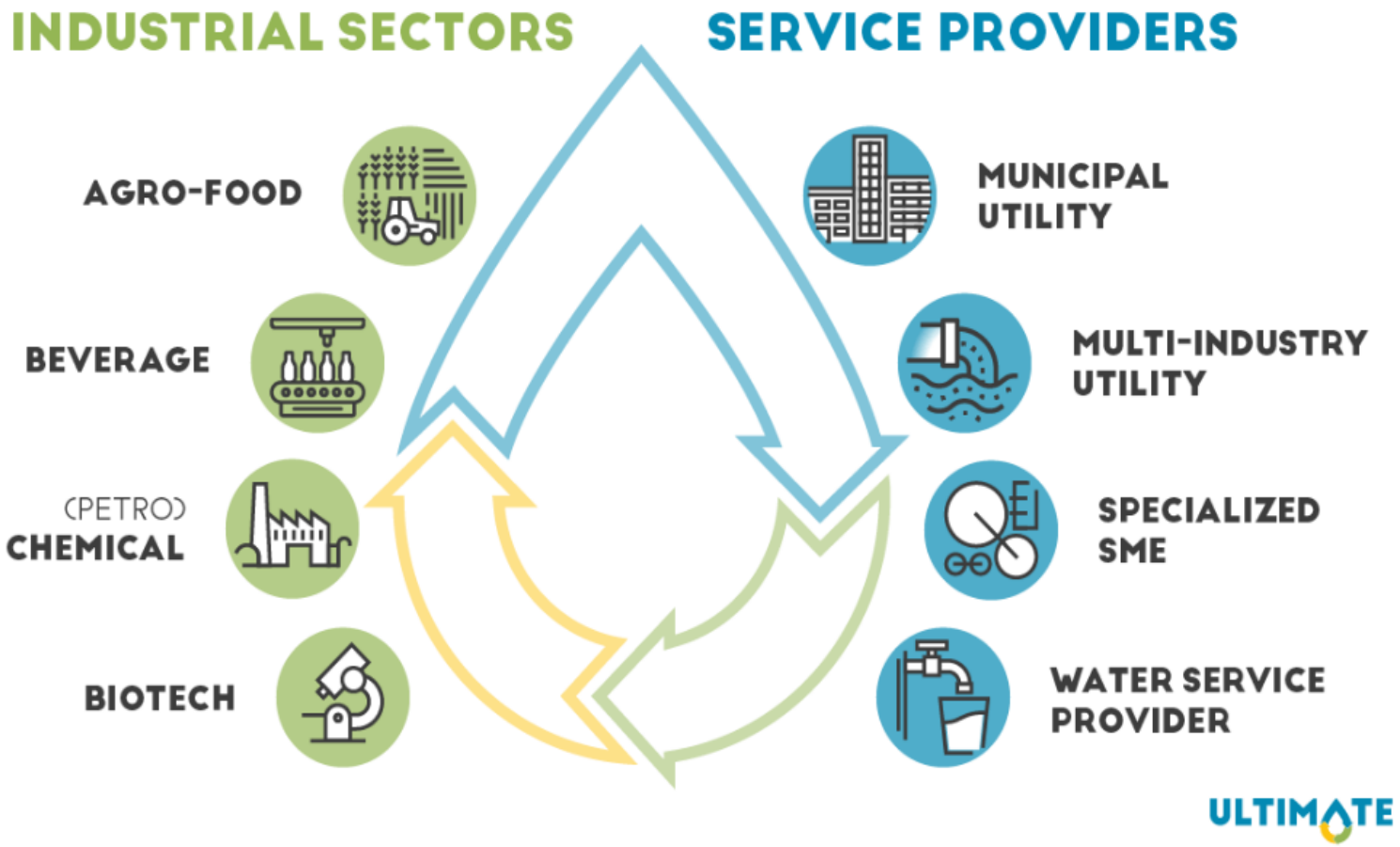
March 23rd 2022



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:

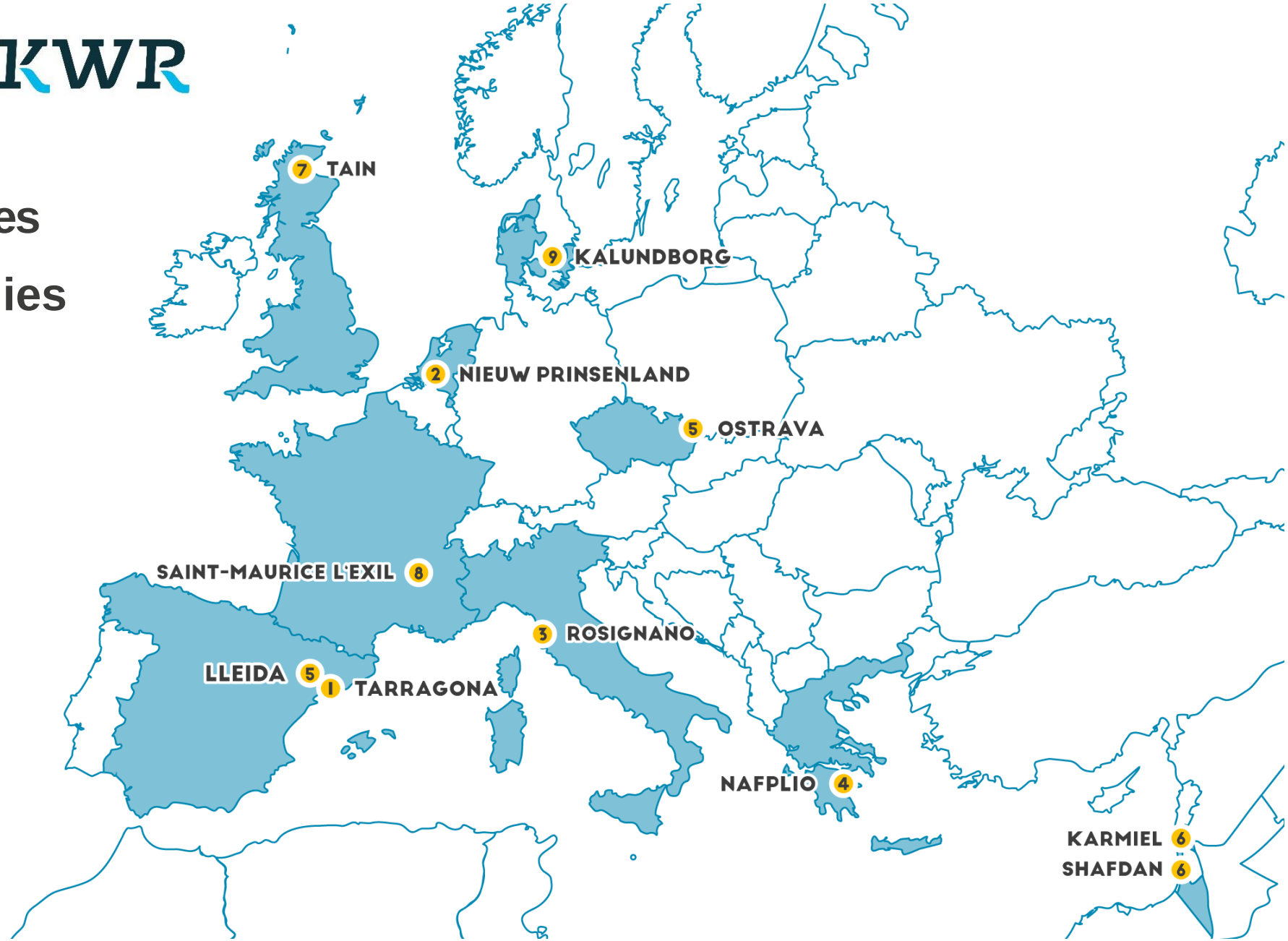


The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

Coordinator: KWR

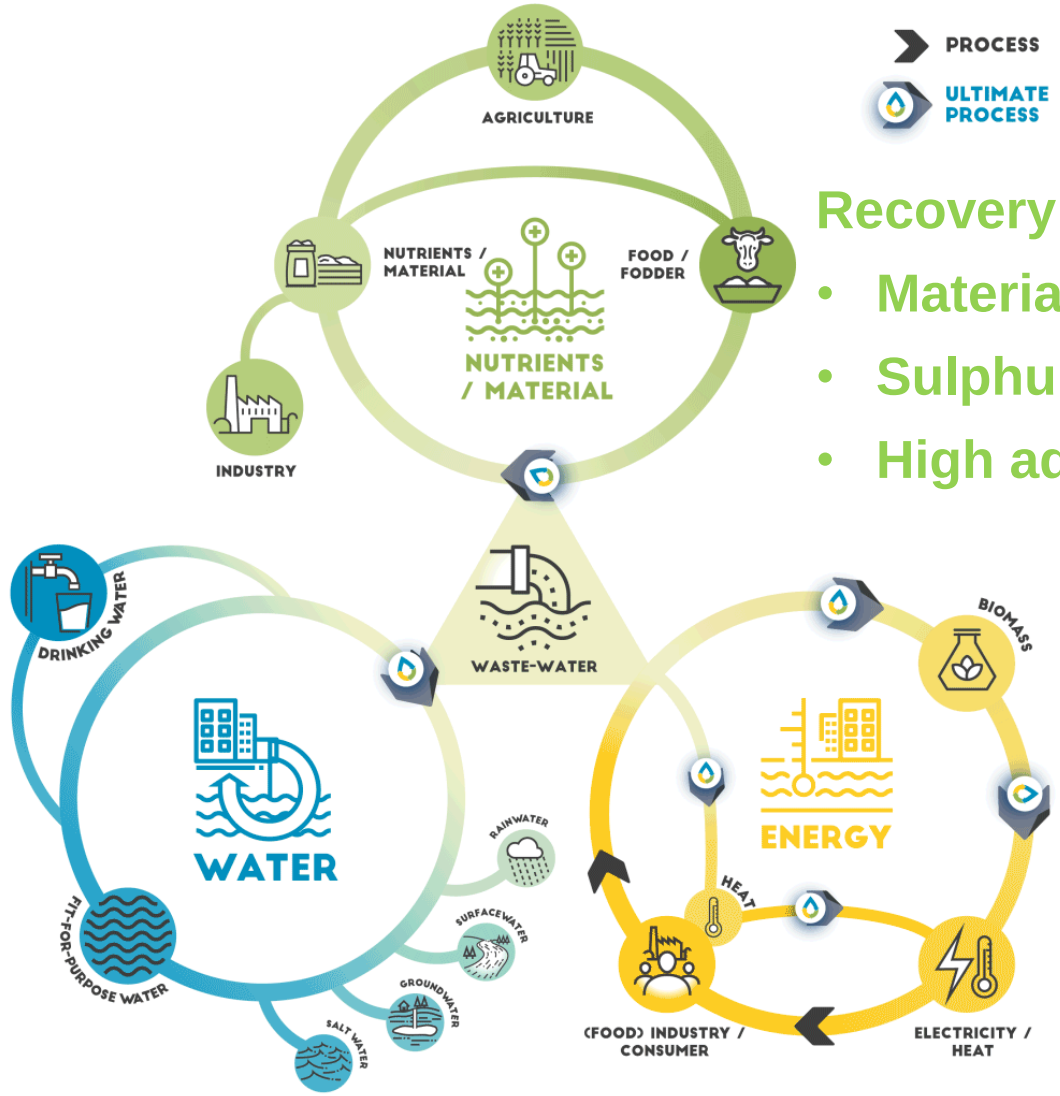
9 Case Studies

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

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Coordinator: KWR

9 Case Studies

37 Technologies



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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.

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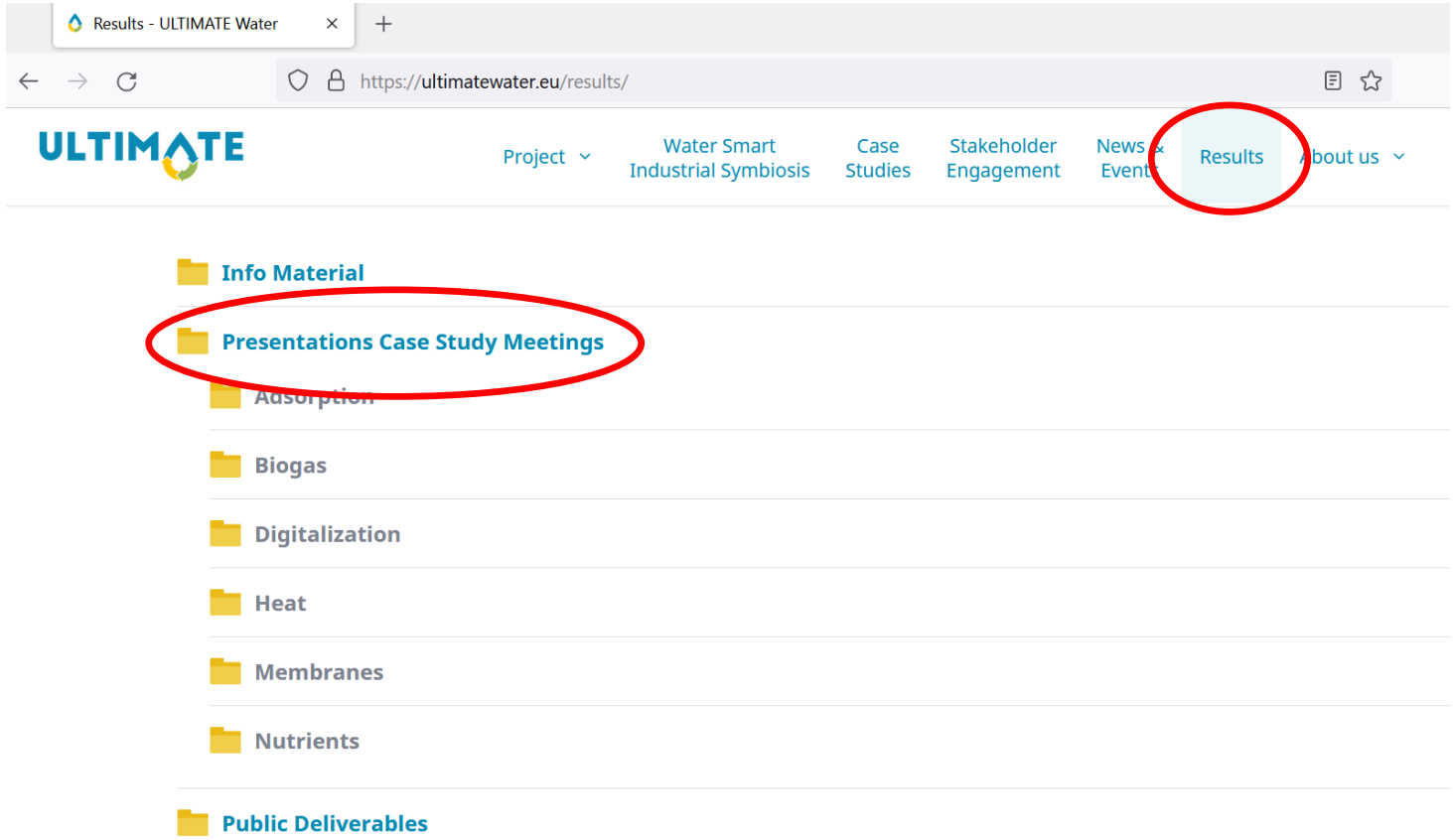
Presentations will be available on our webpage: ultimatewater.eu



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Success of the Tarragona Symbiosis and Strategy of the Water-Smart Industry Vision Leadership

Miquel Rovira Boixaderas and col.

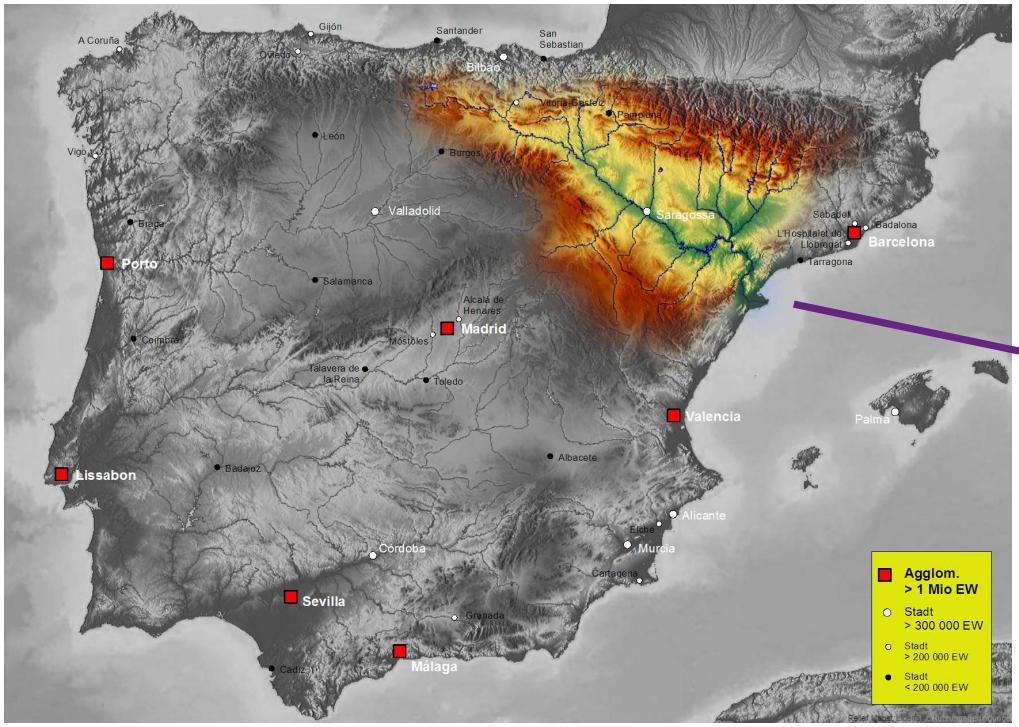
Eurecat – Centre Tecnològic de Catalunya
Water-Smart Industry VLT, Water Europe

23 III 2022

Ebre (Ebro) River

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

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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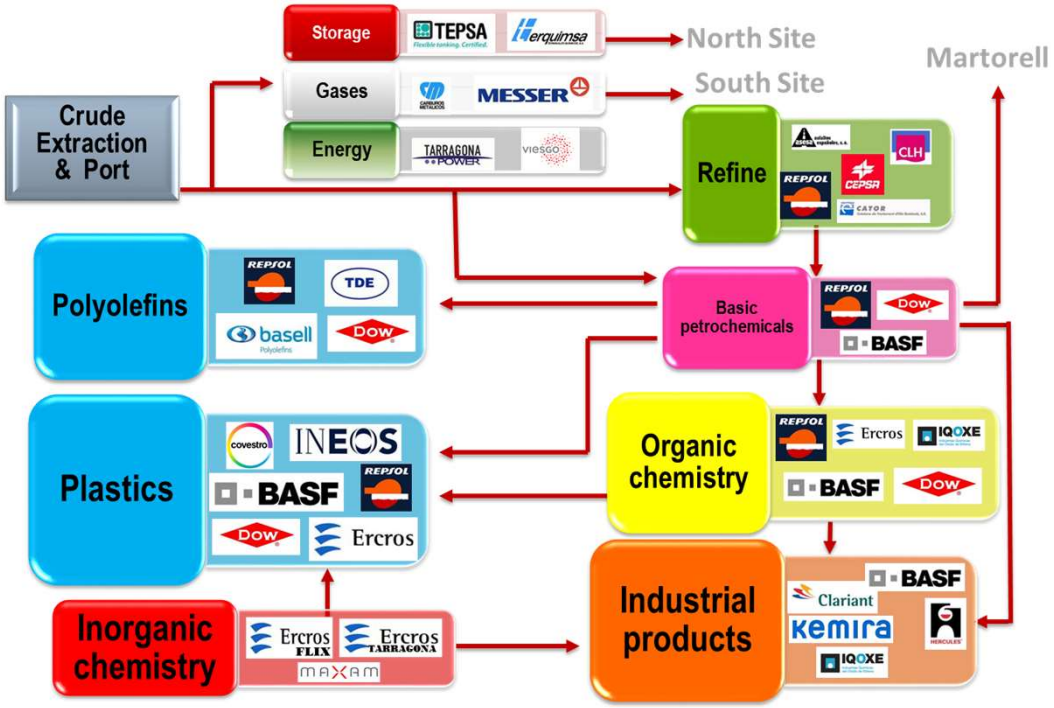
Centre Tecnològic de Catalunya

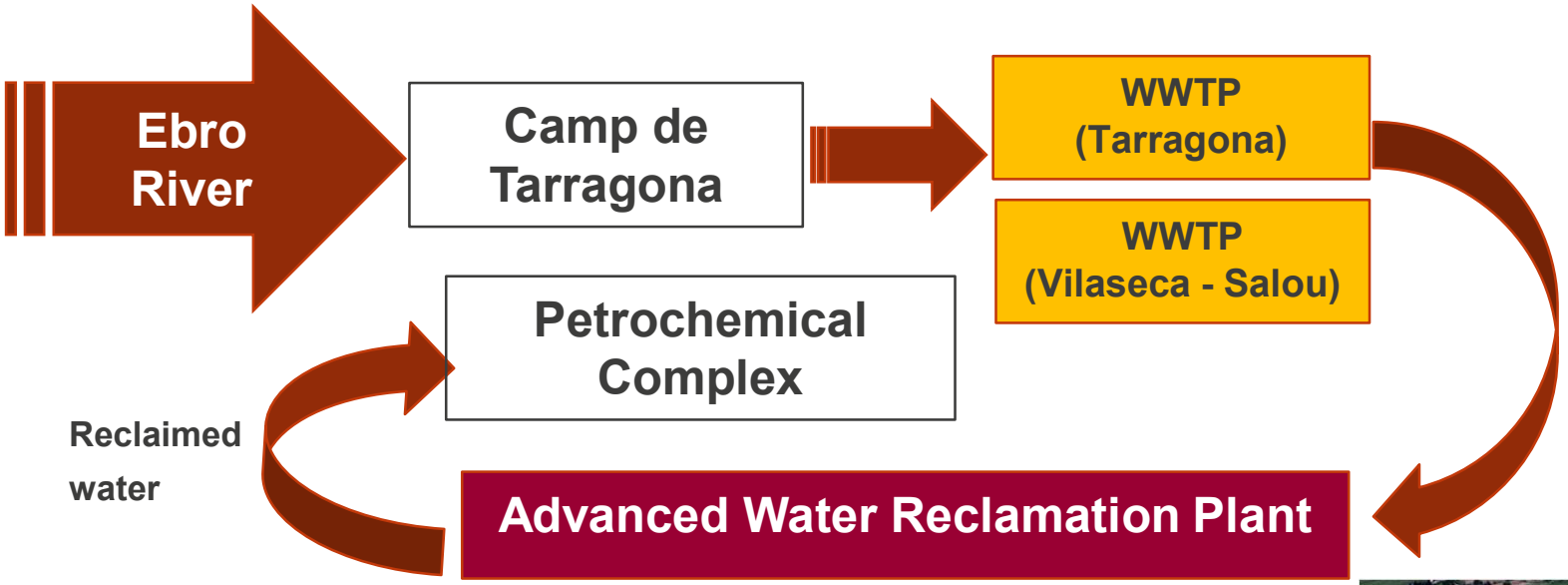
More than 100 chemical companies of all sizes, with 25% of chemical production in Spain and > 40,000 direct and indirect workplaces

Logistics Operators: SM RESINAS · CHEMIPRATS, S.L. · SCHMIDT · KATOEN NATIE · 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

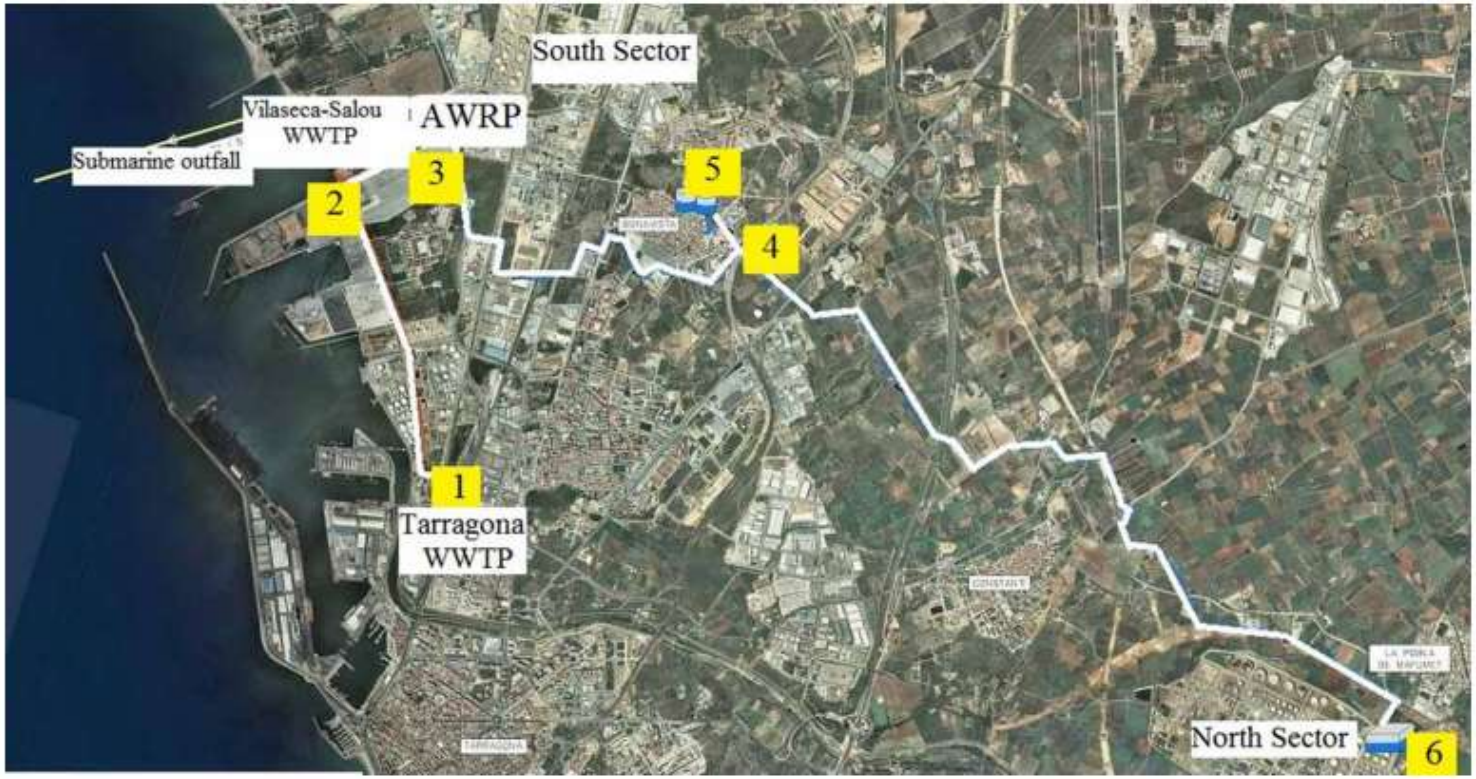


Figure 1 | Camp de Tarragona AWRP and reclaimed water supply network for industrial facilities at the Tarragona petrochemical park. (1) Tarragona wastewater treatment plant (WWTP); (2) diversion for submarine outfall; (3) Vilaseca-Salou WWTP and Camp de Tarragona AWRP; (4) diversion to north and south 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

The Symbiotic Solution

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).

eurecat
Centre Tecnològic de Catalunya

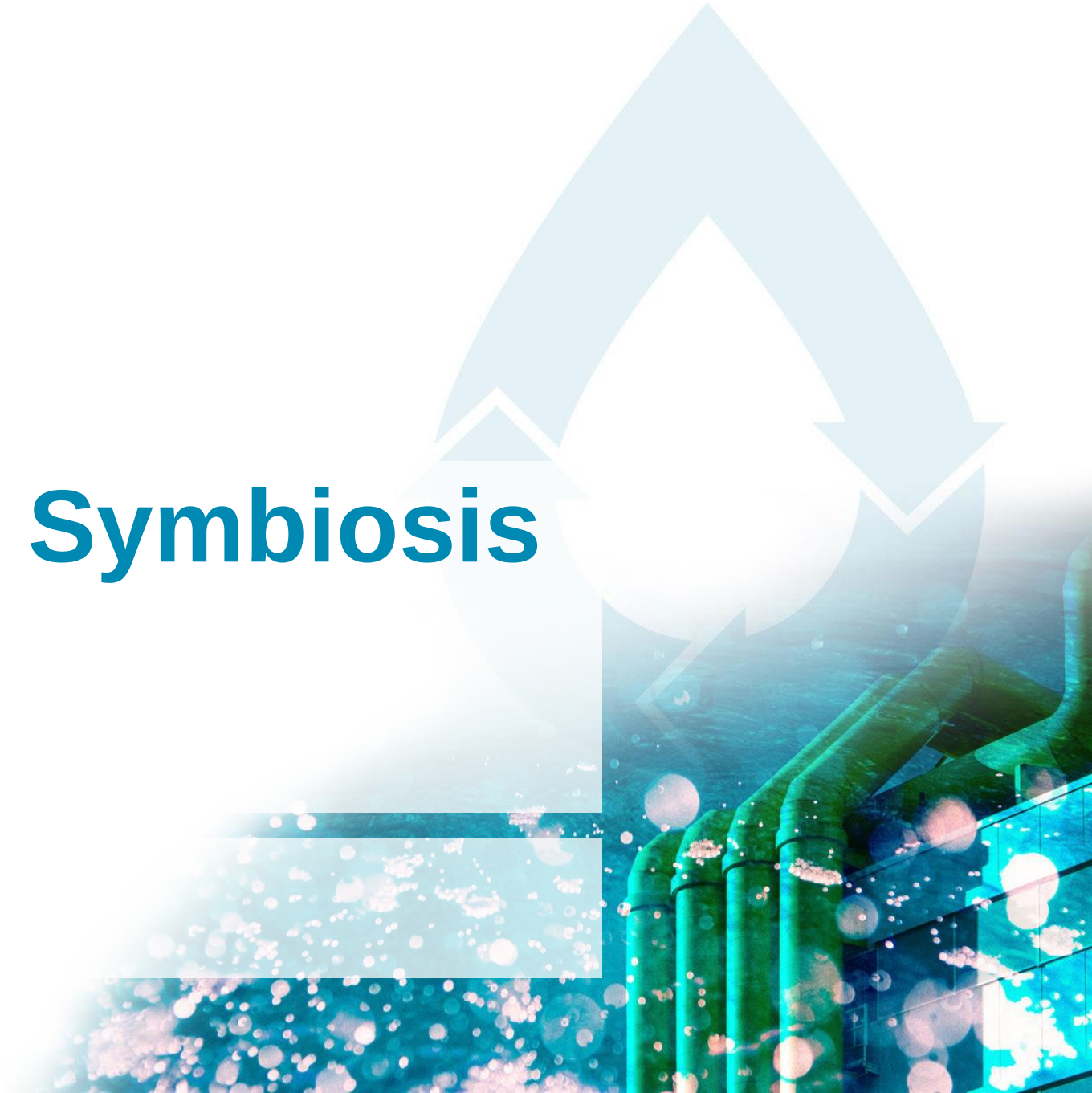
Thank you !

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

Objectives in terms of Water-Footprint reduction:

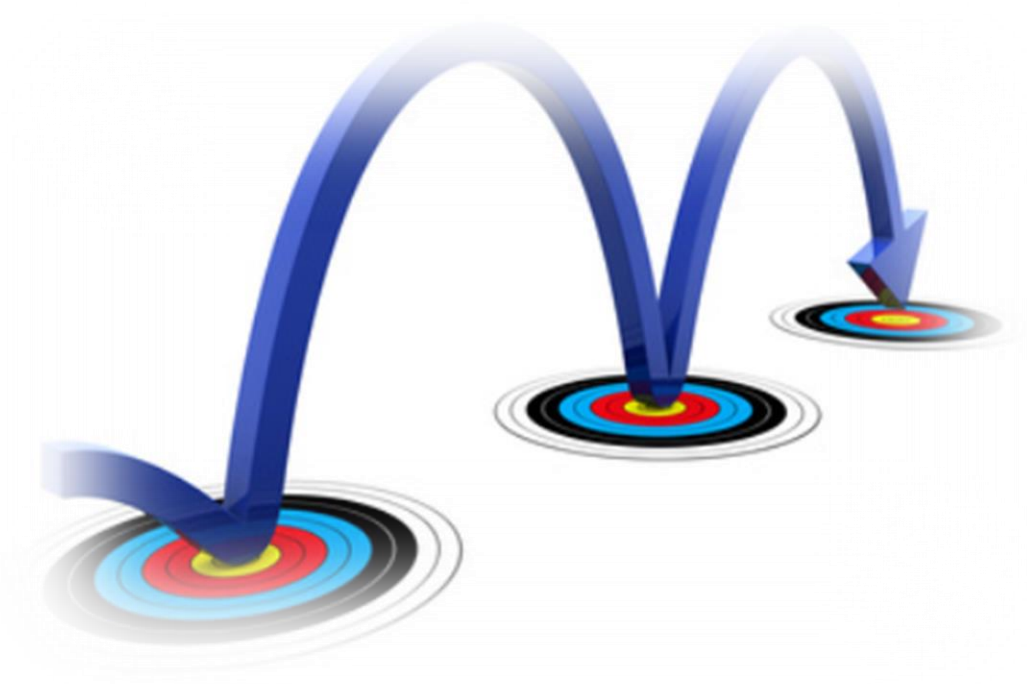
→ Collaboration in the growth of water re-use by Solvay;

→ 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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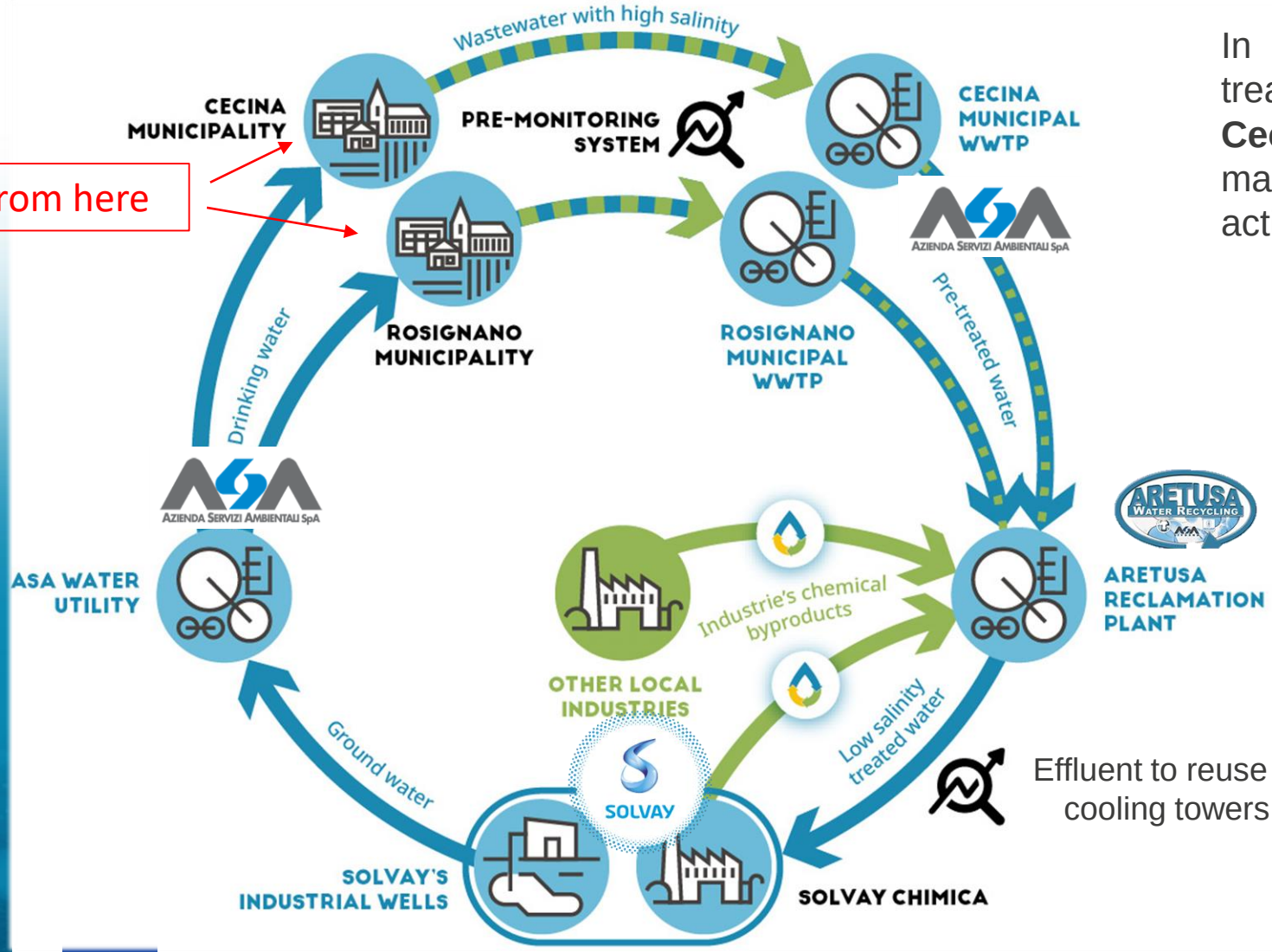
Aretusa concept – The technical idea



Effluent to reuse in cooling towers

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

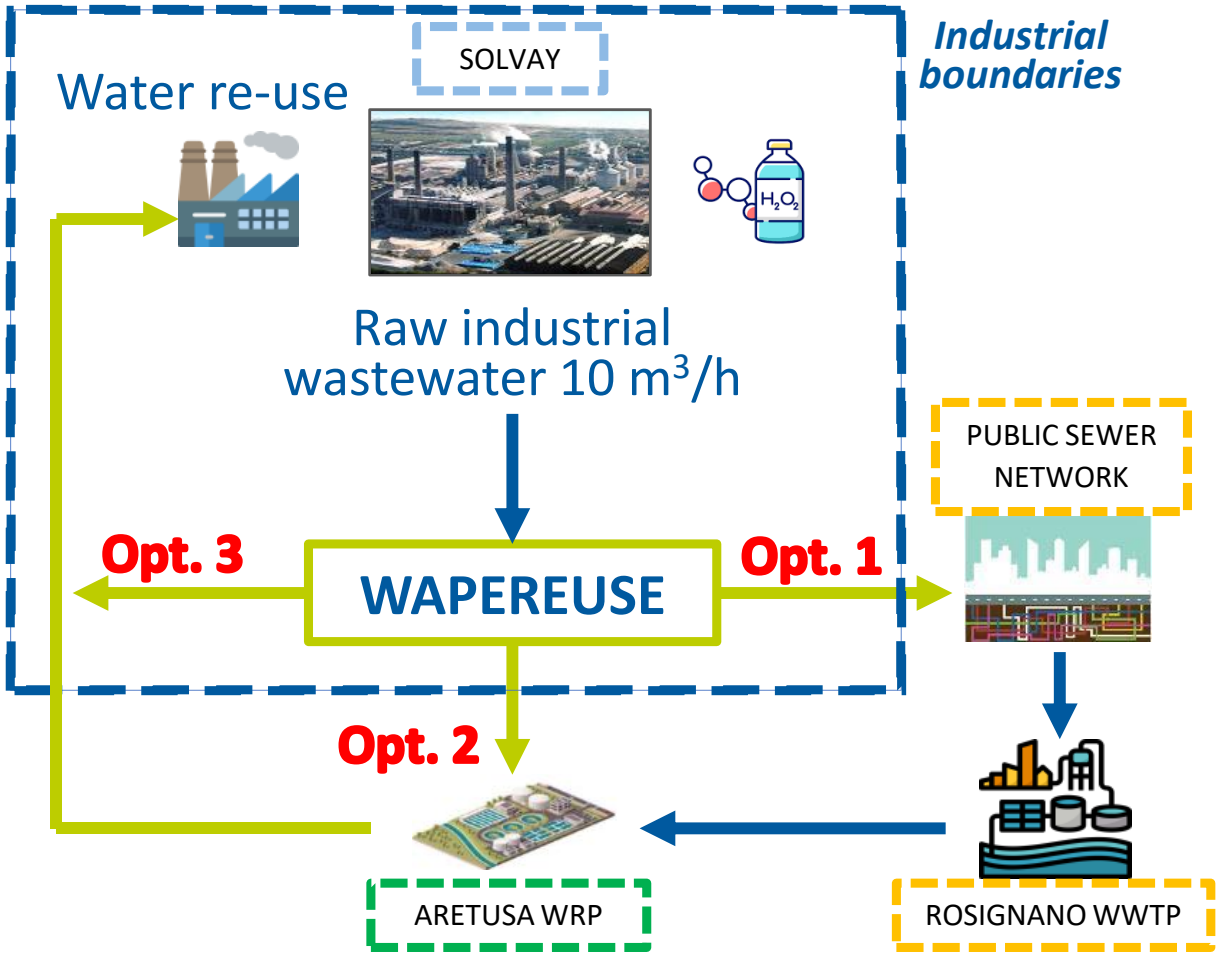
- Because the need to **reduce the environmental footprint** of industry has **grown** over the years
  - More social awareness of the climate change
  - Stakeholders expect the governments and the industries to act and act quickly
- Because the system can be **further optimized**
  - Improved water 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

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

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

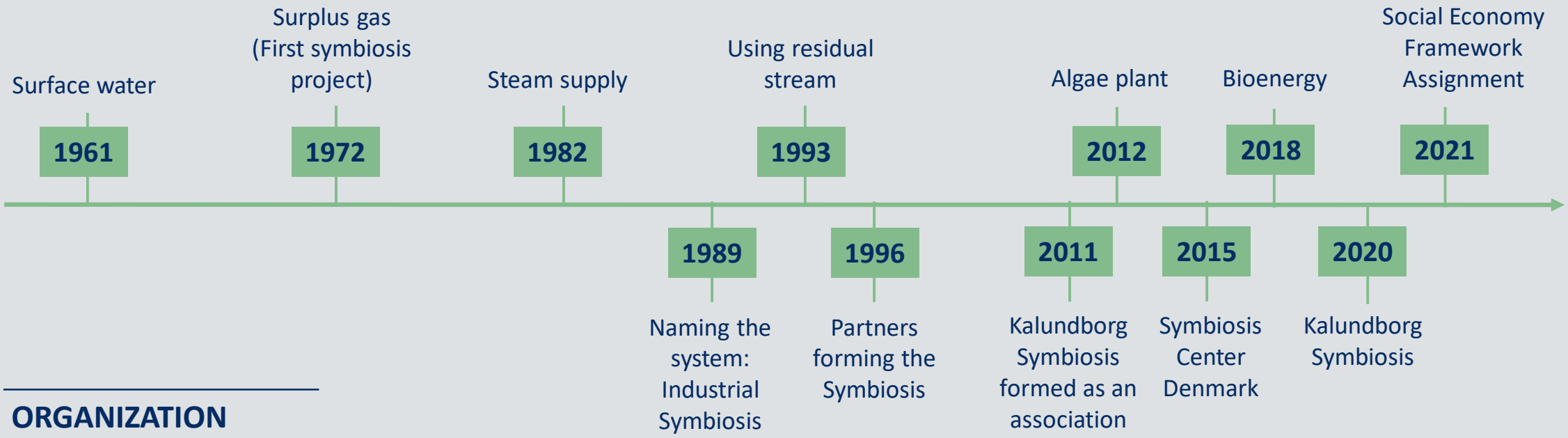
Agenda

- The history
- The ecosystem
- Four drivers for the resilient partnership

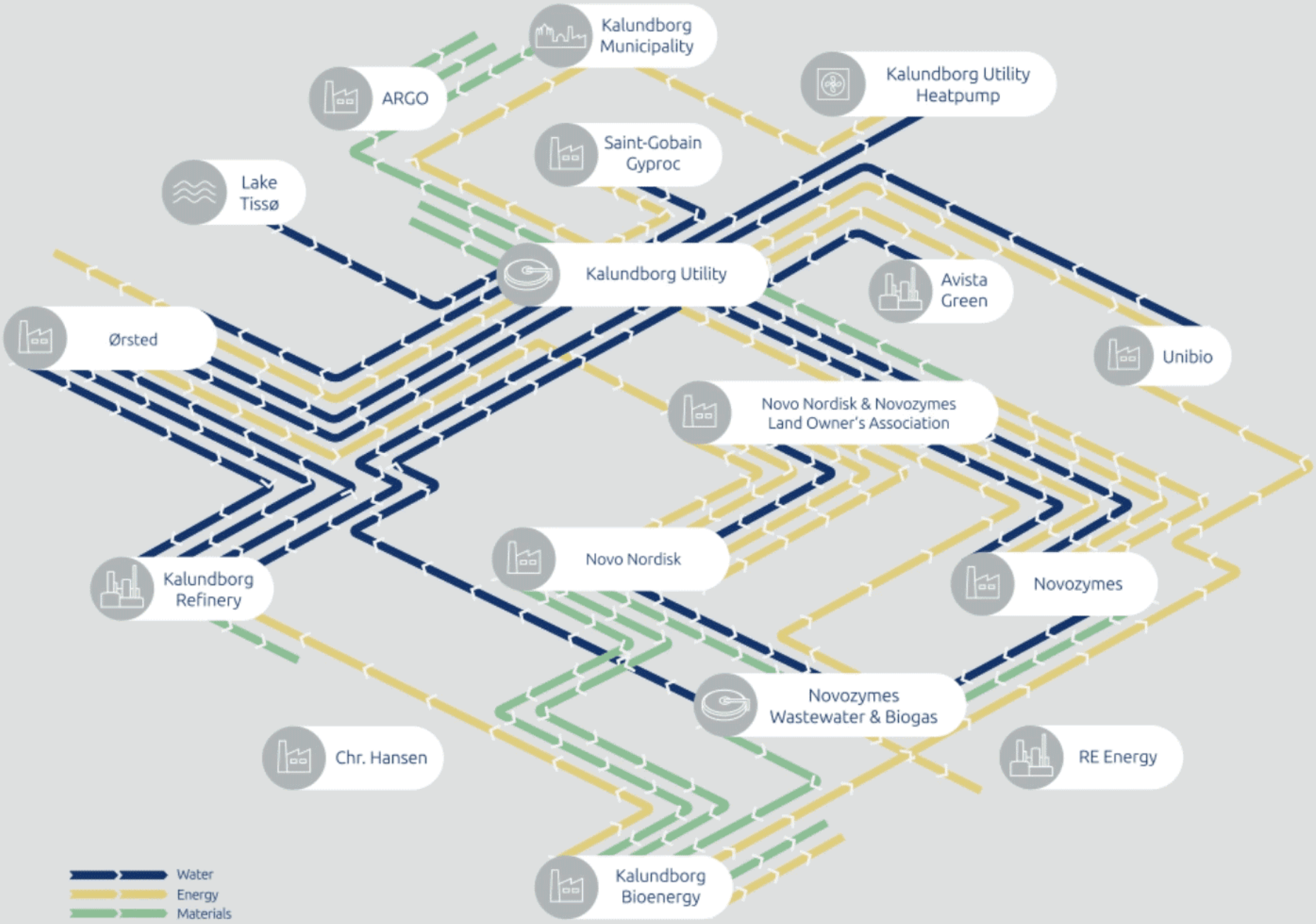


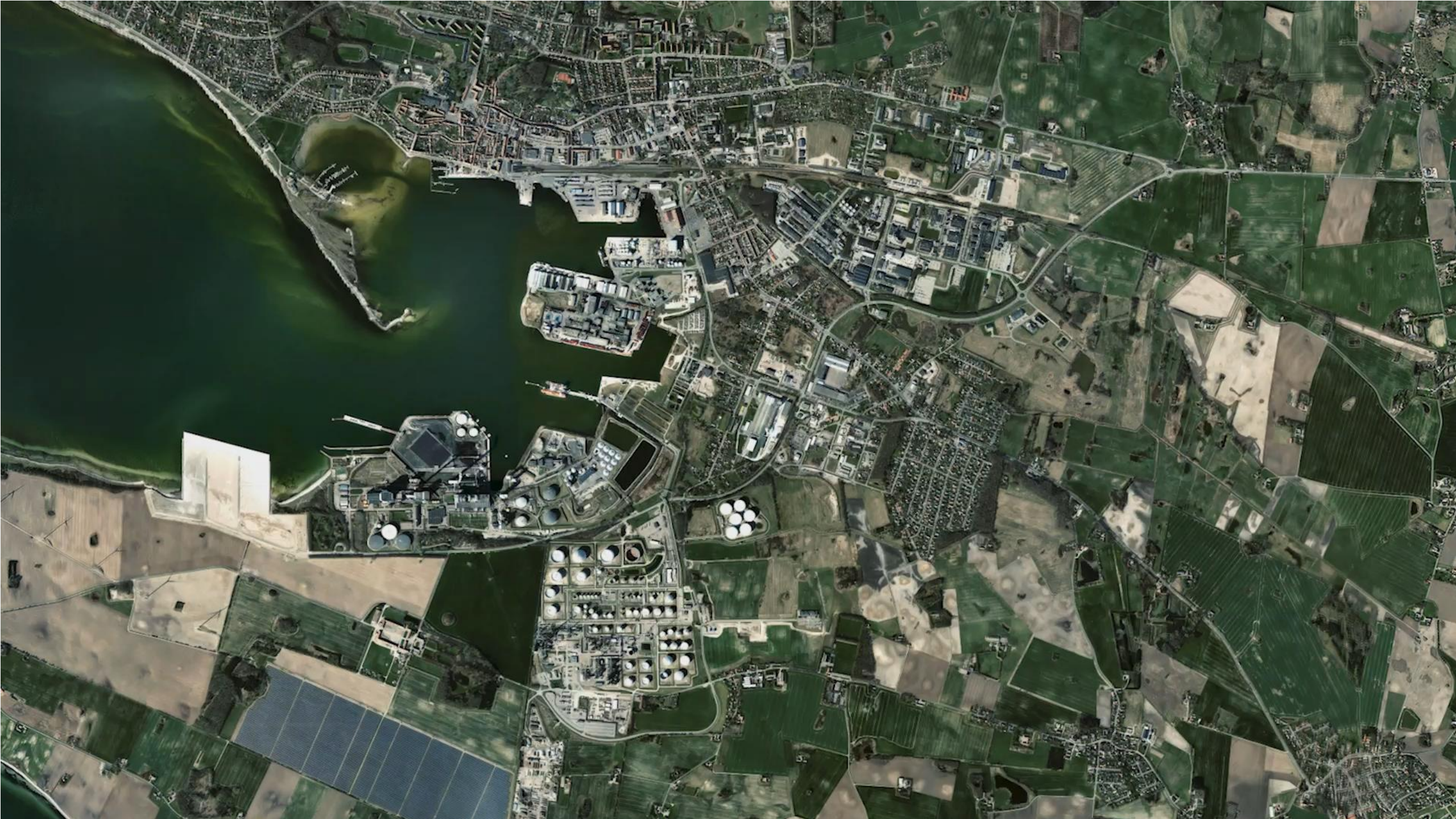
More than 50 years of cooperation

PROJECTS

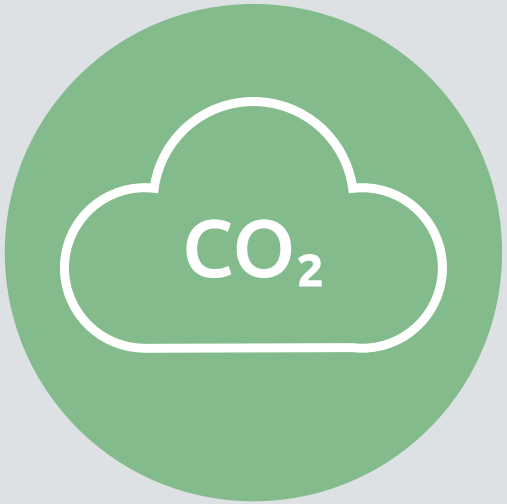


ORGANIZATION


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

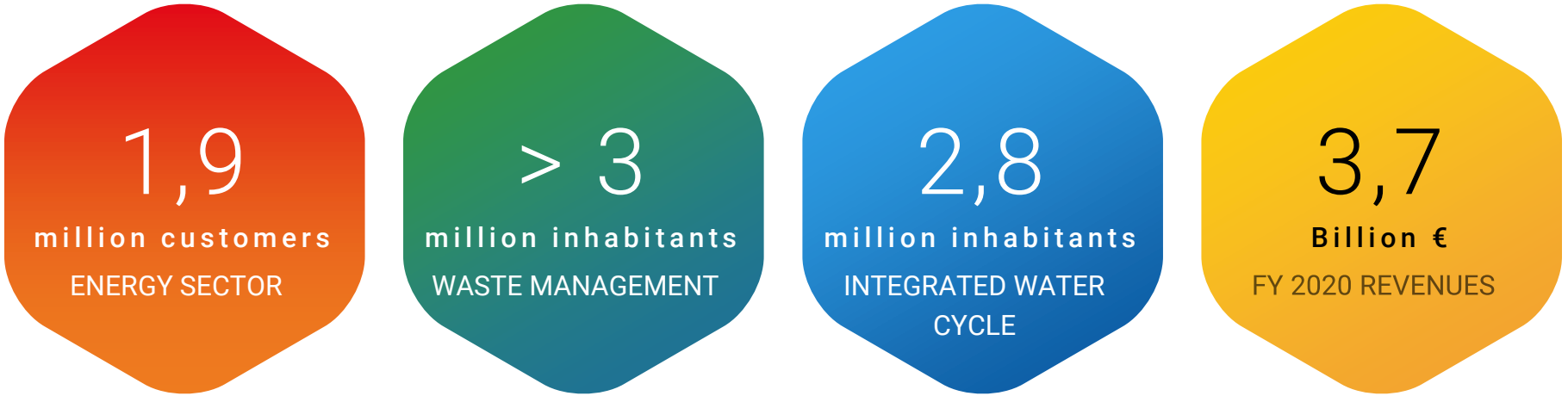
Some figures about IREN

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



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
19% Water Resources
30% Decarbonization
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



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

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*

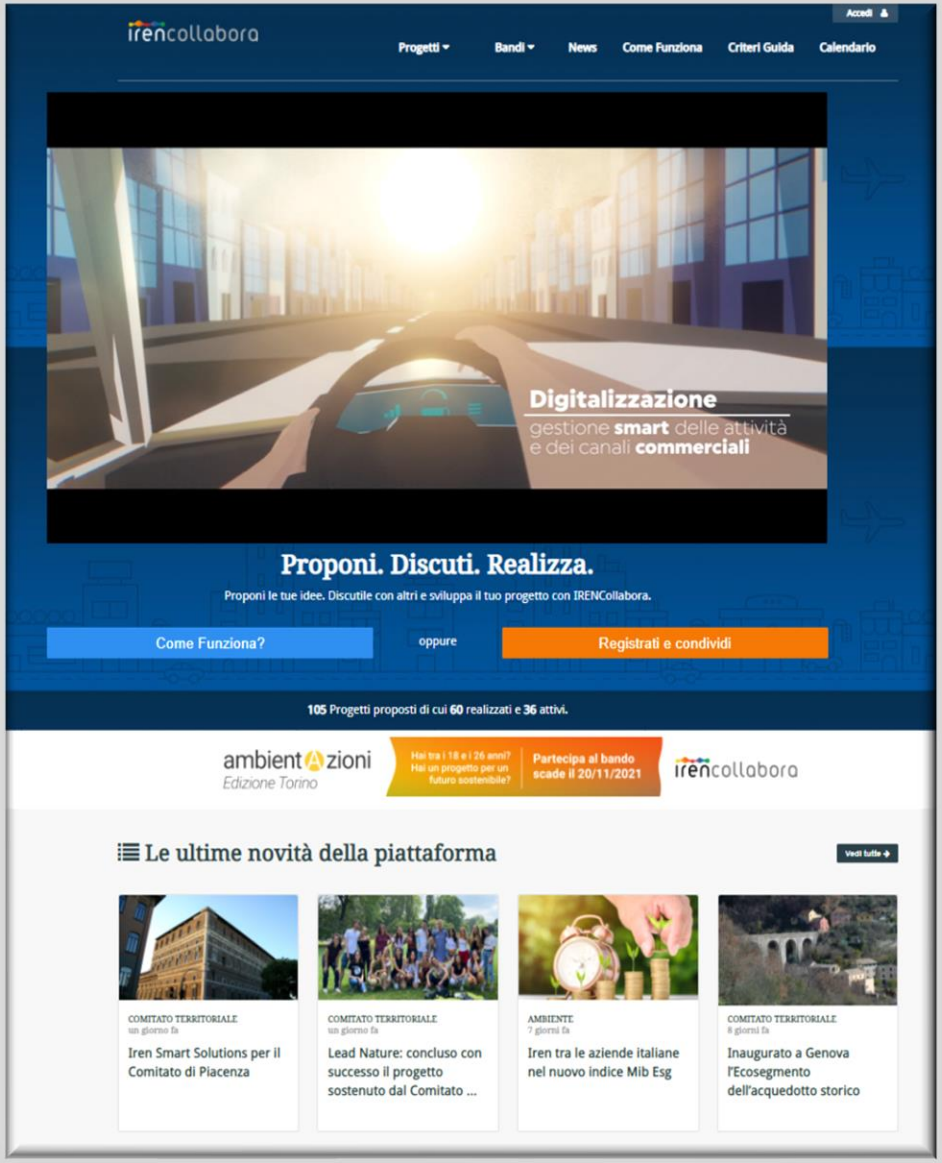
Participation is voluntary and free of charge.

Each committee has an annual budget to implement projects

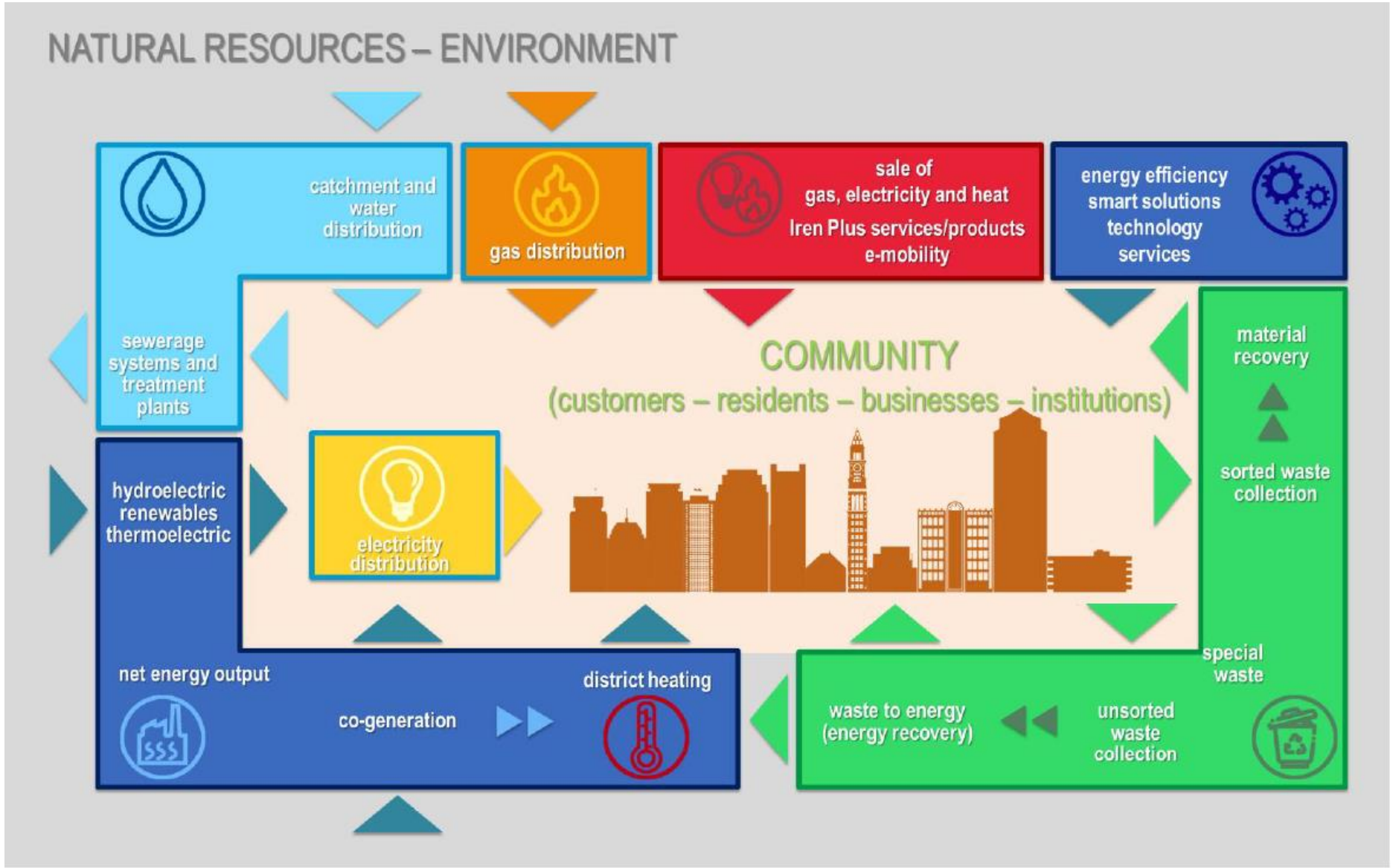
Citizens engagement

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.

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)

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.

Mancasale WWTP: waste water reuse for agriculture

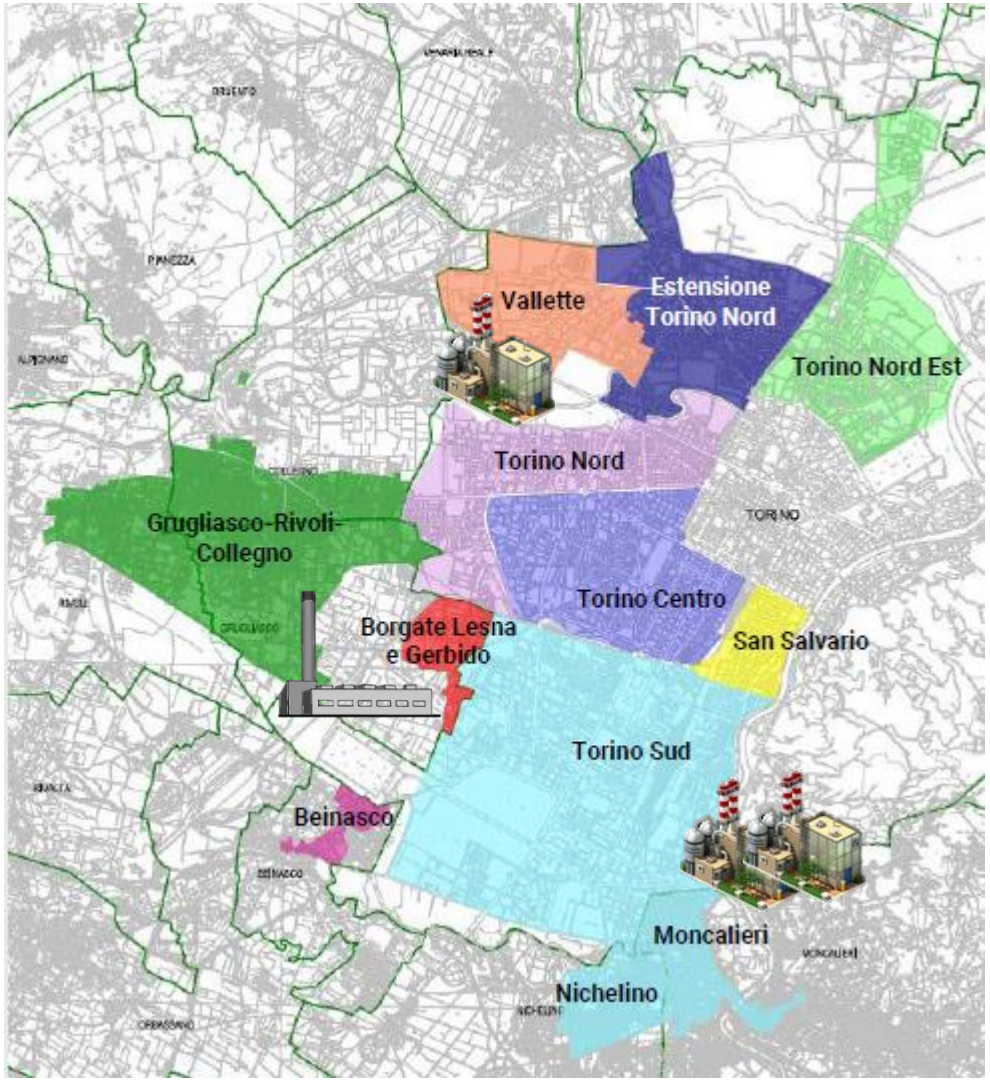
Mancasale (RE) WWTP represents the first plant in Emilia Romagna region equipped with an **advanced tertiary** treatment of waste water for **agriculture reuse.**

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 m³ 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

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

AquaSPICE

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.

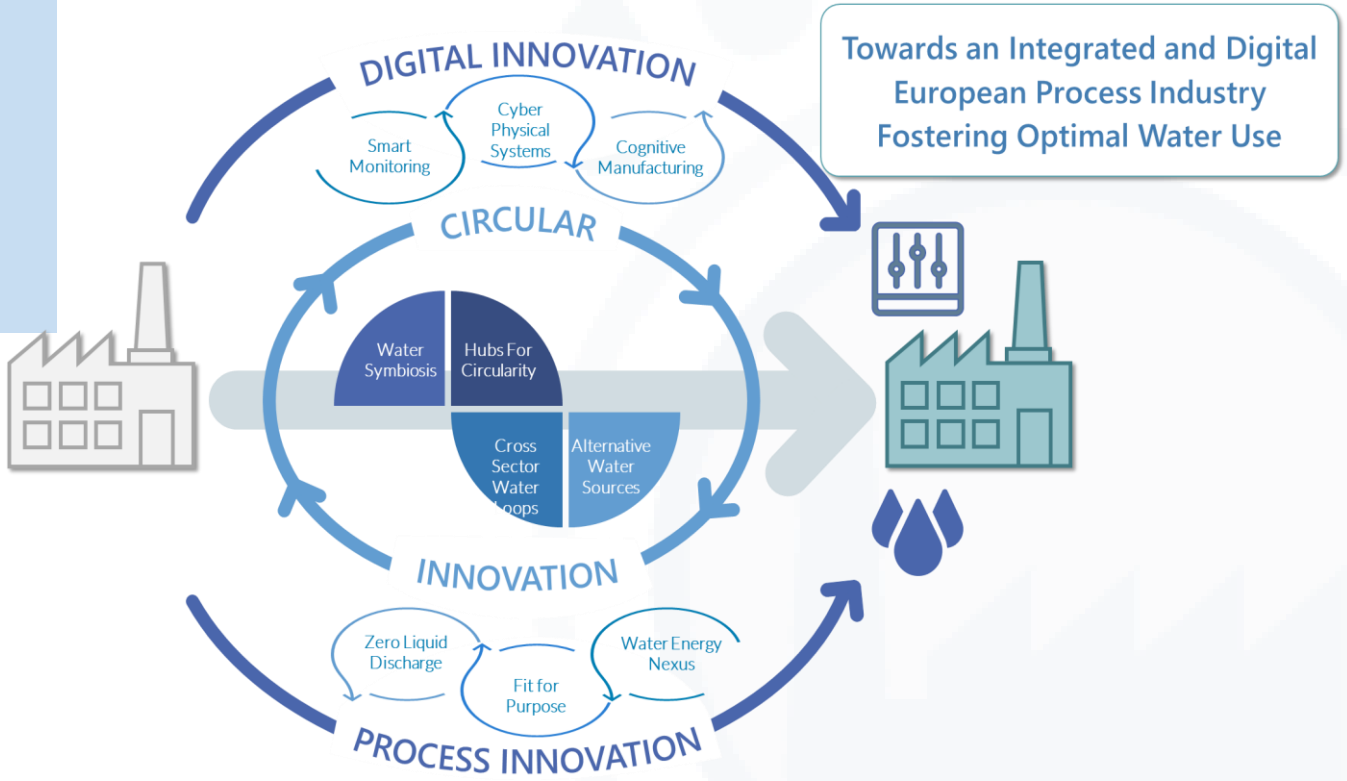
AquaSPICE Innovation Pillars

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$_2$re	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

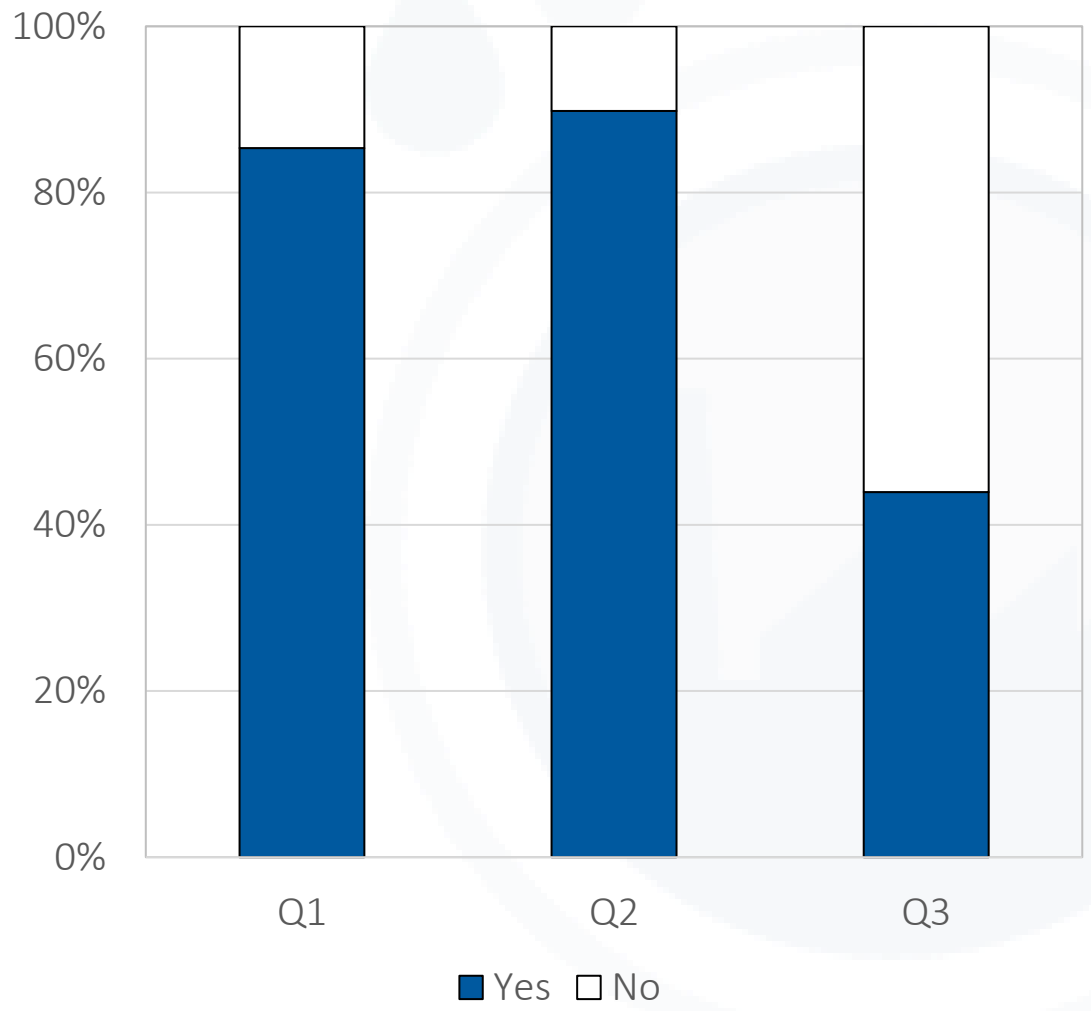
- Different Characteristics, Different Barriers and Different Problems
- Main factors examined
  - Technical Considerations
  - Industrial and Public Awareness
  - Common Sense

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.

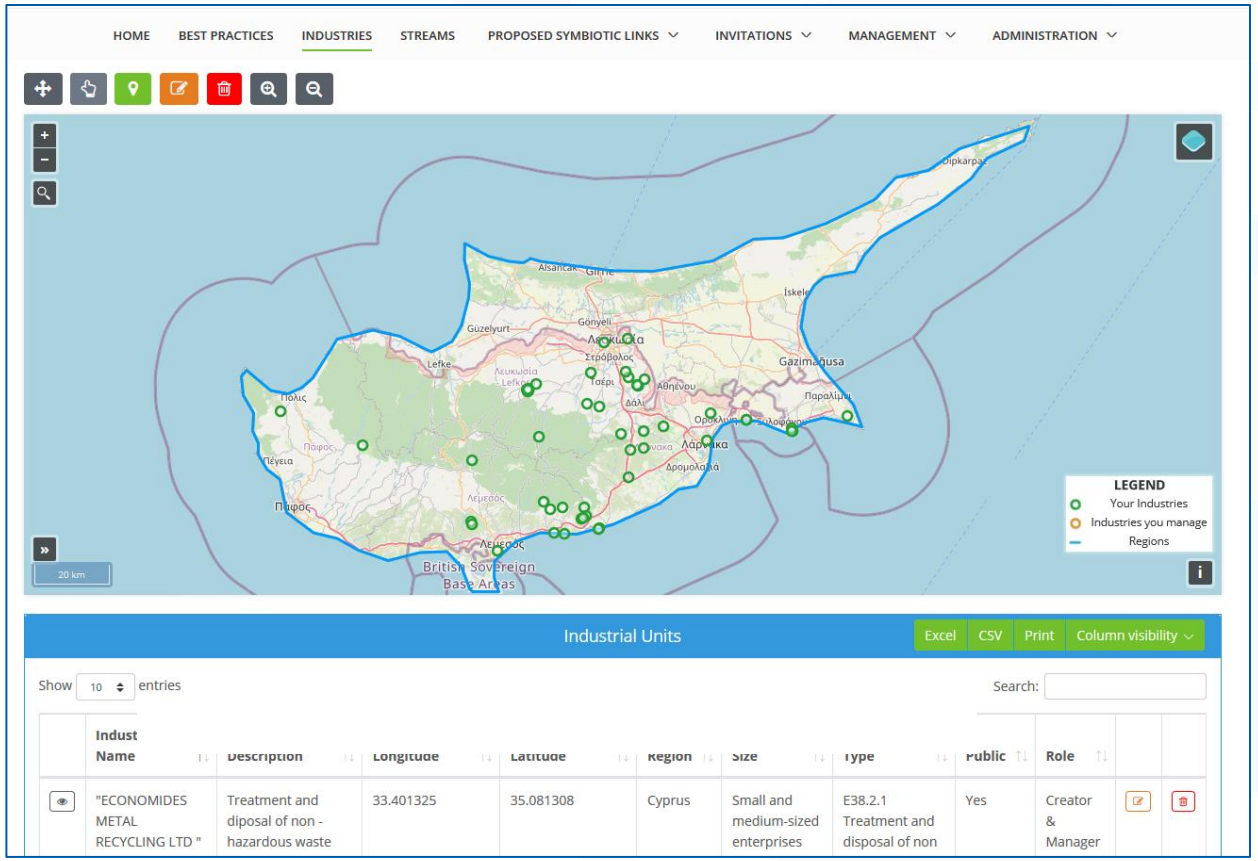
Common Sense

- 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?

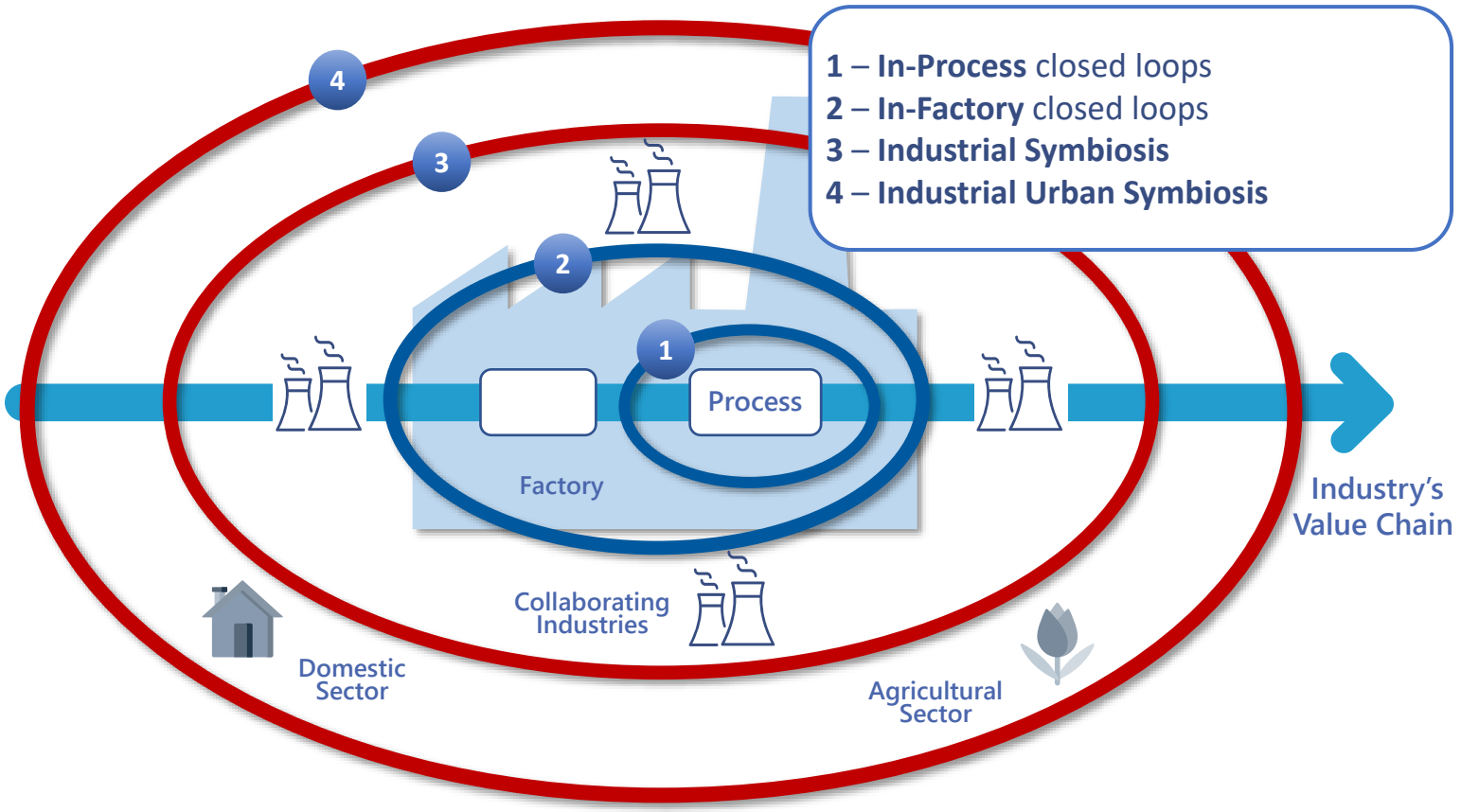
Should we / can we address everything?

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

AquaSPICE

Advancing Sustainability of Process Industries through Digital and Circular Water Use Innovations

Thank You!

Athanasios Angelis-Dimakis (UoH): A.AngelisDimakis@hud.ac.uk

George Arampatzis (TUC): garampatzis@pem.tuc.gr

Johann Poinapen (KWR): johann.Poinapen@kwrwater.nl

CTG meeting:

Membrane technologies in wastewater treatment

When: 6th March 2023 (10-12h)

Where: Online meeting

10:00 h **Opening and Welcome.** Andrea Naves (EURECAT).

10:05 h **ULTIMATE: Membrane technologies for reclaimed water production for the chemical and petrochemical industrial sector (CS1).** Andrea Naves (EURECAT).

10:20 h **ULTIMATE: Experiences in Aqualia with Anaerobic Membrane Bioreactors, core for future water resource recovery facilities (CS5).** Antonio GIménez (Aqualia).

10:35 h **ULTIMATE: Membrane technology for reuse of treated wastewater as fit-for-purpose water – results from the first test period in Kalundborg (CS9).** Jeannette Jährig (KWB).

10:50 h **Break**

11:00h **B-WATERSMART: Brine valorisation for disinfectants production through selective electrodialysis.** Eric Santos (Cetaqua).

11:15 h **WIDERUPTAKE: Water reuse in Sicily within WiderUptake Project.** Giorgio Mannina (Università de Palermo).

11:30 h **Open discussion and closure.** Andrea Naves (EURECAT).

ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

Membrane technologies webinar

A. Naves, S. Casas

March, 6th 2023



ULTIMATE-Membrane technologies 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

Key Ultimate information

Call	2017 - H2020 – Greening the economy in line with the Sustainable Development Goals (SDGS) - H2020-SC5-2018-2019-2020
Topic	CE-SC5-04-2019 - Building a water-smart economy and society
Budget	**TOTAL:** Budget 16.614.814€
Duration	48 months (01/06/2020 – 31/05/2024)
Partners	27 (12 private companies; 8 non-profit/private centers; 7 public centers) from 11 countries
Coordinator	KWR WATER (NL)

Web del proyecto: https://ultimatewater.eu/

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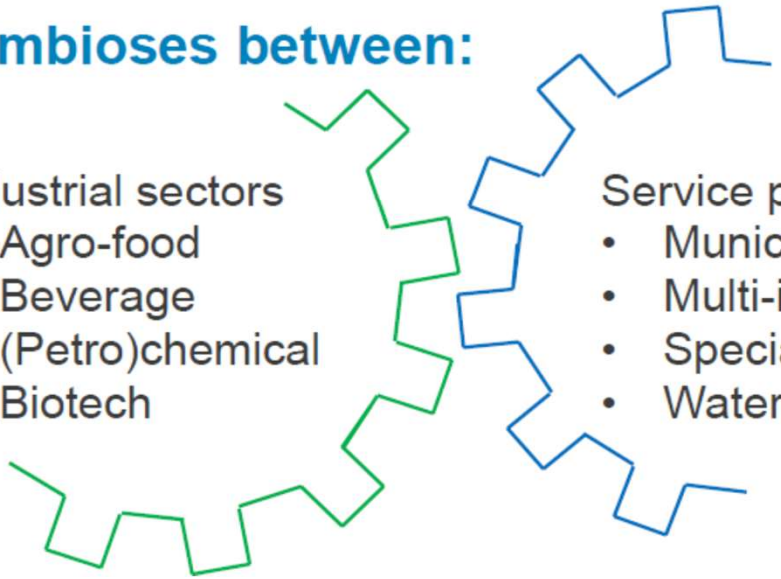
Ultimate (June 2020 – May 2024):

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

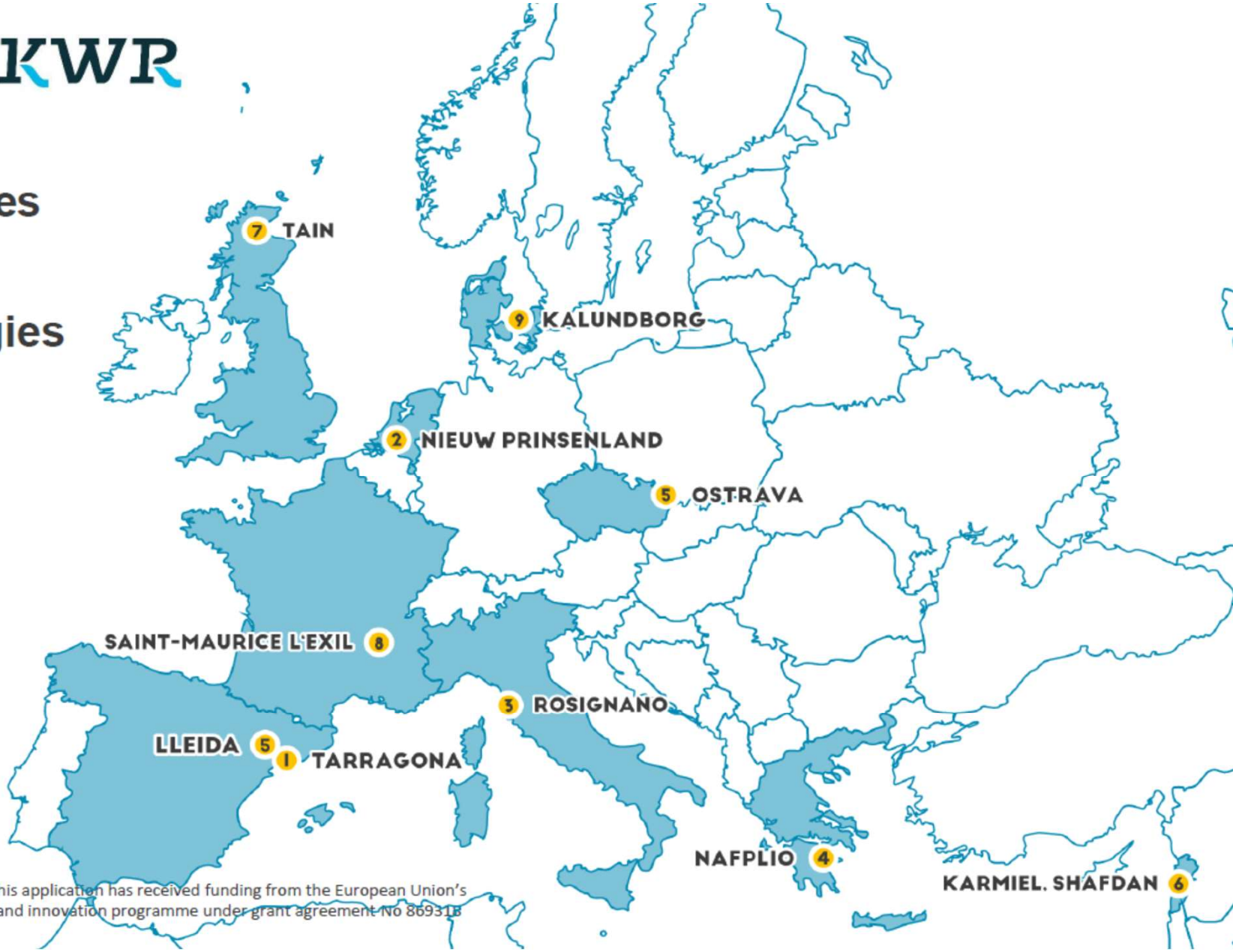
Service providers
- Municipal utility
- Multi-industry utility
- Specialized SME
- Water services provider

Coordinator: KWR

9 Case Studies

27 Partners

37 Technologies



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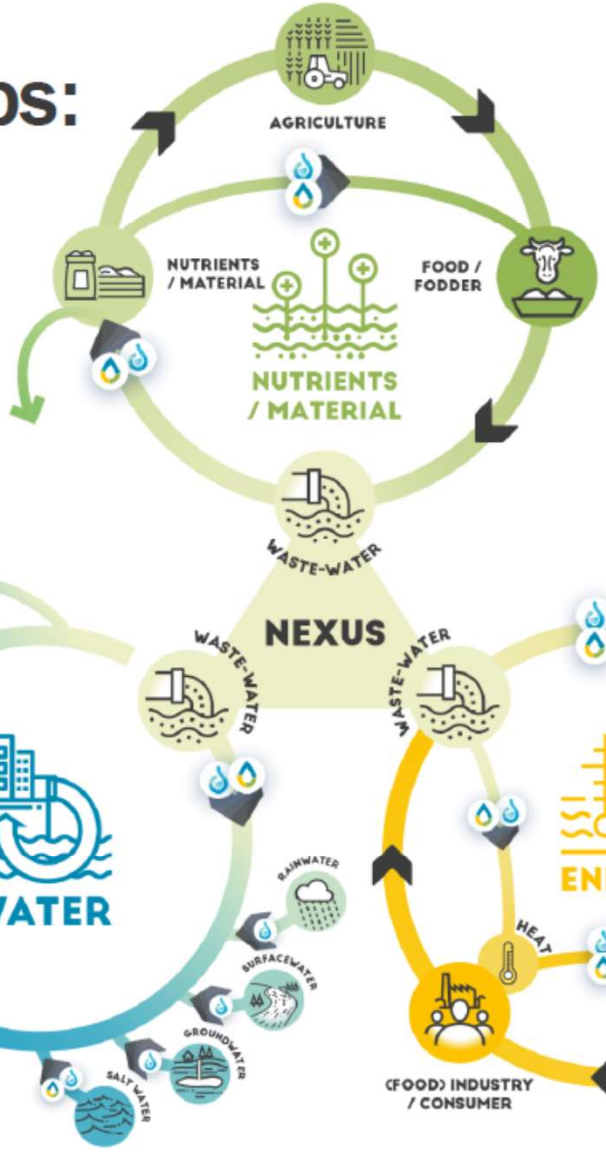
3 Cross-cutting Technology Groups: 9 Topics





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

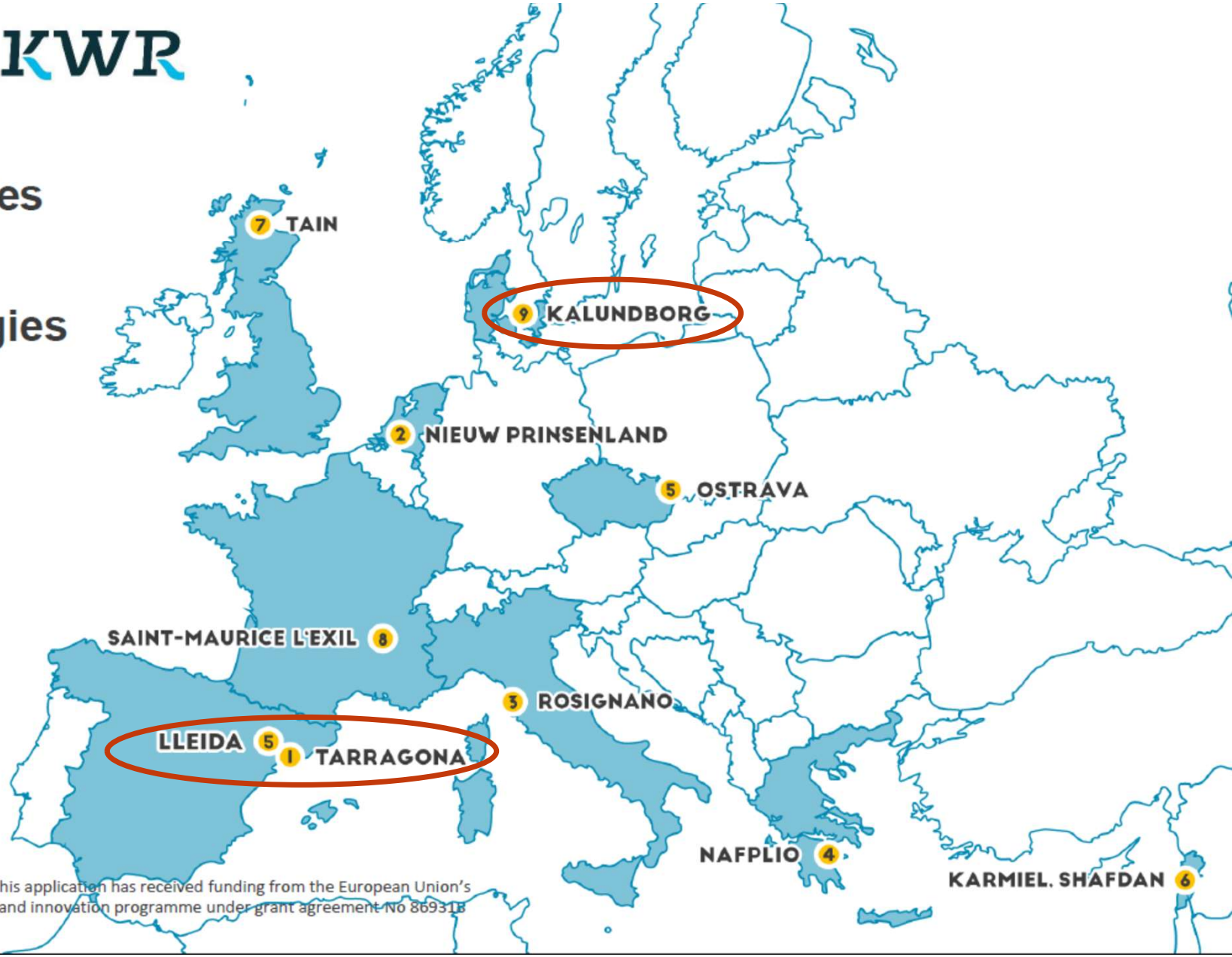
- Biogas technologies
- Heat recovery
- Digitalization

Coordinator: KWR

9 Case Studies

27 Partners

37 Technologies



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Agenda

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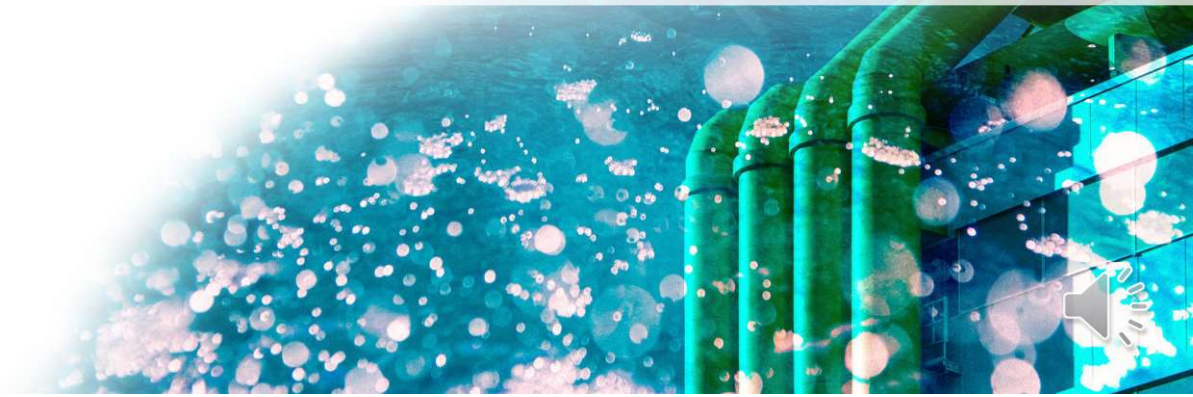
ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

Membrane technologies for reclaimed water production for the chemical and petrochemical industrial sector (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.

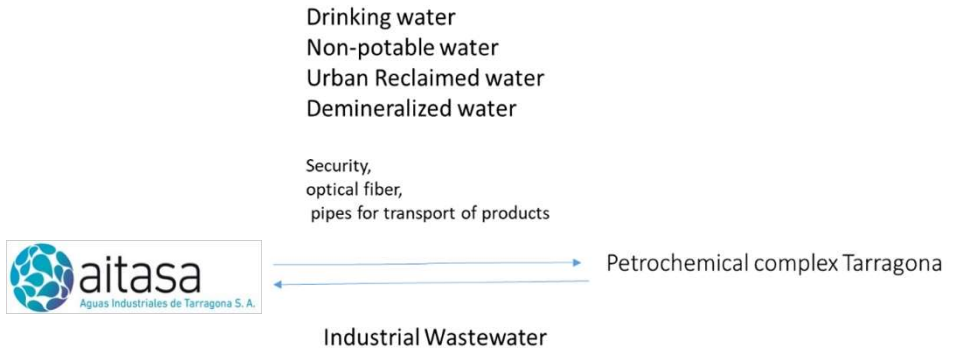
More than 30 companies operate in the petrochemical complex focusing on production of chlorine, alkaline salts, oxygen gas, fertilizers, insecticides, fuels, plastics and synthetic essences.

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
Aguas Industriales de Tarragona S. A.





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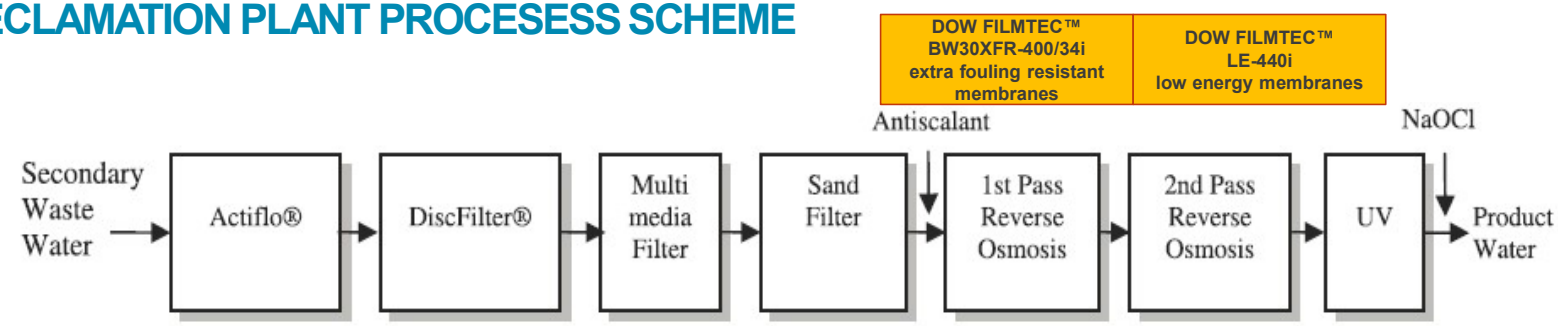
Camp de Tarragona Advanced Water Reclamation Plant

WATER RECLAMATION PLANT PROCESESS SCHEME



RECLAIMED WATER QUALITY

Since 2012, AITASA operates the Water Reclamation Plant (WRP) of Camp de Tarragona producing reclaimed water for boilers and cooling towers of the industry. Reclaimed water has to fulfil with Spanish Royal Decree 1620/2007 that includes the water requirements to be reused in the industry.

Parameter	Requirement	Units
Legionella	Absence	CFU/1 L
Nematode eggs	<1	Eggs/10 L
Escherichia coli	Absence	CFU/100 mL
Suspended solids	<5	mg/L
Turbidity	<1	TNU

Additionally, some restrictions are established for the reclaimed water at the outlet of the WRP to be reused in cooling towers.

Parameter	Requirement	Units
Ammonium	< 0.8	mg/L
Ortho-PO_4	<3	mg/L
BOD_5	<4	mg/L
TOC	< 15	mg/L
Conductivity	20-40	µS/cm

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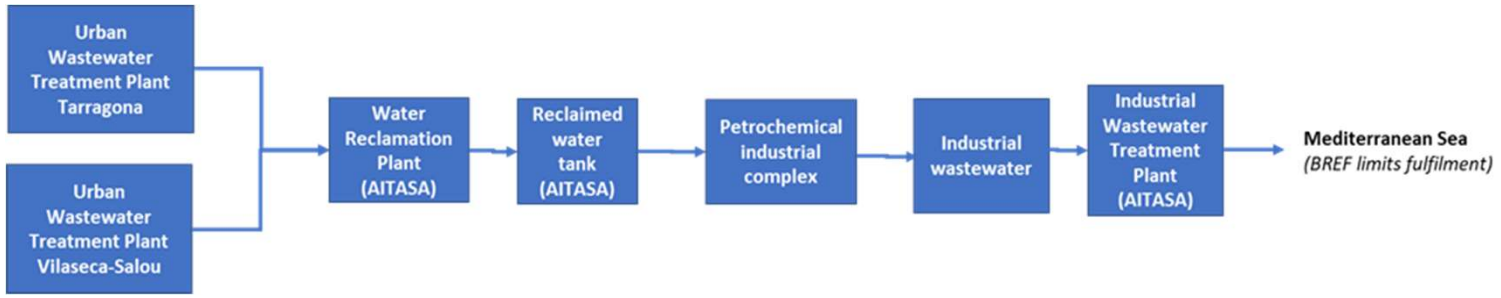
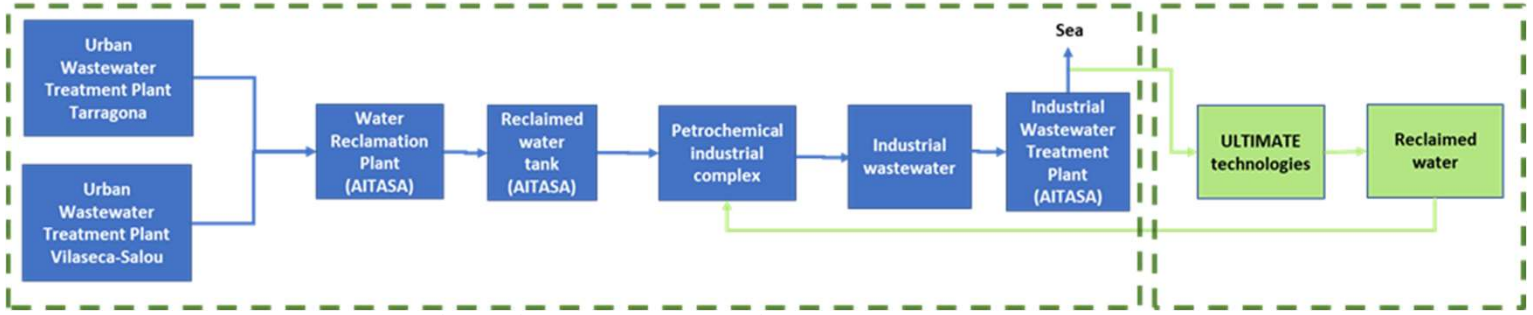
Increase reclaimed water production capacity

Phase 1:19,000 m3/day (current)→ **Phase 2:** 29,000 m3/day

Option 1: to increase reclaimed water production capacity in the current Water Reclamation Plant



Option 2: to produce reclaimed water treating the outlet of the Industrial Wastewater Treatment Plant→ ULTIMATE Project (Case Study 1)



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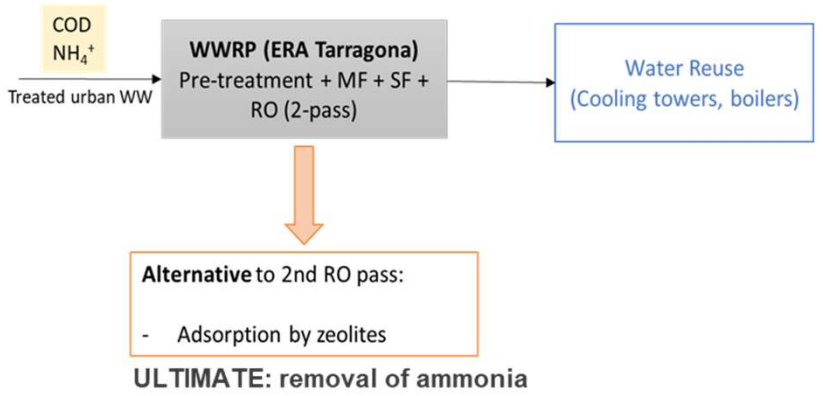
13

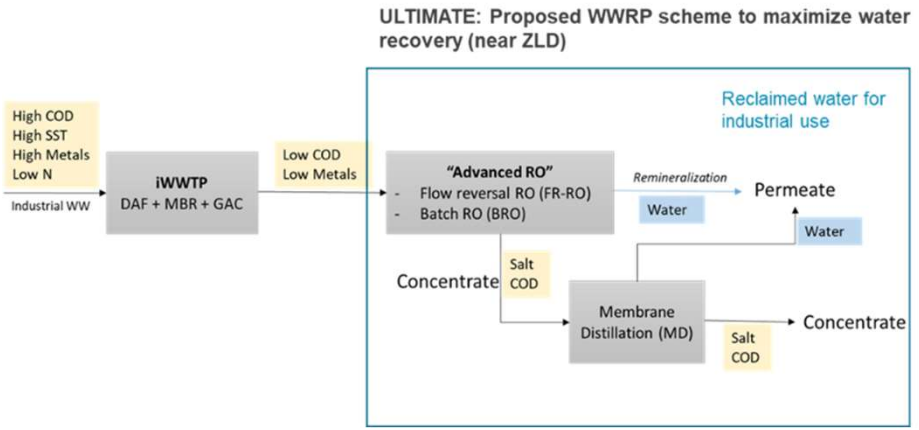
CS1: Objectives of the Ultimate solutions

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

→ **Water Reclamation Plant**:
- → Increase water recovery of the current WWRP with nZLD technologies
- → Remove the ammonium with low-cost technology (zeolite adsorption)

→ **Industrial Wastewater Treatment Plant**:
- → Defining a novel tertiary treatment with nZLD technologies (reverse osmosis and membrane distillation) to obtain reclaimed water





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CS1: Pictures of the technologies at lab scale

Optimal operation conditions obtained experimentally at bench scale→ Pilot plant design

UF bench scale experimental set-up

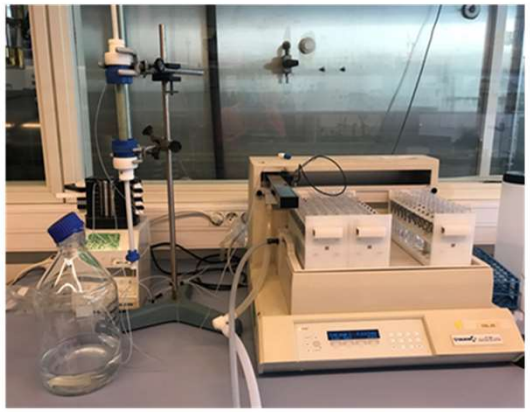




RO bench scale experimental set-up

MD bench scale experimental set-up





Zeolite adsorption bench scale experimental set-up

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Ultrafiltration: Experimental plan

General remarks:

- Tests were carried out with real water sent by AITASA (industrial complex discharge network, not outlet of the iWWTP)
- AITASA sent different water batches during the experimental pase→ Great variabilitiy in analytical water characterization.
- UF Pre-treatment was studied due to the high suspended solids concentration

Experimental plan:

1.- UF pre-treatment: solids removal
2.- Membrane selection: ceramic vs polymeric
3.- Study of cut-off pore size

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

Ultrafiltration: Experimental set-up





- Membranes tested:
  - Tubular **ceramic** membrane, Likuid 0.1micrón (1000kDa)
  - Tubular **PES** membrane, CUT (150kDa)

- Operation parameters:
  - Pressure = 1 bar
  - Temperature = 25ºC

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Ultrafiltration: Pre-treatment tests

- Microfiltration at 800, 200 and 100 μm



Before ceramic membrane
Likuid



Before polyester membrane
CUT

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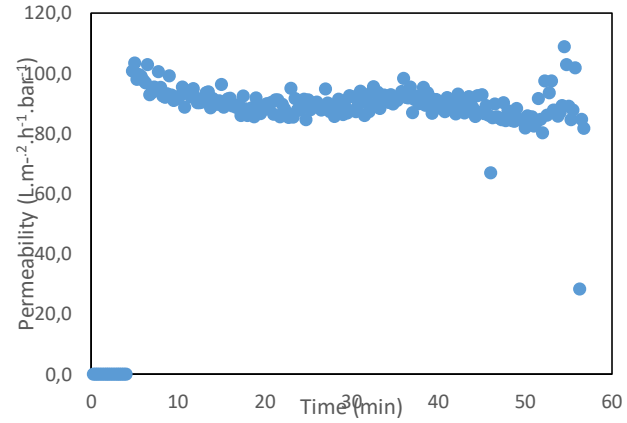
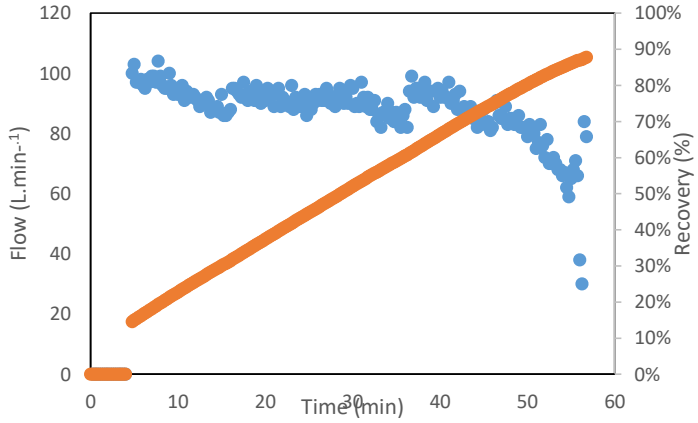
Ultrafiltration: Study permeability and recovery

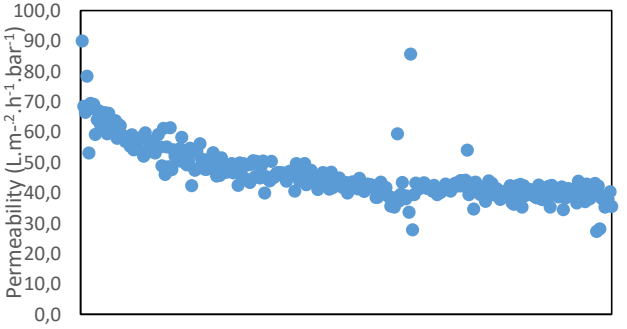
- Pressure = 1 bar
- Temperature = 25ºC
- Total volumen = 50 L

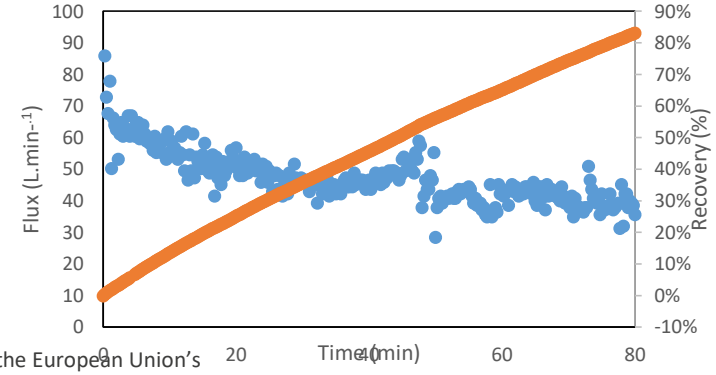
UF membrane	Flux, LMH	Permeability, LMH/bar
Tubular ceramic, Likuid 1000 kDa	90-100	90-100
Tubular PES, CUT 150 kDa	40-60	40-60





Tubular ceramic membrane, Likuid 0.1 μm (1000kDa)





Tubular PES membrane, CUT (150kDa)

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

Ultrafiltration: Permeate quality

- Tubular ceramic membrane, Likuid 0.1 μm (1000kDa)
- Tubular PES membrane, CUT (150kDa)

Membrane	Sample	pH	Turbidity, NTU	TSS, g/L	TOC, mg/L	NH4, mg/L	Ca, mg/L	Mg, mg/L	K, mg/L	Na, mg/L
Likuid	Inlet	7.3	165	15.2	48	<5	227	57	42	5370
	Permeate	7.9	2	13.3	38	<5	212	53	38	4860
	Concentrate	8.2	700	14.7	46	<5	202	51	39	4870
CUT	Inlet	7.2	138	14.6	37	<5	199	56	37	5420
	Permeate	8.2	0.39	13.2	27	<5	184	52	34	4830
	Concentrate	8.5	520	14.6	38	<5	182	51	35	4900

Slightly better permeate quality of the CUT membrane
MWCO of 150 kDa may result in higher rejection factor of TOC, fat and grease.

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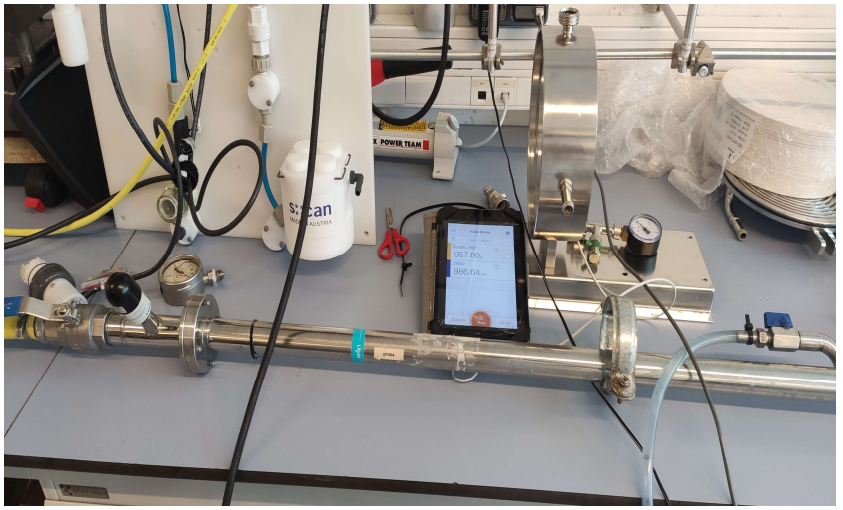
Ultrafiltration: Select molecular weight(MWCO) of ceramic membrane

- Tubular **ceramic** membrane, Likuid 0.1 um (**1000kDa)**
- Tubular **ceramic** membrane, Likuid 0.01 um (**100kDa**)





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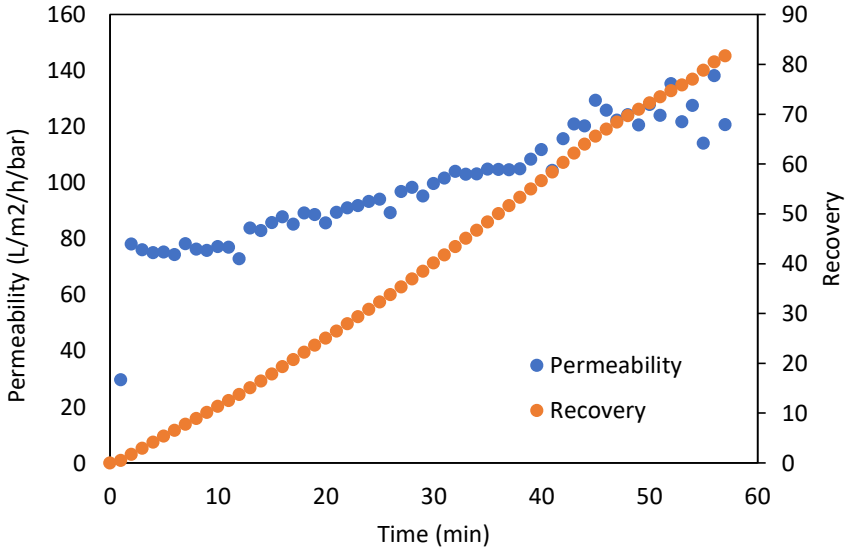
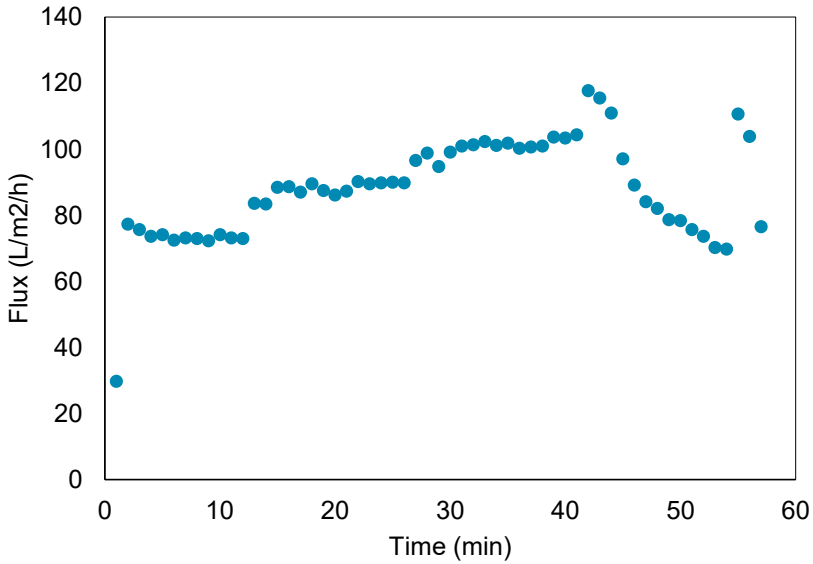
Ultrafiltration: Study permeate and recovery

- Tubular ceramic membrane, Likuid 0.01 μm (**100kDa**)





Stable permeability. Increasing trend may be due to increasing temperature
Permeability = 75 L/m^2/h/bar
Flux = 53 L/m^2/h

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

Ultrafiltration: Permeate quality

- Tubular ceramic membrane, Likuid 0.01 μm (100kDa)

Sample	pH	Turbidity, NTU	TSS, g/L	Oil and grease, mg/L	COD, mg/L	NH4, mg/L	Ca, mg/L	Mg, mg/L	K, mg/L	Na, mg/L	Cl, mg/L	NO3, mg/L	SO4, mg/L
Inlet	8	93	14	370	877	8	190	64	31	5030	4510	30	1489
Permeate	8.1	0.7	13	59	250	5	181	61	31	4580	5410	10	1780
Concentrate	8	420	13	1247	250	14	169	57	30	4570	5460	0.5	1774

Similar values to the previous experiments. Smaller MWCO allows to reach better permeate quality. Turbity < 1 NTU

UF TESTS CONCLUSION:
Selected UF membrane = Tubular **ceramic** membrane, Likuid 0.01 um (**100kDa**); operated at P=1 bar, T=25ºC.

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: Experimental plan

General remarks:
- Experiments were carried out with permeate from previous UF tests (ceramic Likuid membrane 100 kDa).

Experimental plan:
1.- Membrane selection: brackish *vs* seawater
2.- Optimization of operating conditions (PMT)
3.- Study of water recovery
4.- Study of scaling

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: Experimental set-up



- Flat sheet membrane, Toray flat Sheet Membrane UTC-82V, PA, RO (seawater)
- Flat sheet membrane, SUEZ Flat Sheet membrane, SE, PA-TFC, RO (industrial/brackish)





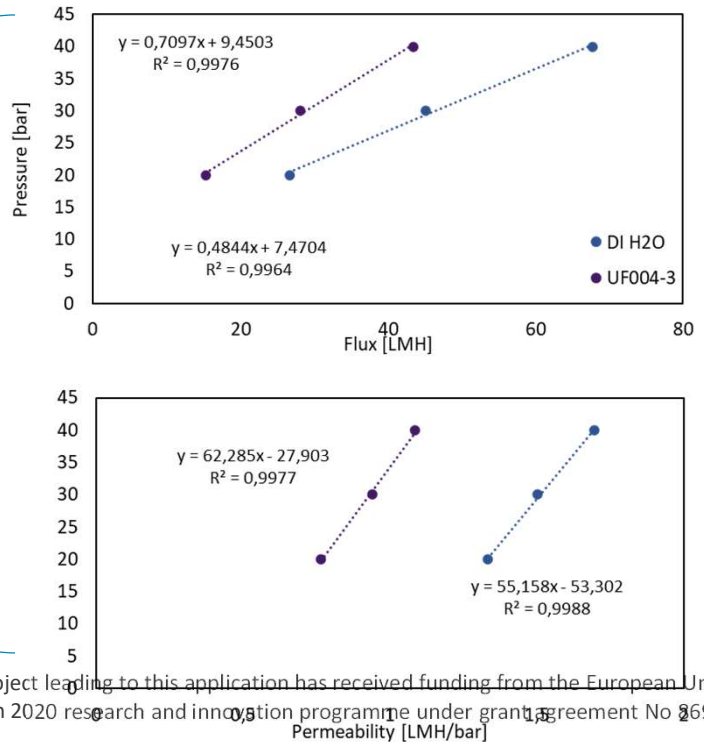
The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

Reverse Osmosis: study flux and permeability

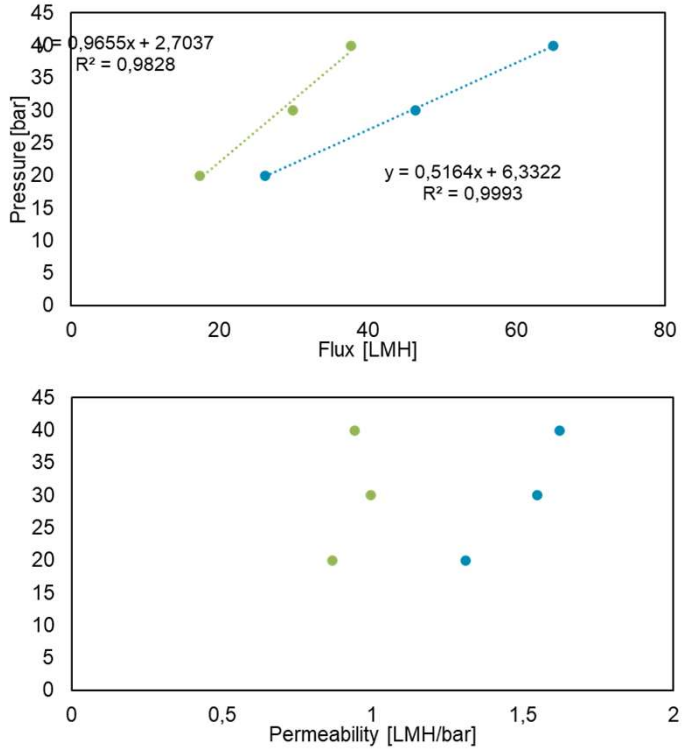
- Operational conditions:
  - Pressure = 20, 30 and 40 bar
  - Temperature = 25ºC
  - Test with distilled water and with permeate Likuid ceramic membrane – 100 kDa

RO Membrane	P, bar	Flux, LMH	Permeability, LMH/bar	Permeate conductivity, µS/cm
Toray flat Sheet Membrane UTC-82V, PA, RO	40	40-45	>1	209
SUEZ Flat Sheet membrane, SE, PA-TFC, RO	40	30-40	<1	1095

Toray membrane (seawater)



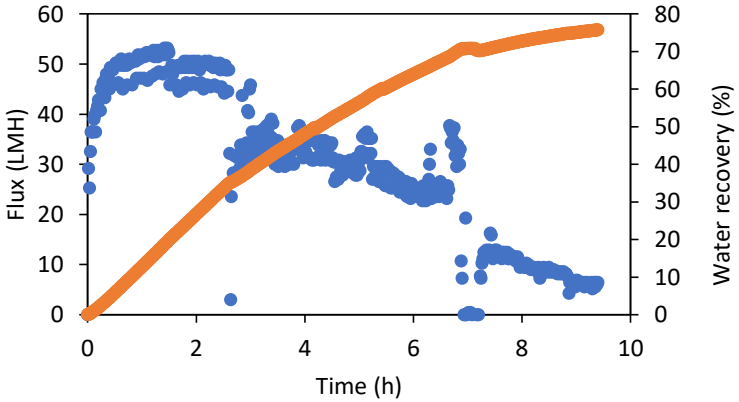
SUEZ membrane (brackish)

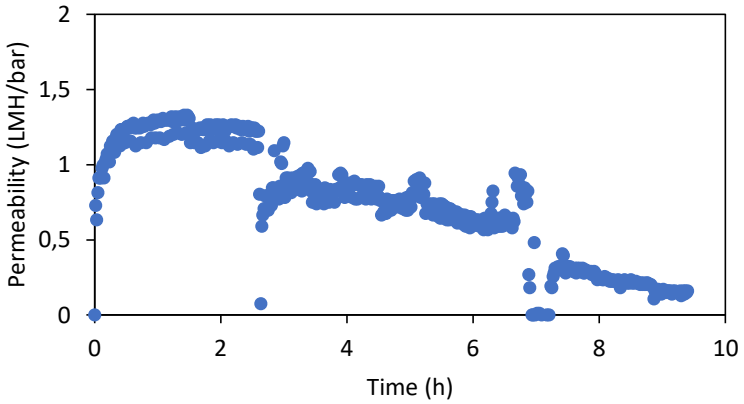


The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

Reverse Osmosis: study permeability, recovery and scaling

- Flat sheet membrane, **Toray flat Sheet Membrane** UTC-82V, PA, RO
- Operational conditions:
  - P = 40 bar
  - Goal = 70% water recovery
  - Check scaling





Almost 80% water recovery
High flux during the first hours of operation. After 3 hours, decreases in the range [40-30 LMH].
After 7 hours it drops to values between 15 LMH and 5 LMH→Possible scaling

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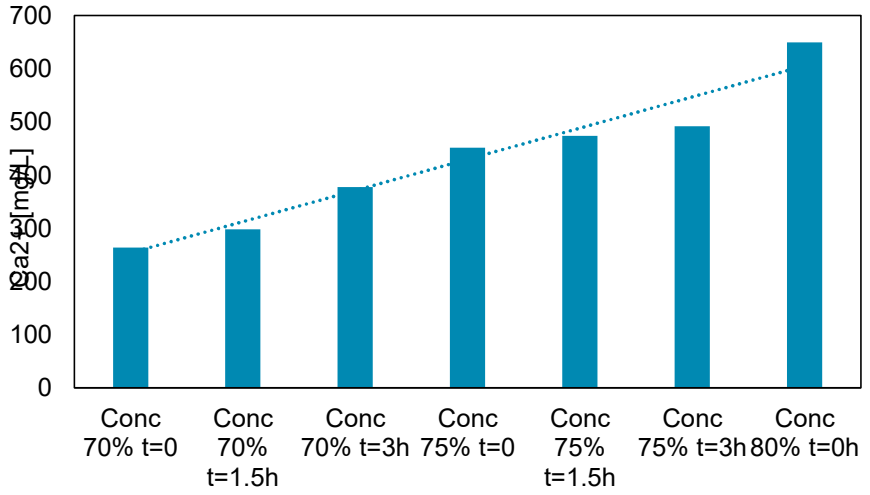
Reverse Osmosis: study permeability, recovery and scaling

- Flat sheet membrane, **Toray flat Sheet Membrane** UTC-82V, PA, RO
- Operational conditions:
  - P = 40 bar
  - Goal = 70% water recovery
- Check scaling: $CaSO_4$ and $CaCO_3$



SO_4 remains constant along the operation

Ca^{2+} decreases its concentration

$CaCO_3$ is precipitating

Preliminary results suggest $CaCO_3$ is precipitating.

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: permeate quality

- Flat sheet membrane, **Toray flat Sheet Membrane** UTC-82V, PA, RO
- Operational conditions:
  - P = 40 bar
  - Goal = 70% water recovery

Sample	Conductivity, mS/cm	NH4, mg/L	Ca, mg/L	Mg, mg/L	K, mg/L	Na, mg/L	Br, mg/L	Cl, mg/L	PO_4, mg/L	NO_2, mg/L	NO_3, mg/L	SO_4, mg/L
Permeate 70% recovery	1.29	3	2.5	1.4	1.7	253	<0.2	348	<0.2	<0.20	1.33	36
Rejection	0.9	0.3	1	1	0.9	0.9		0.9			0.6	1

High quality treated water is produced after the RO step

RO TESTS CONCLUSION:

✓ **Toray flat Sheet Membrane** UTC-82V, PA, RO. At P=40 bar: Flux of 40-45 LMH and Permeability of > 1 LMH/bar. Permeate Conductivity = 209 μS/cm. Possible scaling. Preliminary results suggest $CaCO_3$ is precipitating. Scaling simulations suggest $CaSO_4$ is precipitating after 75% and 80% 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

Membrane distillation: Experimental plan

General remarks:

- Tests carried out with the concentrate of the RO previous tests

Experimental plan:

1.- Study the effect of ΔT=70, 60 and 50ºC on distillate flux

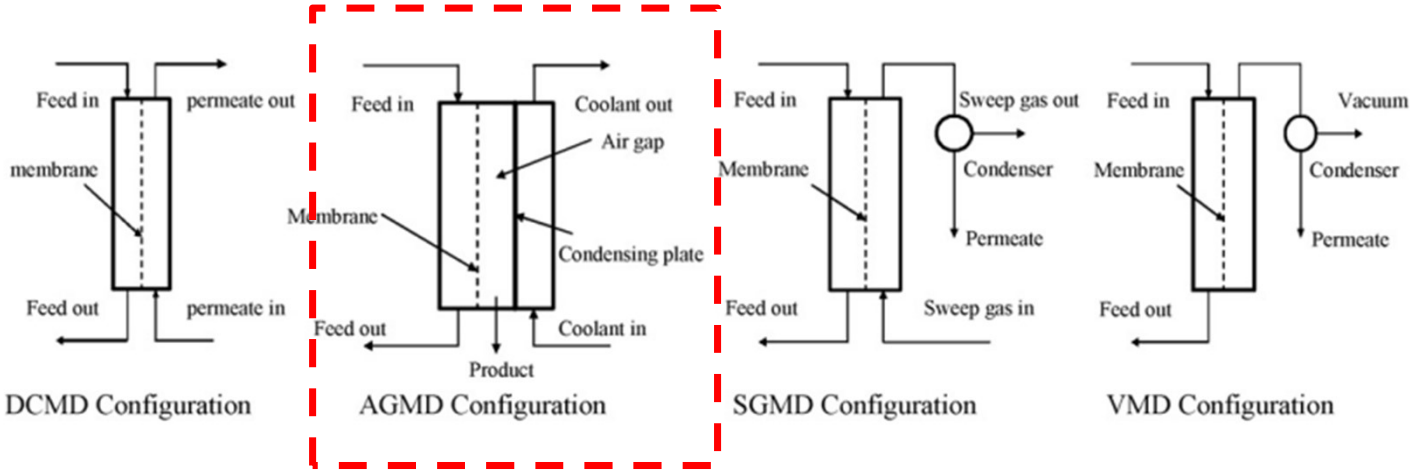
2.- Evaluate the maximum water recovery

3.- Evaluate the quality of distillated 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

Membrane distillation: Experiment set-up





- Ultra High Molecular Weight Polyethylene (UHMw_PE) membrane
- Thickness = 110 μm; Pore size = 0.2 μm
- T_{hot} = 85ºC (ΔT = 70ºC), T_{hot} = 75ºC (ΔT = 60ºC)
- T_{cold} = 15ºC
- Goal = maximum water recovery

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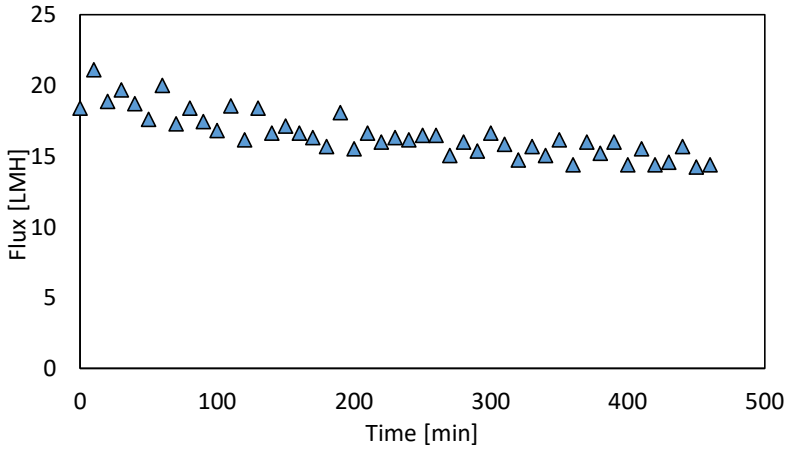
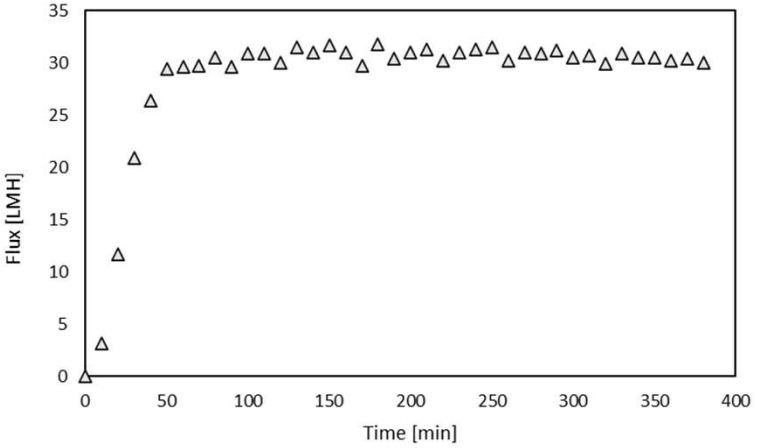
Membrane distillation: Flux and recovery study

- UHMW_PE membrane



ΔT = 60ºC



DT = 70ºC

T_{cold}, ºC	T_{hot}, ºC	ΔT, ºC	Flux, LMH	Water recovery, %
15	75	60	16	80
15	85	70	30	80

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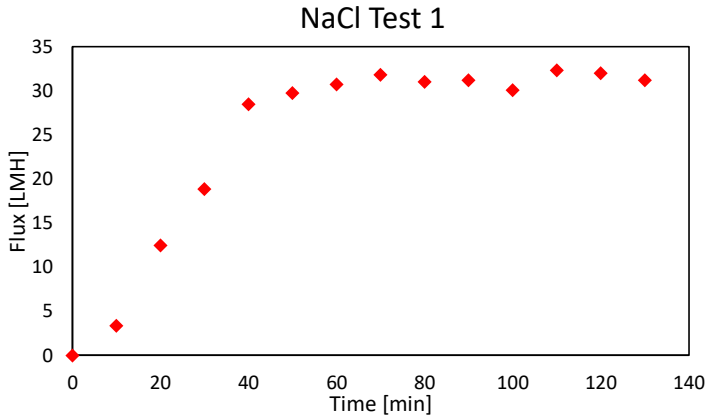
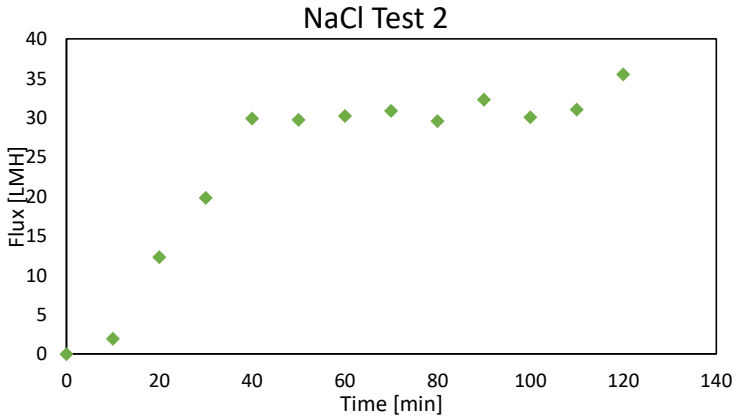
Membrane distillation: Assess membrane performance and fouling

- UHMW_PE membrane
- ΔT = 70ºC (T_{hot} = 85ºC, T_{cold} = 15ºC)
- NaCl = 35 g/L





Average and stable flux = $\pm 31\ LMH$ during both fouling experiments

MD TESTS CONCLUSION:
UHMw_PE ; AGMD ; ΔT = 70ºC ; T_{hot} = 85ºC ; T_{cold} = 15ºC. Average and stable flux = ± 30 LMH. Recovery = 80 %. Average and stable flux = ± 31 during both fouling experiments.

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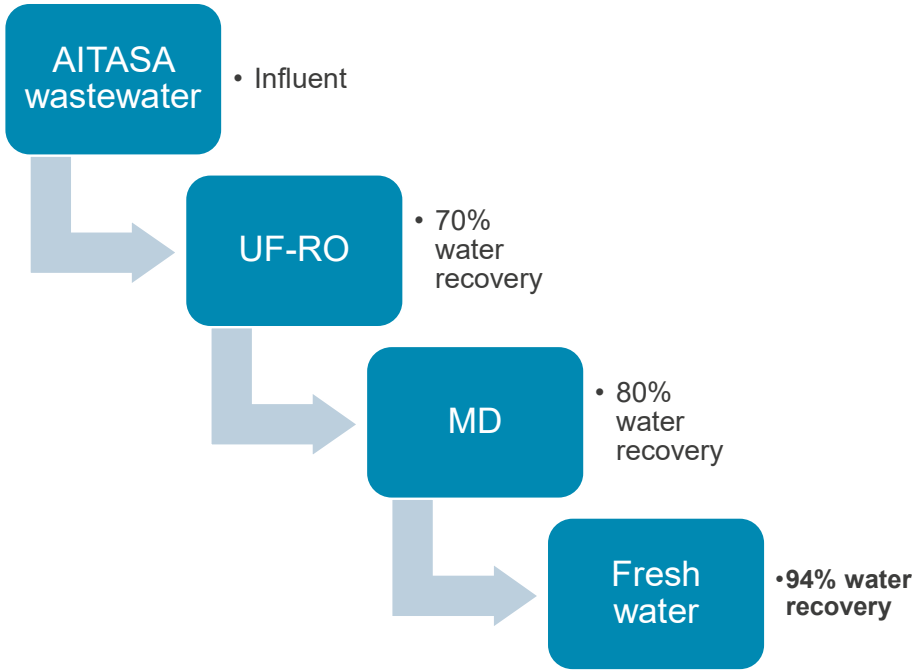
CS1: UF+RO+MD experimental conclusions

Technology	Preliminary results
Pre-treatment	100 μm
Ultrafiltration	Ceramic membrane 100 kDa P=1bar
Reverse Osmosis	Seawater RO membrane P=40 bar Possible scaling agents: $CaCO_3$ and $CaSO_4$
Membrane Distillation	AGMD ΔT=70ºC



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CS1: Technologies at pilot plant scale

Process	Treatment capacity
Cartridge filter (pre-treatment)	12 m^3/day
Ultrafiltration	12 m^3/day
Reverse Osmosis	12 m^3/day
Membrane Distillation	1 m^3/day
Zeolite adsorption	1 m^3/day



Maritim container and tanks



UF unit (left) and RO unit (right)



Membrane distillation



Adsorption with zeolites column

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CS1: Pilot plant first results

- UF and RO currently in operation (since November 2022).

Parameter	Ultrafiltration	Reverse Osmosis
Membrane area, m2	6,2	37,2
TMP, bar	0,4-0,5	1,6-1,9
Recovery (average), %	87	50-60
Flux (ave.), LMH	118-173	14,2
Permeability (ave.), LMH/bar	118-173	4
Rejection, %	-	98,4

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CS1: Next steps

UF + RO

- To increase recovery in RO process (70-75%)
- To study a second pass RO (treating the RO permeate in the same unit again)
- To study the effect of removing UF as pre-treatment in the quality of the RO permeate

MD

- To study the effect of ΔT in the quantity of the obtained permeate

General

- To assess the global recovery that can be obtained with this technological train
- To assess the quality of the permeate (reclaimed water?) that can be obtain with this technological train.

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ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

Thank you!

Sandra Casas, Andrea Naves

Sandra.casas@eurecat.org

Andrea.naves@eurecat.org



ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

ULTIMATE: Experiences in Aqualia with Anaerobic Membrane Bioreactors, core for future water resource recovery facilities (CS5)

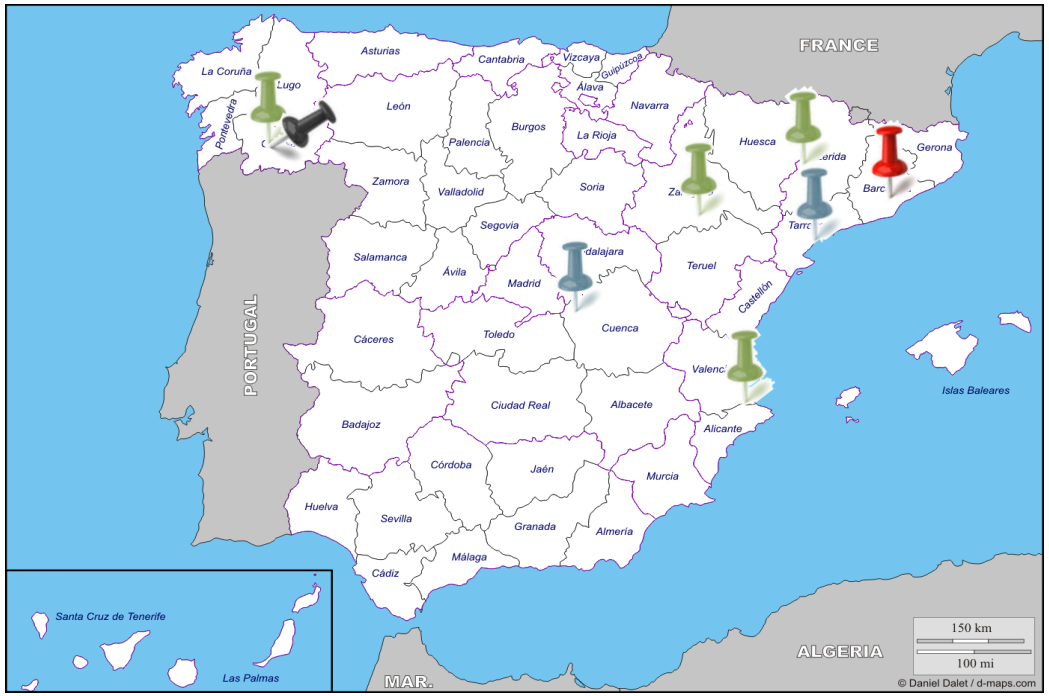
A. Giménez-Lorang

aqualia



06.03.2023

R&D projects by Aqualia in the AnMBR field



Municipal Black water Industrial OFMSW

www.life-methamorphosis.eu



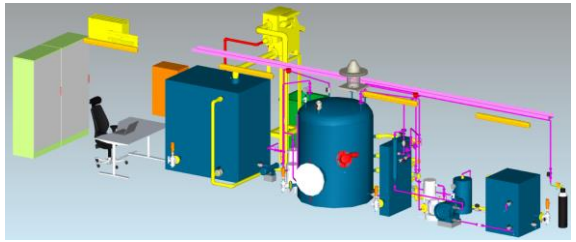
www.life-memory.eu

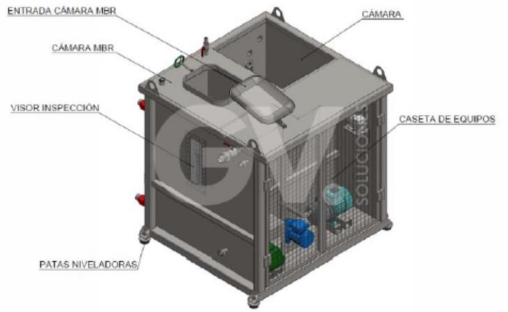


http://eranetbestf.eu/call/bestf2/project-results/biowamet/



www.ultimatewater.eu





www.run4life-project.eu

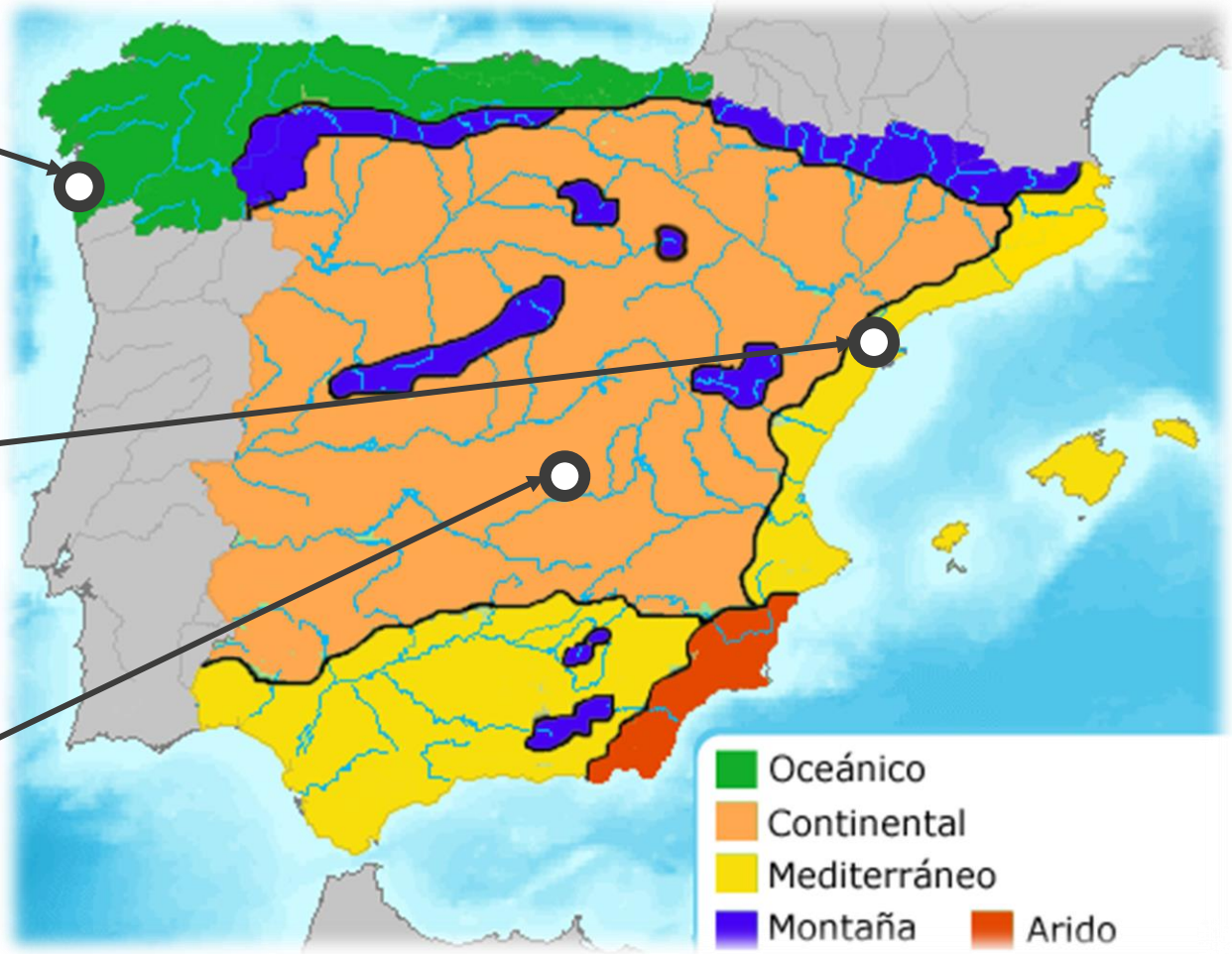
The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

AnMBR run by Aqualia at ambient temperatures

C.N. Porto do Molle, Nigrán, Pontevedra

WWTP Bítem, Tortosa, Tarragona

WWTP Alcázar de San Juan, Ciudad Real



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 run by Aqualia at ambient temperatures

PROJECT	LIFE Memory	Run4Life	BESTF2 Biowamet
Location	WWTP Alcázar de San Juan, Ciudad Real	C.N. Porto do Molle, Nigrán, Pontevedra	WWTP Bítem, Tortosa, Tarragona
Wastewater type	Municipal (industrial discharge)	Black	Municipal
COD inlet [$g \cdot L^{-1}$]	1,165 ± 0,54	1,49 ± 0,80	0,77 ± 0,97
Flux av. ($L/m^2/d$)	15 … 25	8,8 … 12,8	11,9
Temperature (ºC)	11 … 30	18 … 27	10 … 29
Membrane type	Submerged, HF	Submerged, FS	Submerged, FS
Reaction volume (m^3)	3 x 0,8 + 34,4	1,3 + 1	15 + 8
Filtration surface (m^2)	3 x 41	1 x 6,25	2 x 31,5

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

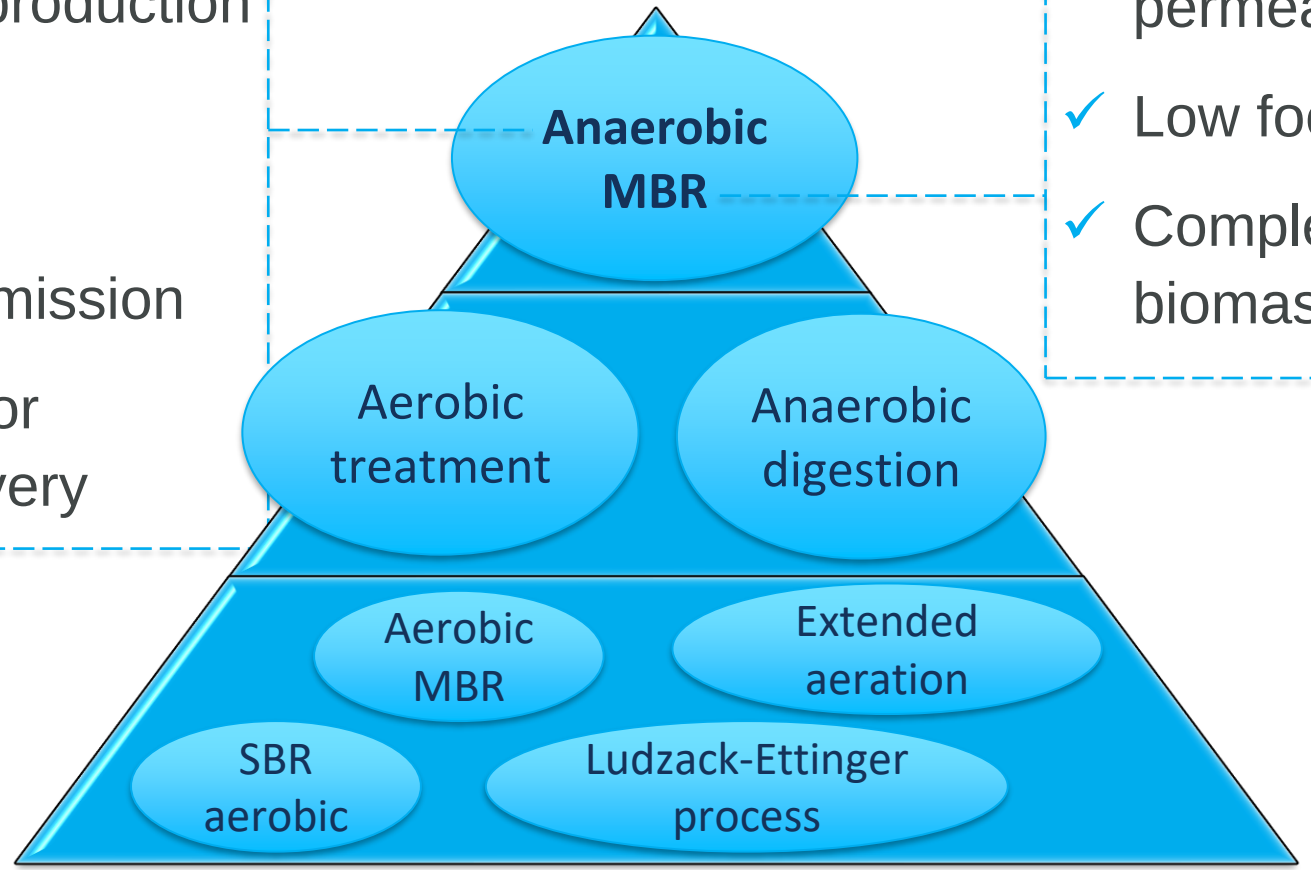
- Silva-Teira A, **Vázquez-Padín JR**, Weiler R, **Fernández-González R**, **Rogalla F**, Garrido JM. Performance of a hybrid membrane bioreactor treating a low strength and alkalinity wastewater. Process Biochemistry, Volume 66, 2018, Pages 176-182, https://doi.org/10.1016/j.procbio.2017.12.015
- Jiménez-Benítez 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.
- A. Jiménez-Benítez, A. Ruiz-Martinez, Á. Robles, J. Serralta, J. Ribes, **F. Rogalla,** A. Seco and J. Ferrer. A semi-industrial AnMBR plant for urban wastewater treatment at ambient temperature: analysis of the filtration process, energy balance and quantification of GHG emissions. Journal of Environmental Chemical Engineering, (2022). doi: https://doi.org/10.1016/j.jece.2023.109454

EP16382140.8: *Anaerobic process with filtration procedure for treating wastewater at room temperature*.
FCC Aqualia, S.A., Universitat Politècnica De València, Universitat De València

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

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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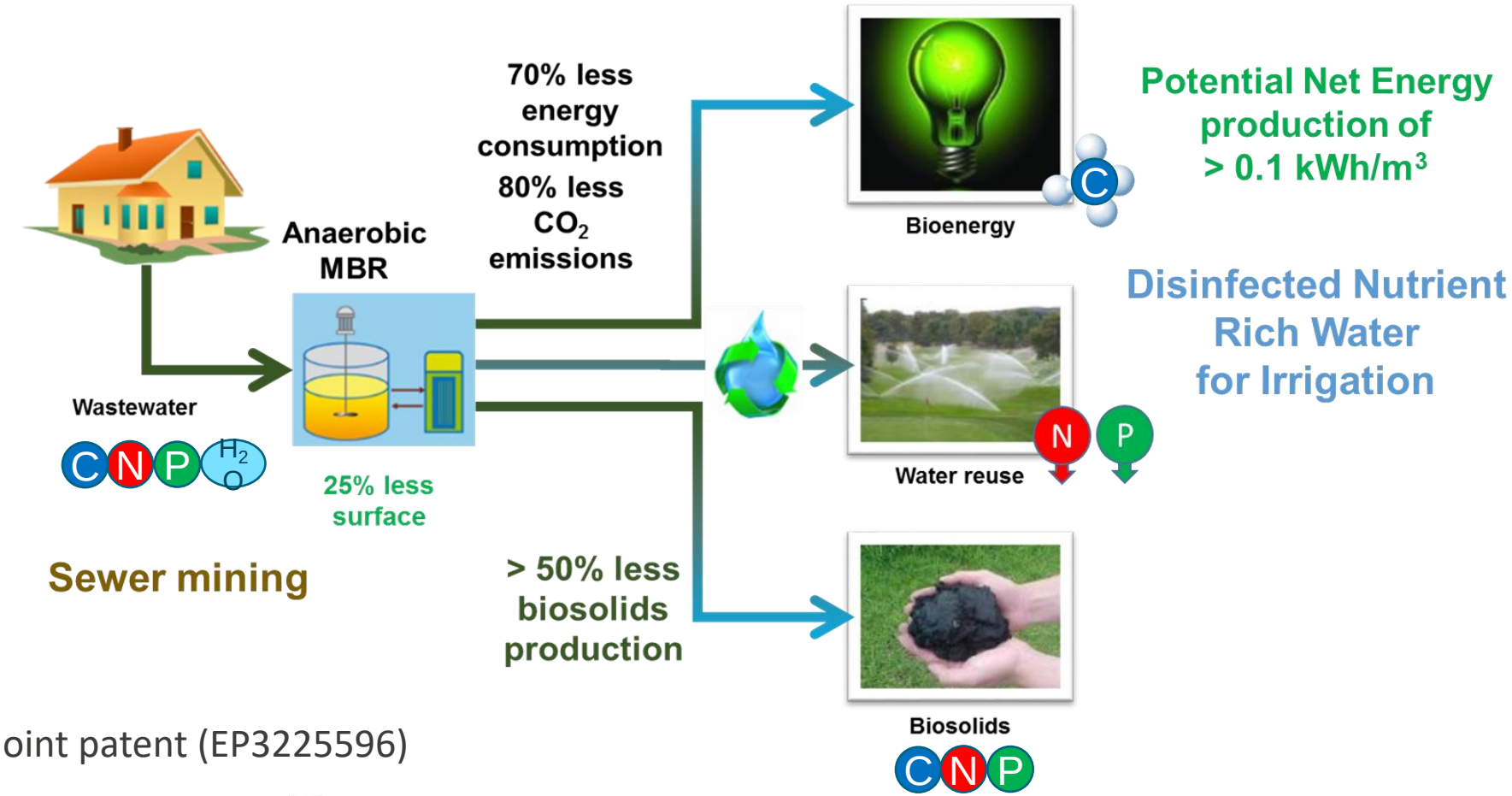

Joint patent (EP3225596)

aqualia

VNIVERSITAT DE VALÈNCIA

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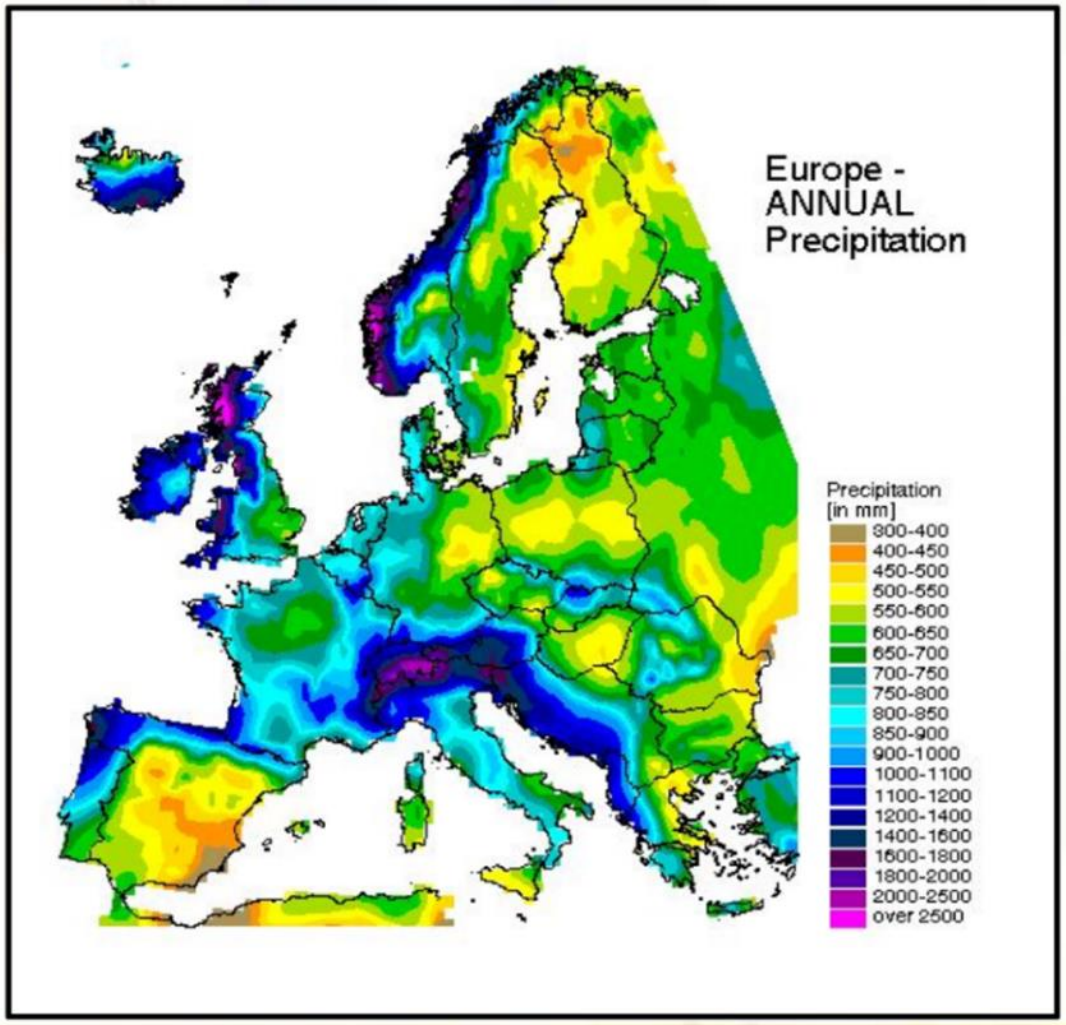
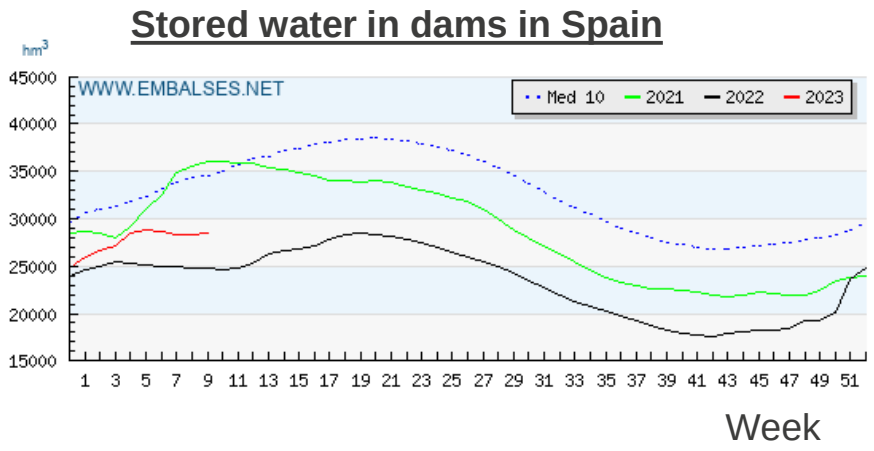


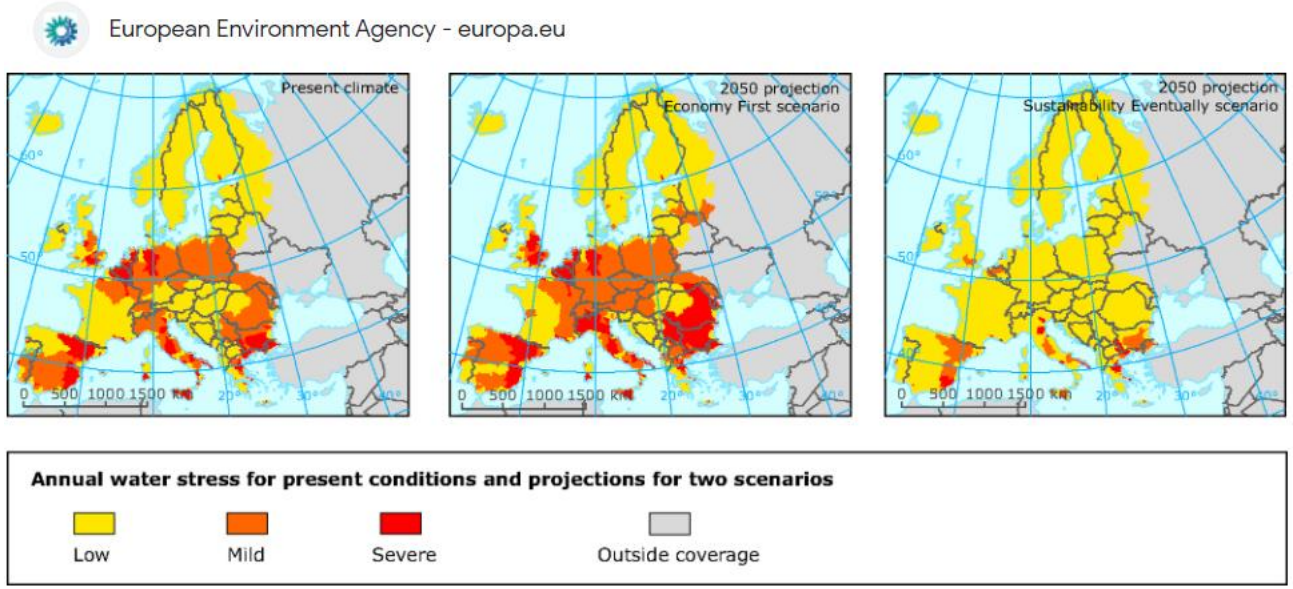


MORE THAN 2,5 MILLION TONS OF AGRICULTURAL PRODUCTS ARE PRODUCED EVERY YEAR

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

Drought & local context





Annual water stress for present conditions and projections for two scenarios
— European Environment Agency

- **Spain:**
  - **No. 1 in Europe in Reuse**
  - **No. 5 in the World for installed reuse capacity**
  - **27 % of 2000 larger WWTP are equipped with tertiary treatment**
  - **400 hm^3/yr are reused… up to 13% of treated wastewater**

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

Spanish Regulation for Water Reuse. Royal Decree 1620/2007

Applications		Quality	E. Coli (CFU/100 mL)	Nematodes eggs/10 L	Legionella spp. 100 CFU/L
- Industrial 3.2 a)	· Refrigeration towers and evaporation condensers.	A	Absence	Absence	Absence
- Residential 1.1 a) and b)	· Private garden watering. · Discharge of bathroom appliances.		Absence	1	100
- Direct Recharge 5.2 a)	· Recharge of aquifers by direct injection.		Absence	1	No limit set
- Urban 1.2 a), b), c), d) - Agricultural 2.1 a) - Recreational 4.1 a)	· Watering of urban green areas · Hosing down streets. Fire-fighting systems. · Industrial car wash. Irrigation with contact · Irrigation of golf courses.	B	< 100 -200	<1	< 100
- Agricultural 2.2 a), b) and c) - Industrial 3.1 c)	· Irrigation of crops for human consumption not avoiding direct contact of regenerated water with edible parts. · Irrigation of pastureland for milk or meat producing animals. · Aquaculture · Process and cleaning water for use in food industry.	C	< 1000	< 1	No limit set
- Environmental 5.1 a)	· Recharge of aquifers by localized seepage through the soil		<1000	No limit set	No limit set
- Agricultural 2.3 a), b) and c) - Industrial 3.1 a) y b)	· Localized irrigation of ligneous crops impeding contact of regenerated water with food for human consumption. · Irrigation of ornamental flowers, greenhouses and nurseries with no direct contact of regenerated water with crops. · Process and cleaning water except in food Industry	D	<10000	<1	<100
Recreational 4.2 a)	· Ponds, bodies of water and running water with no public access				
· Environmental 5.3 a) y b)	· Irrigation of forests, green zones and similar areas with no public access	E	No limit set	No limit set	No limit set
· Environmental 5.4 a)	· Maintenance of wetlands, minimum flows and similar uses	F	The minimum quality required is studied on a case by case basis		

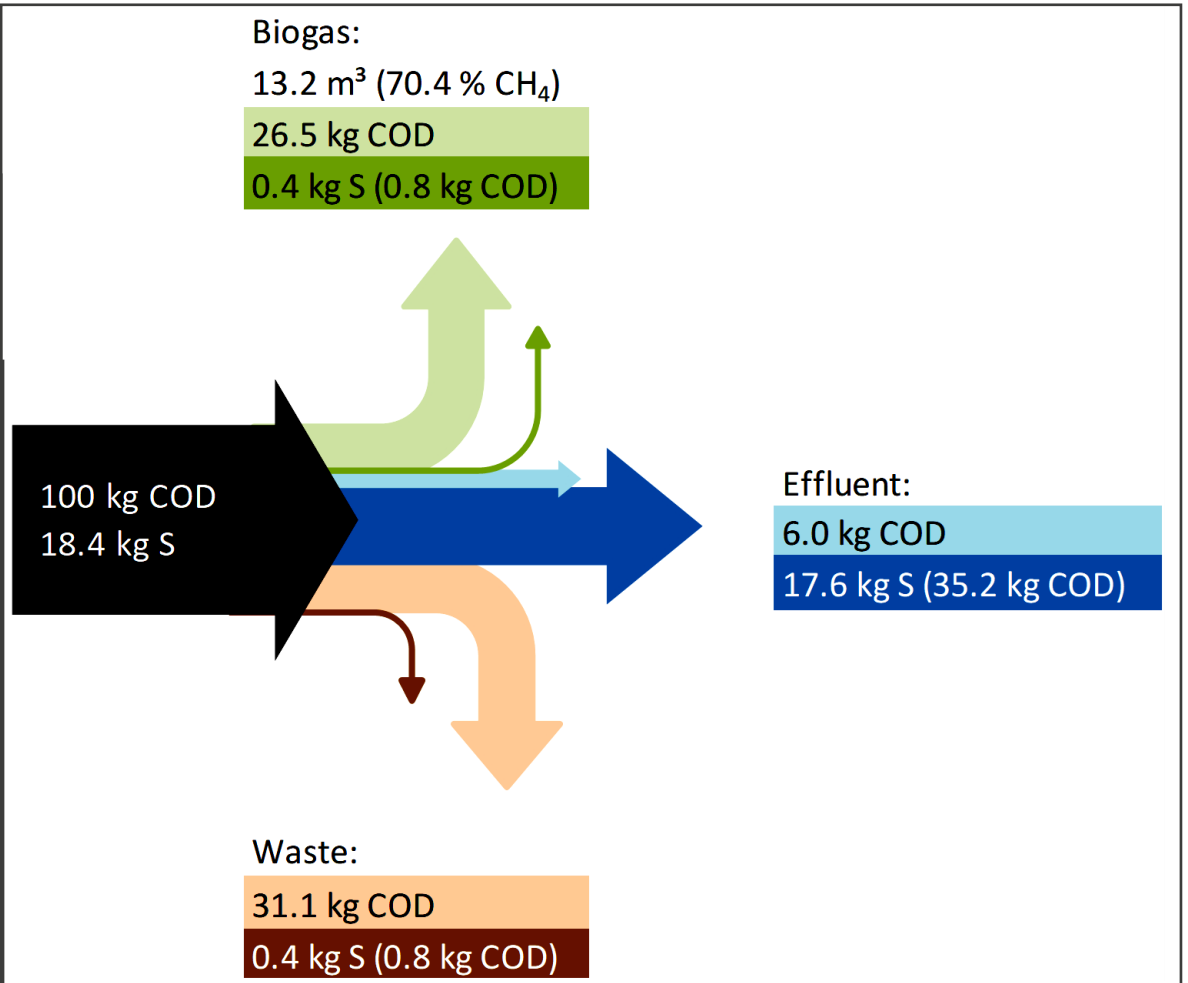
LIFE Memory

LIFE Memory aims to validate at demostrative scale the AnMBR technology as an alternative to traditional urban wastewater treatment

Conclusions in a demo-scale AnMBR fed with urban WW during 900 days

- Energy consumption from -0.4 – 0.08 kWh/m³ in AnMBR to 0.25 – 0.6 kWh/m³ in CAS or 0.5 – 2.5 kWh/m³ in AeMBR.
- 59% less waste sludge production vs. CAS
- High COD and BOD removal efficiency 89.3 ± 4.5 % and 90.30 % ± 1.6 %, respectively.
- Sludge is stabilized (biodegradable VSS <35%).
- 88% reduction of GHG vs. CAS

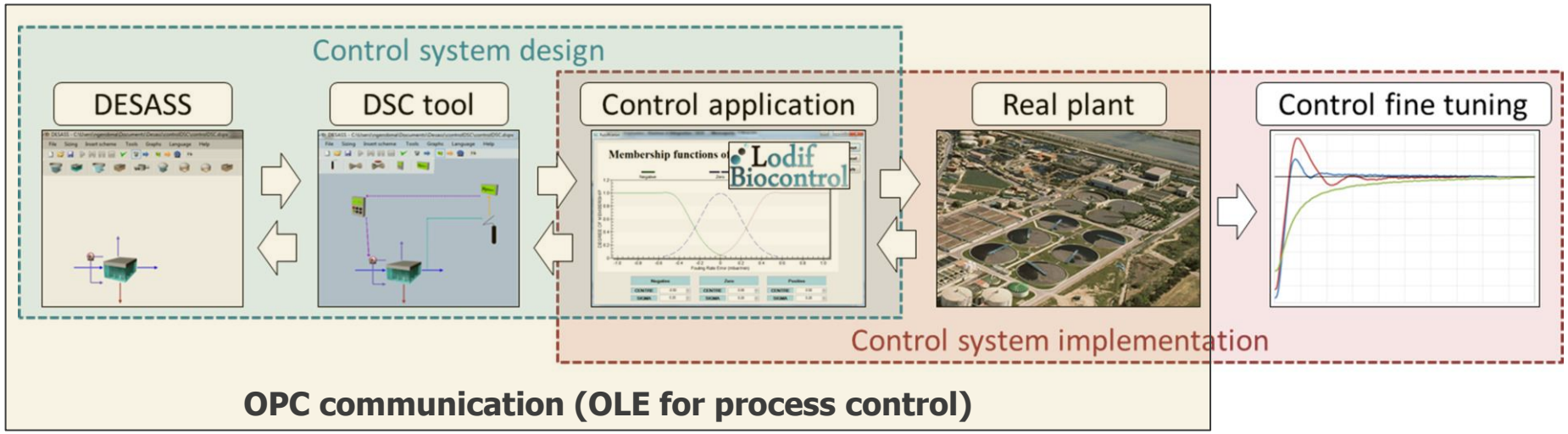
Source: https://www.life-memory.eu/



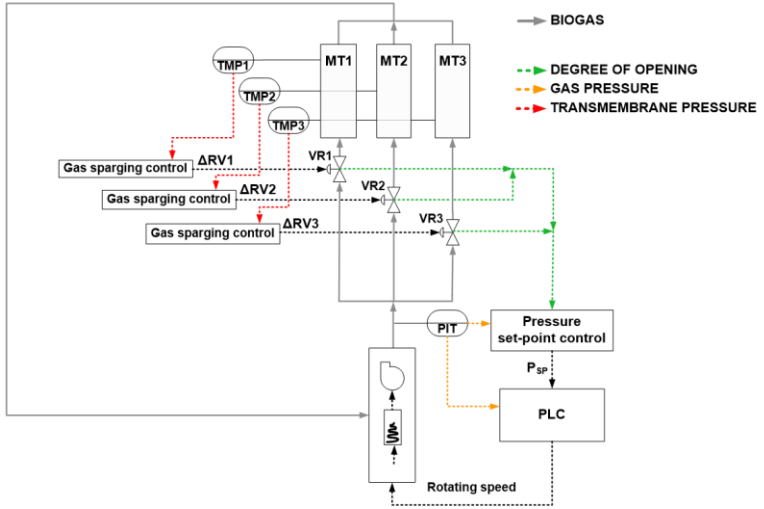
Methane productivity = 105.7 $L_{CH4\ STP}$/ removed kg COD. Low value due to high sulfate content in WW

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

LIFE Memory



- Control architecture of the fouling control system.

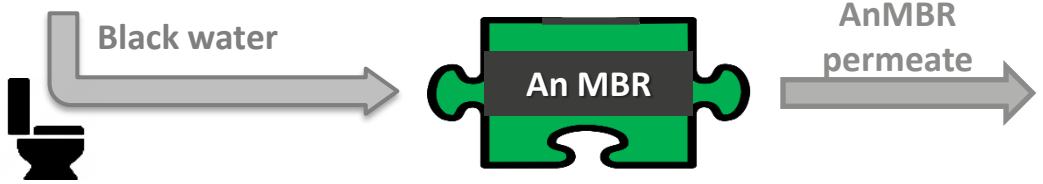


The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

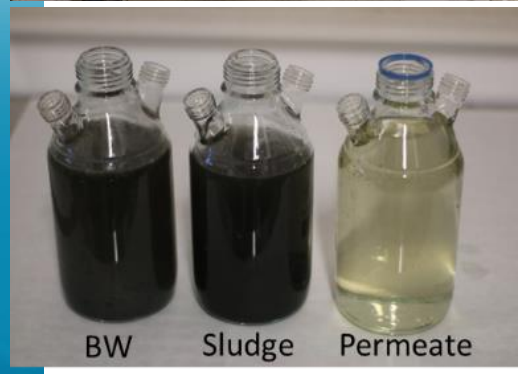
Run4Life. Vigo Demosite (100-200 PE)

Resource recovery in an office bulding

AnMBR
(2.4 m^3 + 1.0 m^3 / 6.25 m^2)
35 nm nominal pore







(2021)	Obtained quality**	*E. coli* * (UFC/100 mL)	*Legionella* (u.f.c./L)	Nematode eggs (ud/10 L)	NTU	BOD_5 (mg/L)	Suspended solids (mg/L)
1	A	0	ND	<1	<0.25	6.7	<10
2	B	8	ND	<1	0.89	11.6	<10
3	A	<1 / 0.01 ml	<1	<1	0.91	9.88	8.06
4	B	<1 / 0.1 ml	ND	<1	5.12	22.4	6.06
5	A	<1 / 0.1 ml	<1	<1	1.89	9.03	< 2
6	C	Presence in 1 ml	<1	<1	0.47	14.5	< 2
7	D	Presence in 0.1 ml	<1	<1	0.51	11.8	< 2
8	B	<1/1 ml	<1	<1	61.5	8.32	<2
9	B	<1/0.1 ml	<1	<1	<2	10.6	<2
10	B	<1/0,1 ml	<1	<1	<0.20	14	<2
11	B	<1/0.1 ml	ND	<1	0.86	23.7	7.7

* For *E. coli:* "< X ml" means "Not detected in X ml"
** According to REGULATION (EU) 2020/741 : minimum requirements for agricultural water reuse

AnMBR can be used directly as A or B class water reuse.
There were contaminations after the membrane in some samples, which produced class C and D water.

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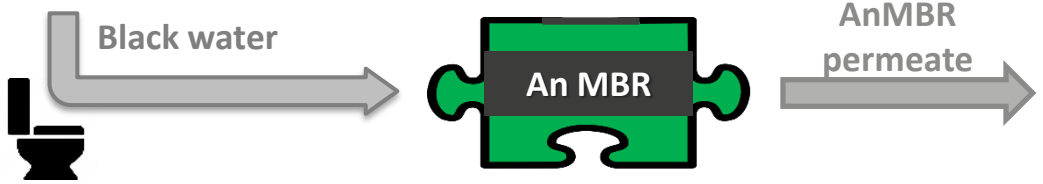
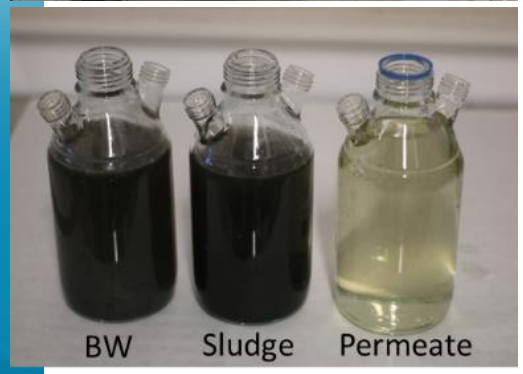
Run4Life. Vigo Demosite (100-200 PE)

Resource recovery in an office bulding

AnMBR
(2.4 m^3 + 1.0 m^3 / 6.25 m^2)
35 nm nominal pore







BLACK WATER	NoV GI (ARN/L Copies)		NoV GII (ARN/L Copies)	
Sample	BW inlet	BW outlet	BW inlet	BW outlet
1	3,39E+01	ND	3,56E+01	ND
2	3,94E+01	ND	3,15E+01	4,03E+01
3	4,05E+01	ND	2,77E+01	3,50E+01

NoV GI detected and removed.
NoV GII removal efficiency not conclusive

Virus: SARS-Cov-2 by qPCR →
was never detected in GW or BW influent, nor in GW or BW effluent

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Form a septic tank to an AnMBR

BioWaMet

Bio-Water Methanisation

Bio-methane production from urban organic matter

- ¿First real urban WWTP based on AnMBR?
- TRL >7
- Running since 2019

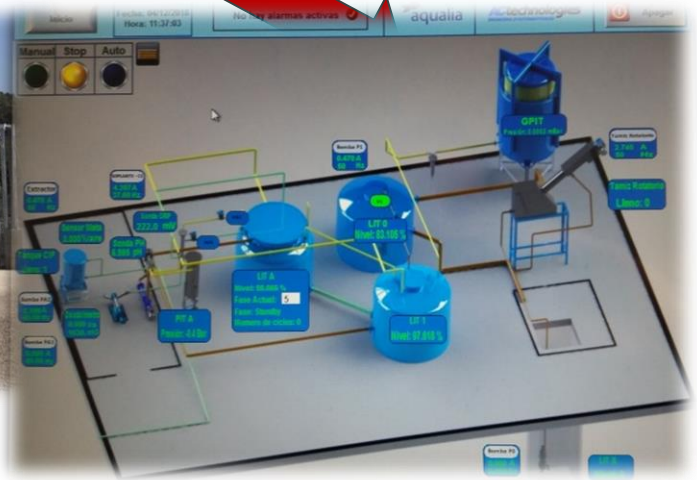
Removal performance (1 year)

- TSS 99,7%
- Turbidity 74%
- COD 83%
- BOD_5 93%
- QAC 91% and no inhibition







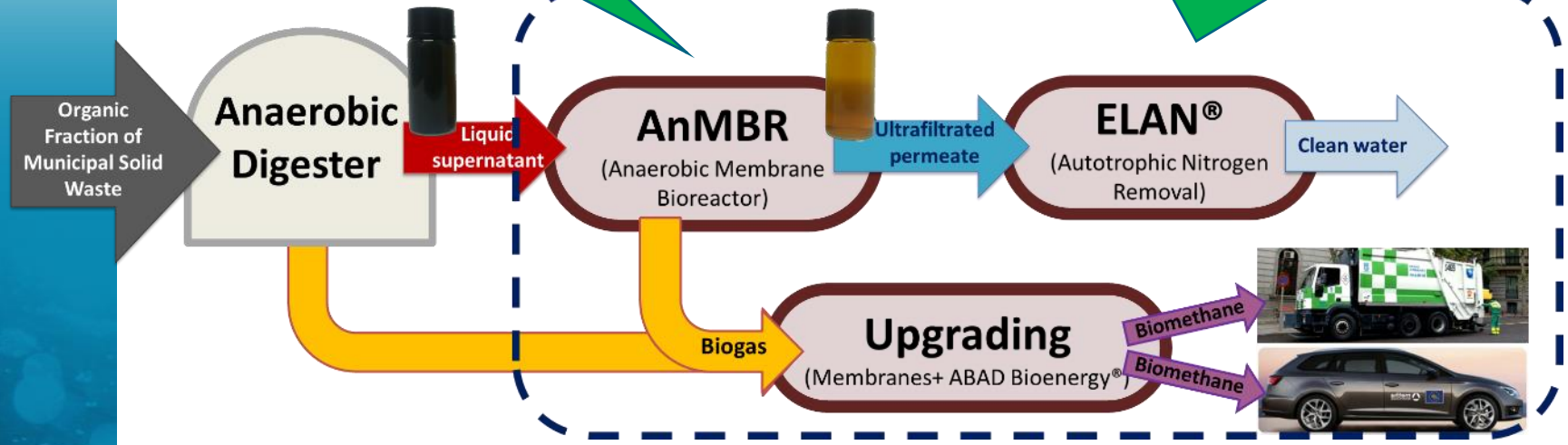


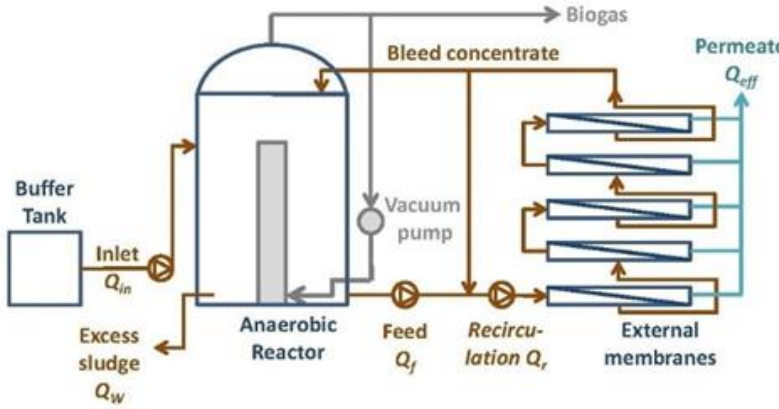
The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

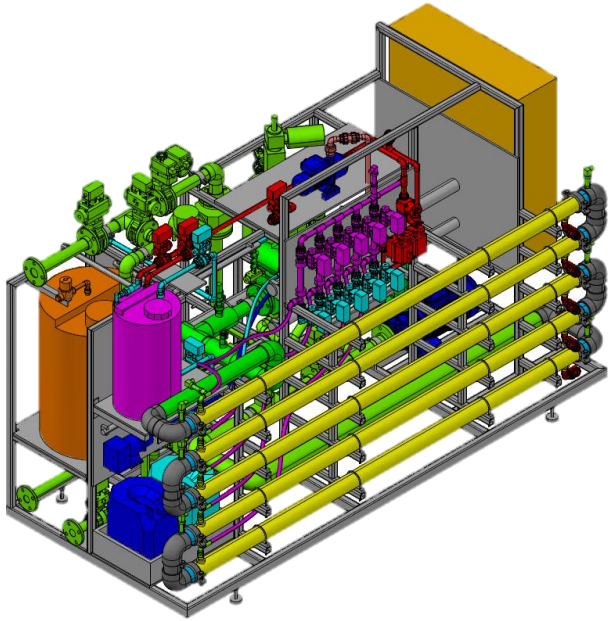
LIFE Methamorphosis

- No need for aeration
- Low sludge production
- No undesirable heating or foaming problems

- 57% less energy requirements compared to conventional treatment
- Almost no excess sludge production
- No biodegradable organic matter is required for the process







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LIFE Methamorphosis

Anaerobically treatable

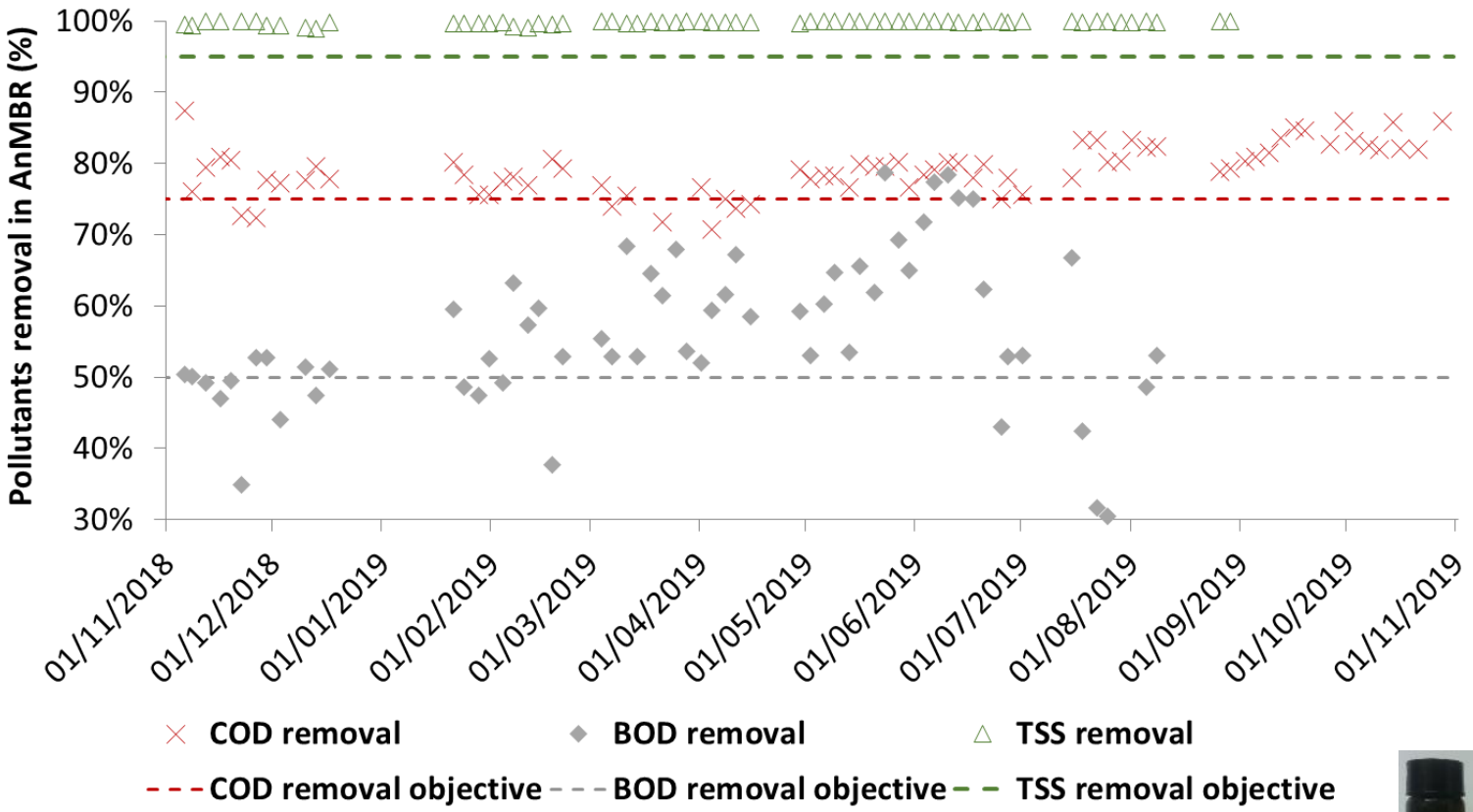
- From 1 m^3 of anaerobic supernatant up to 4 Nm^3 of biomethane could be extracted[1], enough to run 60 to 85 km with a light natural gas vehicle.
- 3 x BMP.

Quality of biogas

- Usually 73-77% v:v CH_4

Performance

>75% COD ; >95% TSS ; >50% BOD_5



Removal of pollutants in the AnMBR of the UMBRELLA prototype



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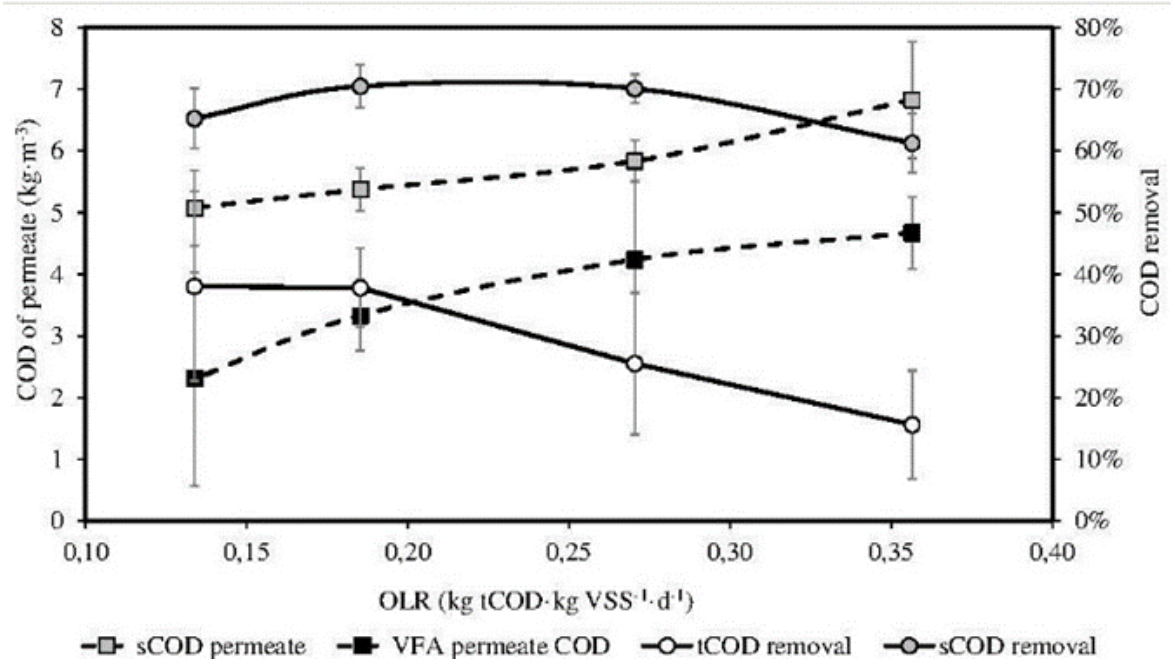
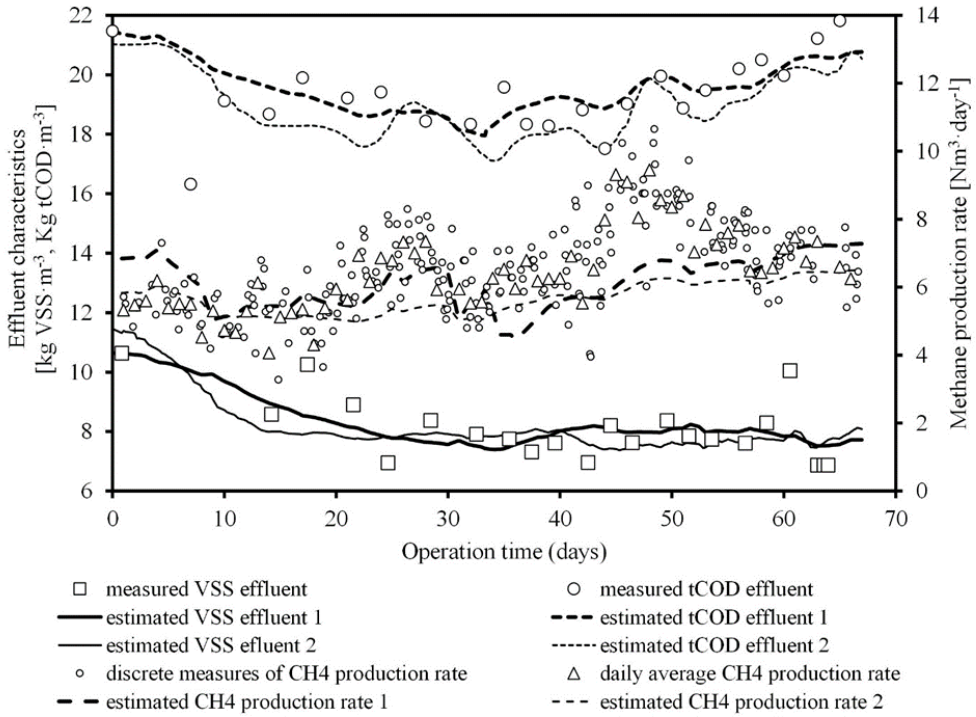
LIFE Methamorphosis





Ammonia inhibition

- The higher the organic loading rate (or the lower the sludge retention time), the worst is the performance.

Simulation

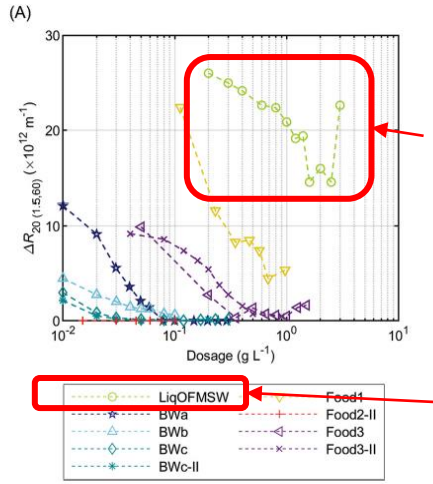
- Process is predictable by means of a mathematic model.

Source: https://doi.org/10.3389/fbioe.2021.642747

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

LIFE Methamorphosis

• Bad filterability of sludge[1]



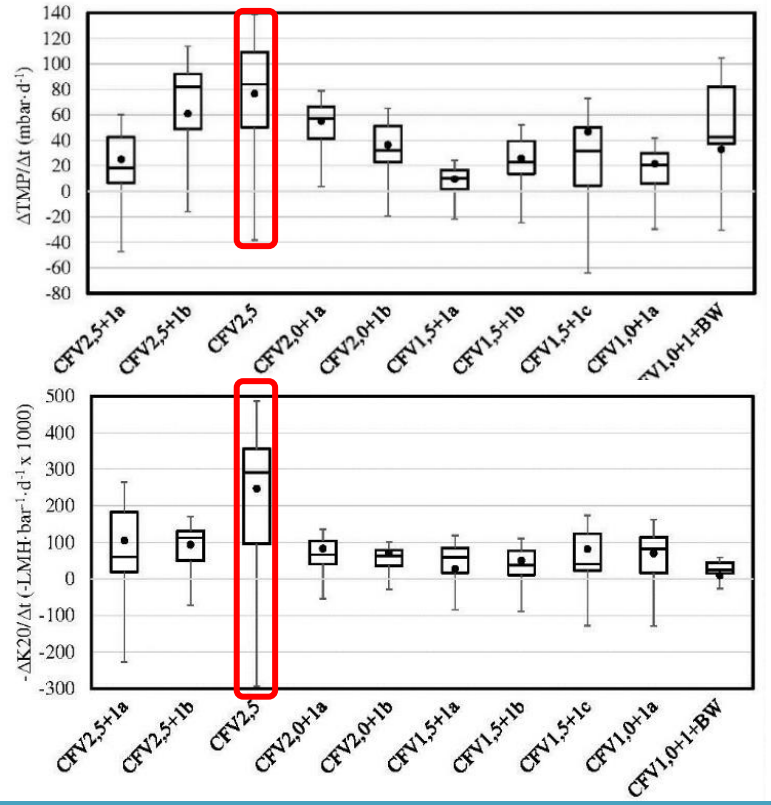
- Any other studied had a better filterability
- Slightly improved by means of cationic polymer

AnMBR sludge of Methamorphosis

Fig. 3. ΔR_{20} during FE dosage-step test in the AnDFCm installation for sludge samples from different sources. ΔR_{20} was measured by applying a flux of 60 L m^{-2} h^{-1} and cross-flow velocities of (A) 1.5 m s^{-1} and (B) 0.5 m s^{-1}.

[1] Source: https://doi.org/10.1016/j.memsci.2020.118776

• Factors affecting fouling



- Apparently, no correlation of fouling propensity vs. CFV (crossflow velocity) or SRT.
- However, CFV alternation achieved UF process to be sustainable.

Source: https://doi.org/10.3389/fbioe.2021.642747

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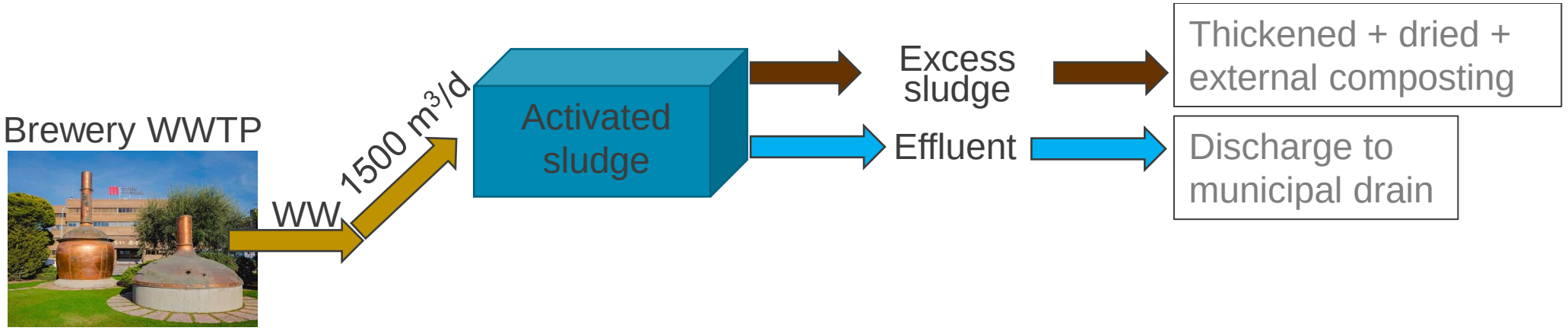
Case study nr. 5: baseline conditions



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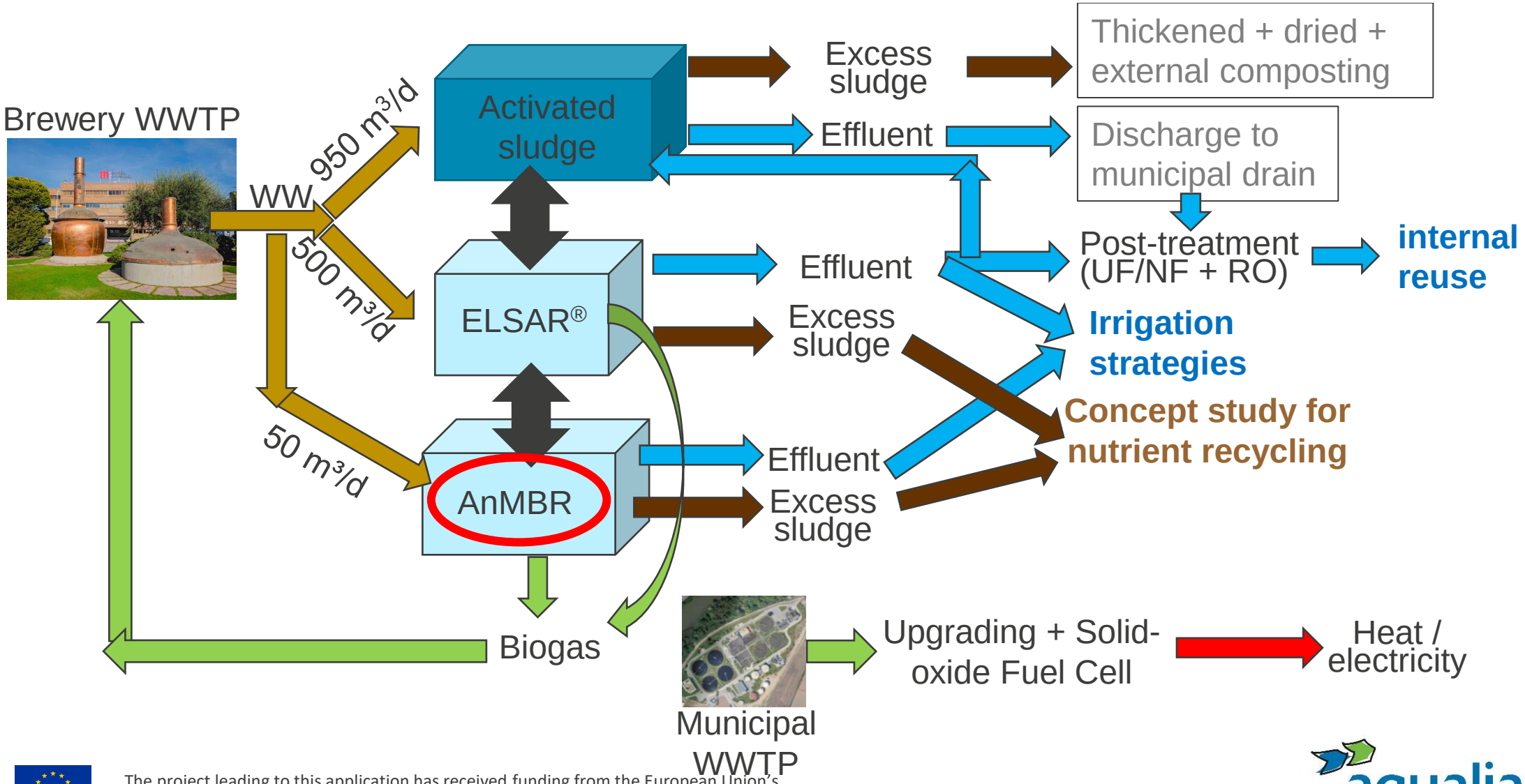
Case study nr. 5: ULTIMATE water-smart solution



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ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

ULTIMATE: Experiences in Aqualia with Anaerobic Membrane Bioreactors, core for future water resource recovery facilities (CS5)

A. Giménez-Lorang

aqualia



06.03.2023

ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

Membrane technology for reuse of treated wastewater as fit-for-purpose water –

Results from the first test period in Kalundborg (CS9)

J. Jährig, A. Kleyböcker, U. Miehe, L. Vredenbregt, F. Brendecke,
L. Rodenkam Melchiorsen, P. Thisgaard

06.03.2023



Case Study 9 – Kalundborg



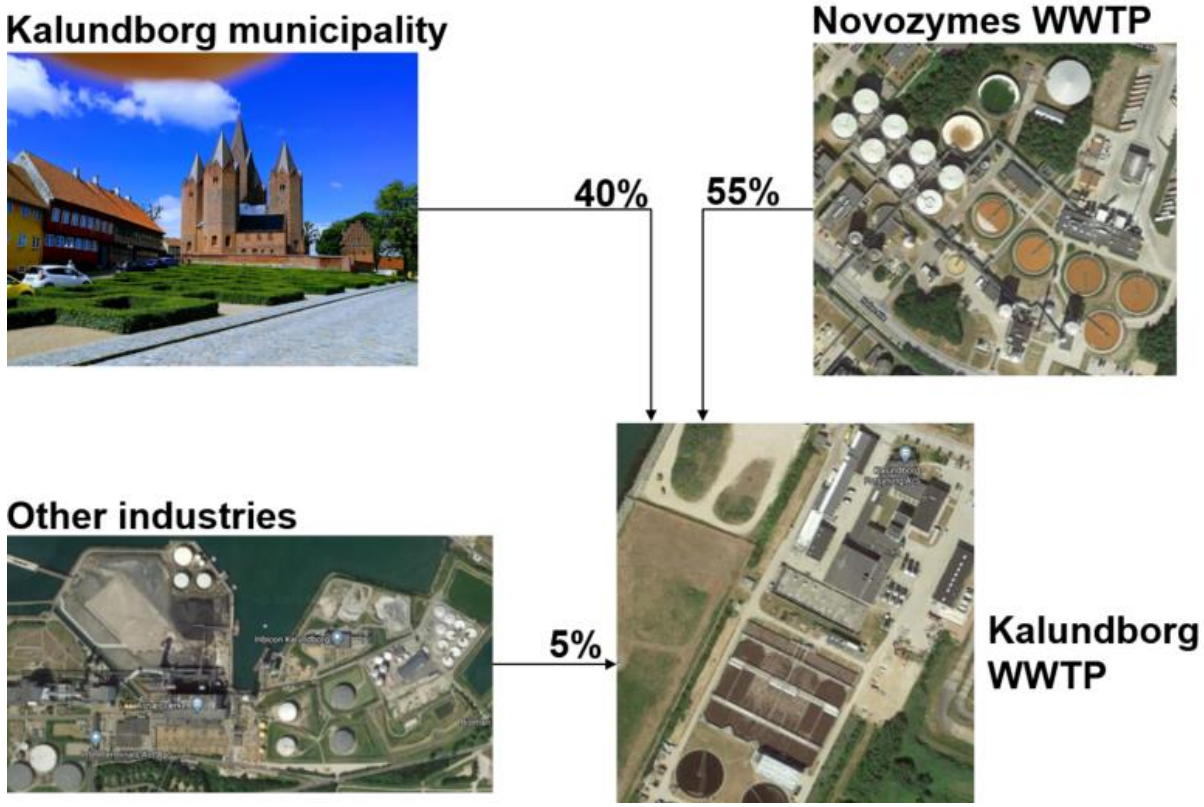
The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

What are the goals at CS 9 – Kalundborg?

- Biotech & pharmaceutical industry, etc.
- No water reclamation from WWTP effluent
- Each WWTP has its separate control system

Goals of the project:

- Joint control system for two WWTPs
- Fit-for-purpose water for industrial reuse



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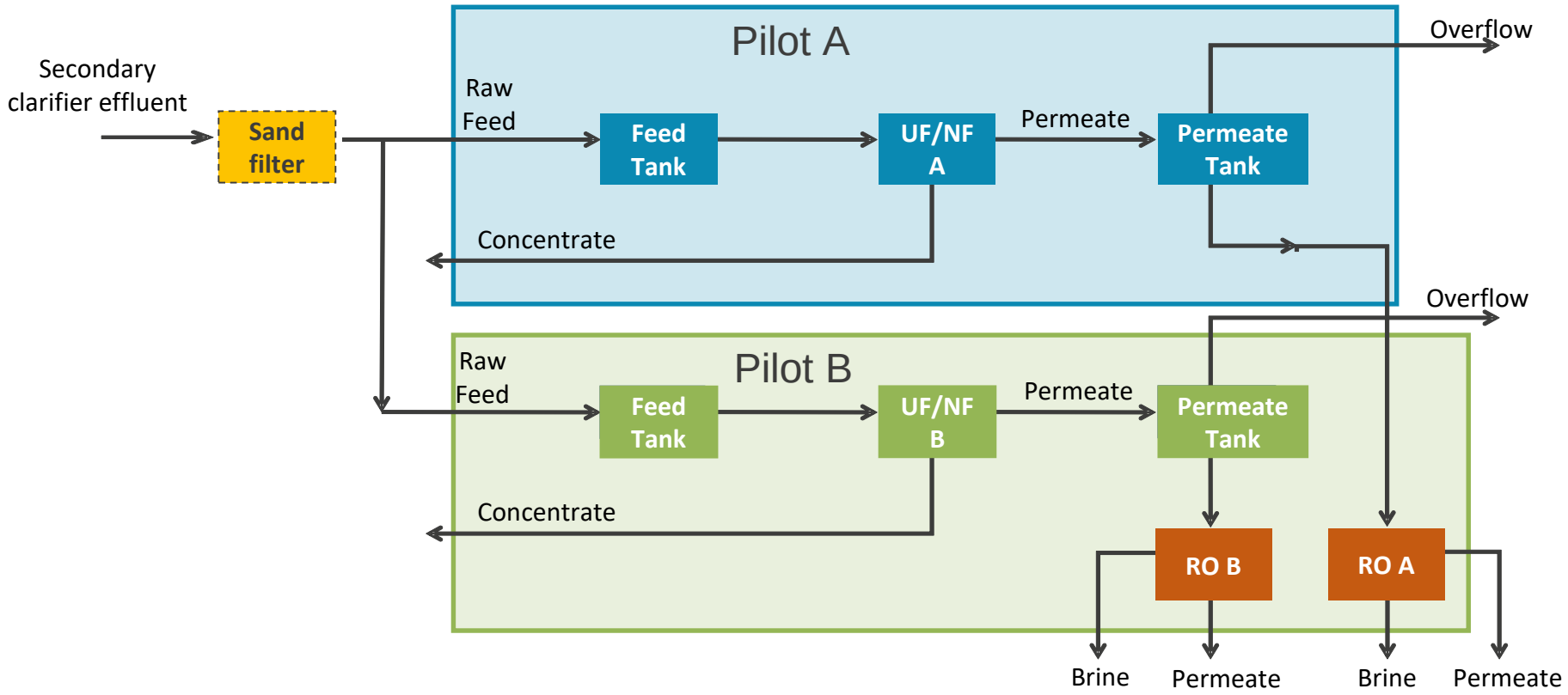
Fit for purpose water production via membranes



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

Membrane pilot plants

Pilot container A



Pilot container B



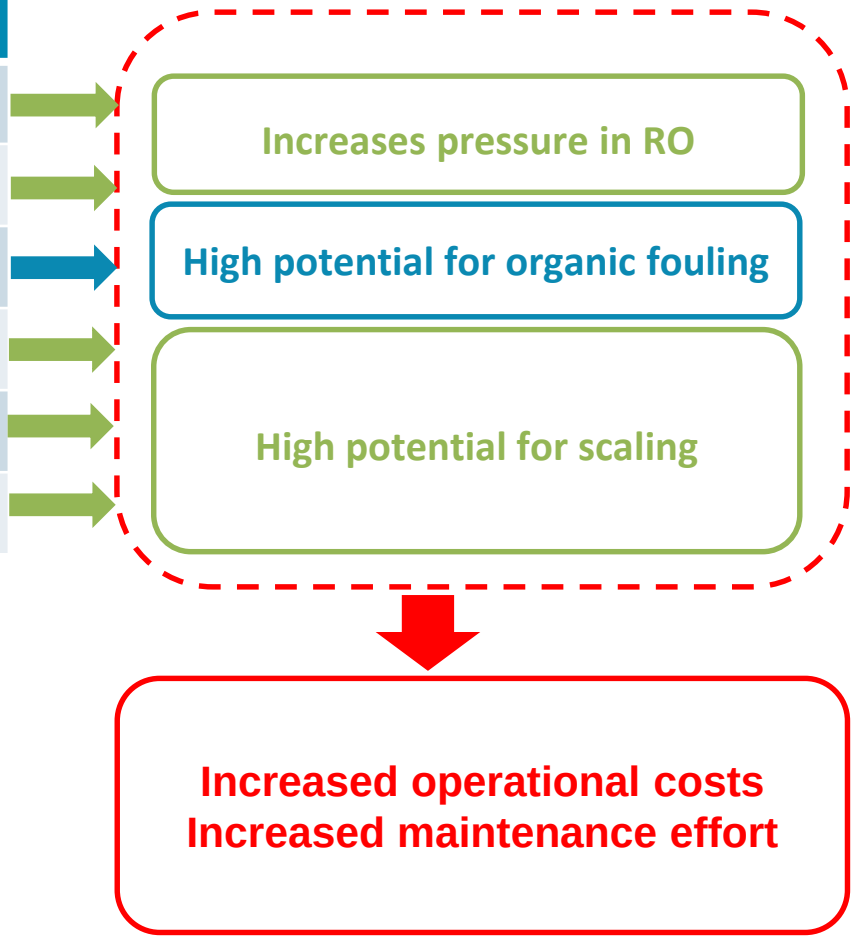
Reverse osmosis



Specific challenges at KCR WWTP

Parameter	Unit	Content
Electrical conductivity	µS/cm	2800-8200
Total dissolved solids	mg/L	3500-4200
TOC / COD	mg/L	20-60 / 50-190*
Calcium	mg/L	98-130
Hydrogen carbonate	mg/L	1000-1100
Sulfate	mg/L	440-510

* before ozonation for COD removal



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Why do we need research?

Fouling prevention:

- Does the novel ultra-tight UF membrane prevent better the RO from fouling than a conventional UF or open NF?

➢ performance comparison in parallel pilot containers

Production of fit-for-purpose water:

- Can we produce fit-for-purpose water for cooling towers and/or boilers?
- Which water quality is reached after UF/NF and for which reuse purpose can the water be used (truck or street cleaning)?

➢ Investigation of water quality after each treatment step

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

Practical challenges: pretreatment



pre-filter of UF/NF



blocked screen of pre-filter → requires a lot of manual cleaning



pre-filter of RO



cartridge of pre-filter → requires exchange very often

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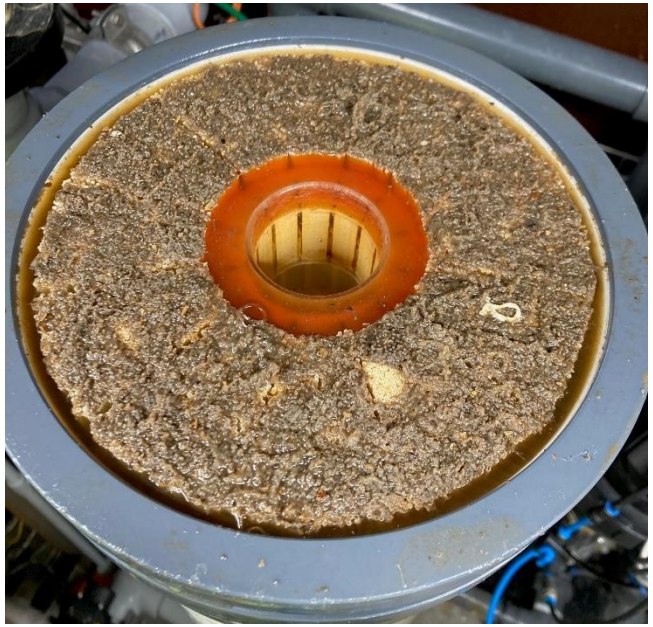
Practical challenges: membranes



UF/NF membrane module



clean UF/NF membrane



blocked UF/NF membrane

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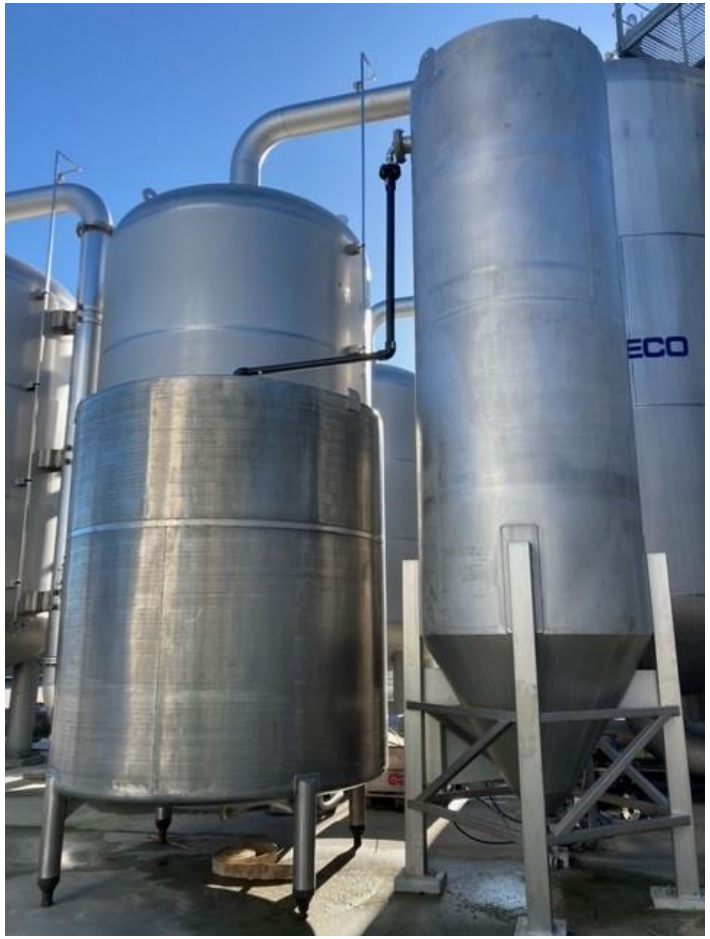
Intermediate solution: Install a DynaSand filter





continuously operated sand filter

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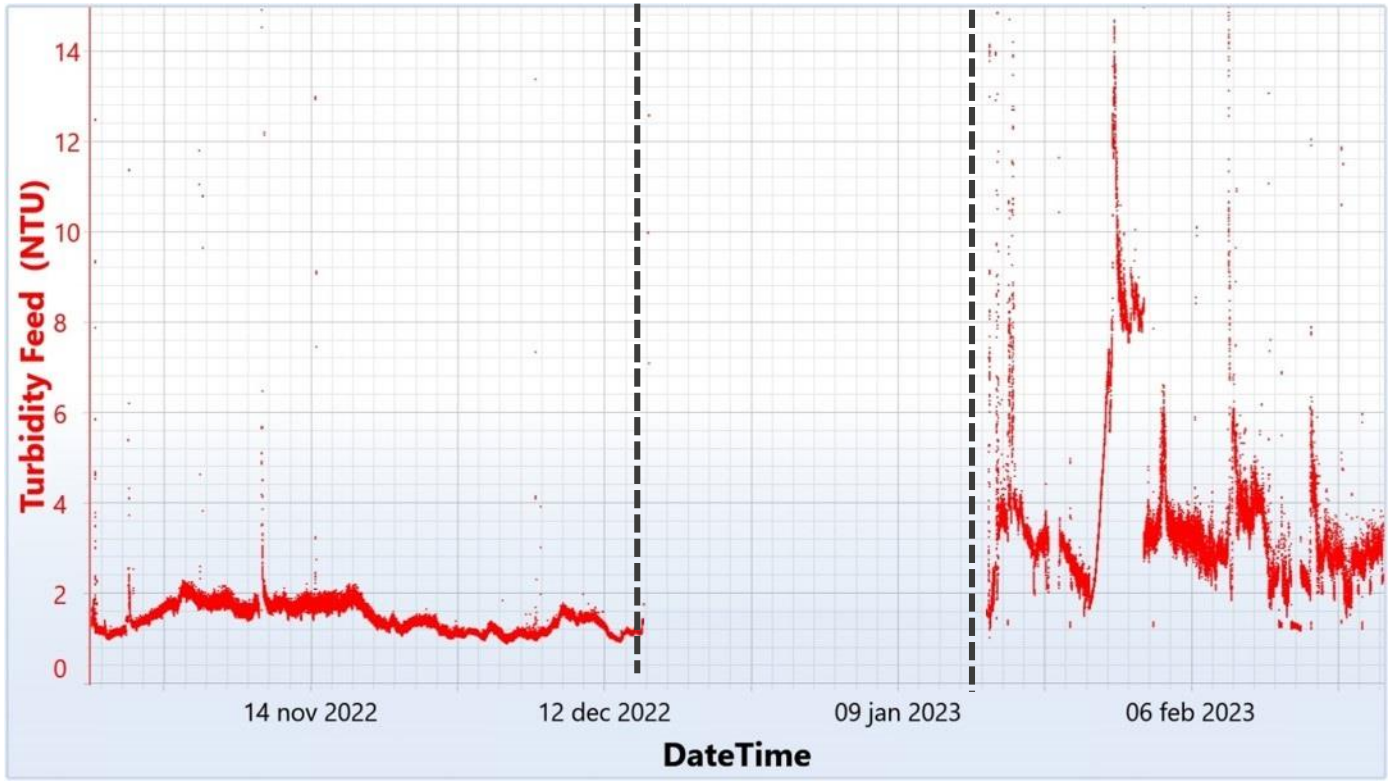
Impact of DynaSand filter

SF in operation

pilots out of operation

no SF operation



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Which treatment stage has which purpose?

Parameter	Sand filter	Prefilter	Ultrafiltration/ Nanofiltration	Reverse osmosis
Suspended solids	+	(+)	++	-
Microorganisms (bacteria, virus, protozoa)	(+)	-	++	+
Dissolved salts / hardness				++
Heavy metals				++
Dissolved organic matter and chemicals	-	-	-	++
	pretreatment		**main treatment**	

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Results: cooling water quality

Parameter	Unit	Goal: cooling tower	UF 150 kDa [1]	n	Ultra tight UF 4 kDa [1]	n	open NF 1 kDa [1]	n	RO [2]	n
Aluminium	µg/L	<500	< 30 ✓	4	38 ✓	6	< 30 ✓	3	✓	
Calcium	mg/L	> 20 / <500	127 ✓	6	135 ✓	12	140 ✓	7	< 0,5	6
Carbon. hardness	°dH	< 4 / < 20	26	2	29	4	33	3	0,13 ✓	6
Chloride	mg/L	< 50 / <250			1100	1	1000	1	19 ✓	7
Copper	µg/L	< 500			1,1 ✓	1	0,6 ✓	1	2,6 ✓	7
Conductivity	µS/cm	50 - <3000	5030	6	5200	8	5040	7	69 ✓	10
Iron	mg/L	< 0,1 / < 0,5			< 0,05 ✓	1	< 0,05 ✓	1	< 0,05 ✓	7
Magnesium	mg/L	<100	28,17 ✓	6	24 ✓	12	21 ✓	7	0,17 ✓	5
pH		7 - 9	8,2 ✓	2	8,2 ✓	5	8,1 ✓	4	6,4	10
Sulphate	mg/L	< 50 / < 600	498 ✓	4	437 ✓	10	337 ✓	6	2,0 ✓	6
TDS	g/L	<1,8	3,0	2	3,2	3	2,9	3	0,05 ✓	4
Total hardness	°dH	0,1 - <8	26	2	23	4	24	3	< 0,1 ✓	6
TSS	mg/L	<5	1,2 ✓	2	0,6 ✓	3	3,9 ✓	3	1,6 ✓	4
Turbidity	FNU	< 1	1,4	6	0,39 ✓	10	< 0,1 ✓	6	✓	
Escherichia coli	MPN/100 mL	Absence			< 2 ✓	1	< 2 ✓	1	✓	
Legionella	CFU/L	< 100			< 10 ✓	1	< 10 ✓	1	✓	

1) Independent from operational parameter
2) Independent from pre-treatment, results of both ROs together
3) Only one grab sample, currently reuse water quality
4) Only one grab sample, drinking water quality

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

Results: steam production quality

Parameter	Unit	Goal: steam production	UF 150 kDa [1]	n	Ultra tight UF 4 kDa [1]	n	open NF 1 kDa [1]	n	RO [2]	n
Alkalinity	mmol/L	0.5-15	18	2	15	4	16	3	0,2 ✓	7
Clarity		clear, free from particles	6/7		13/13 ✓		8/8 ✓		10/10 ✓	
COD	mg/L	3-5	61	7	55	16	42	11	< 5 (✓)	12
Copper	µg/L	< 3 - < 100			1,1 ✓	1	0,6 ✓	1	2,6 ✓	7
Conductivity	µS/cm	≤ 30/ > 30 *	5030	6	5200	8	5040	7	69	10
Oil and fat	mg/L	< 1 / < 0.5			< 0,1 ✓	1	< 0,1 ✓	1	✓	
Iron	mg/L	< 0.01 - < 0,3			< 0,05 ✓	1	< 0,05 ✓	1	< 0,05 ✓	7
Sodium	mg/L	< 0.01 (Na+K)			890	1	870	1	15	7
pH		> 7.0 / > 9.2 / 7-10	8,2 ✓	2	8,2 ✓	5	8,1 ✓	4	6,4	10
Potassium	mg/L	< 0.01 (Na+K)			210	1	200	1	3,8	7
Silicate	mg/L	< 0,02	7,9	4	8,6	8	9,1	5	0,09 **	7
TOC	mg/L	< 0.2 - < 0.5	25	6	23	11	17	8	0,46 ✓	7
Total hardness	°dH	< 0,028 - < 0,28	26	2	23	4	24	3	< 0,1 ✓	6

* very wide range, depending on the type of vessel

1) Independent from operational parameter
2) Independent from pre-treatment, results of both ROs together
3) Only one grab sample, currently reuse water quality
4) Only one grab sample, drinking water quality

** 4/7 samples < LOQ (< 0,02)

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 have we learned from the pilot operation?

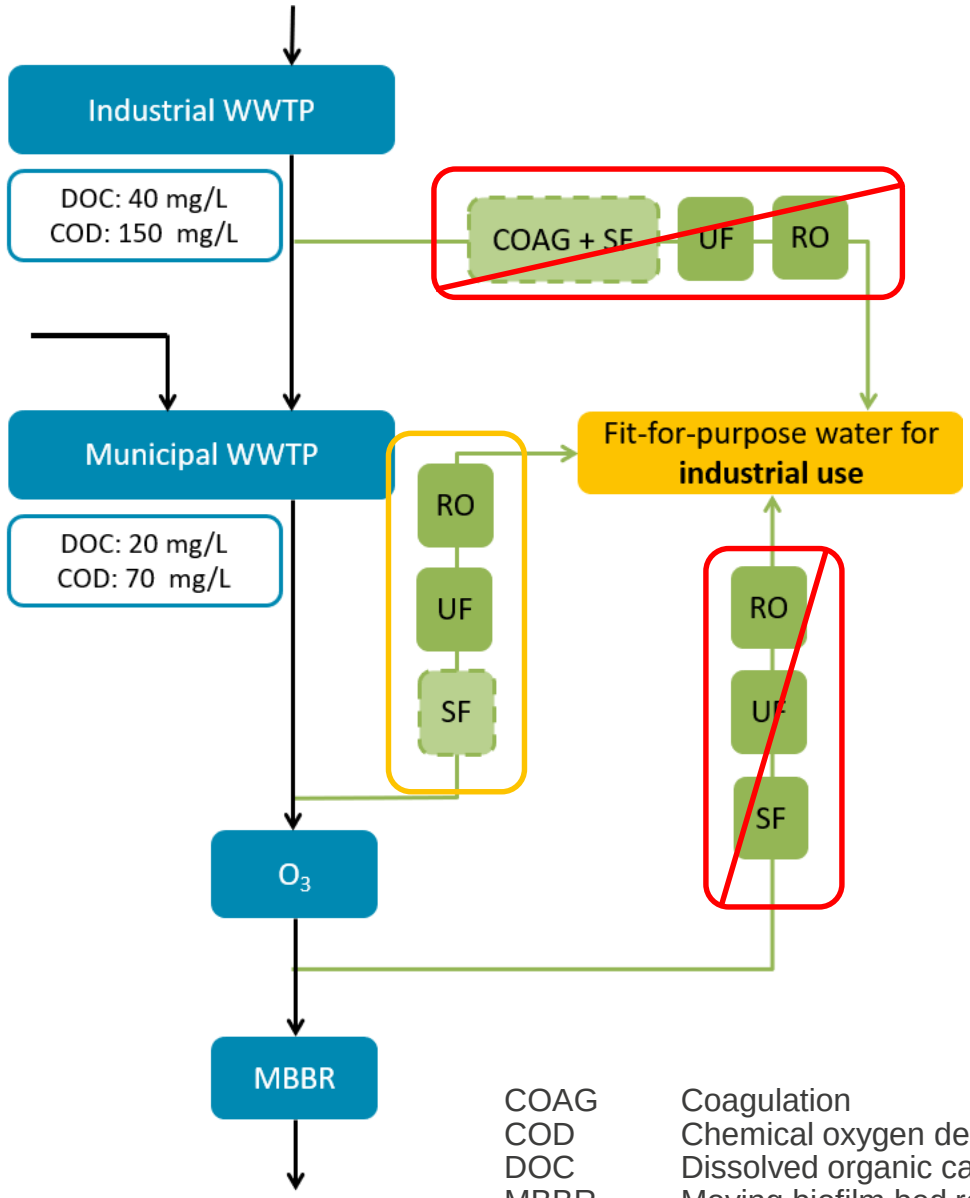
- Chemical parameters for cooling water can be easily met with UF-RO treatment
- ➢ Current used Lake water/Tisso II water could be substituted with RO permeate (pH adjustment/ stabilization required)

- Main challenge is the operation (no standard secondary effluent)
- ➢ More efforts on proper prefiltration (With DynaSand: reliable operation for 5 months)
- ➢ Significant fouling potential on membranes (high organic matter, high alkalinity)

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 are the next steps?

- Installation of dual media filter before membrane unit
- Optimization of operational parameter for continuous and reliable operation
- More measurements on microbial parameter needed for validation of cooling water quality
- Microbial risk assessment concept



COAG	Coagulation
COD	Chemical oxygen demand
DOC	Dissolved organic carbon
MBBR	Moving biofilm bed reactor
RO	Reverse Osmosis
SF	Sandfiltration
UF	Ultrafiltration
WWTP	Wastewater treatment 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

Than you for your attention!



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

CETAQUA
WATER TECHNOLOGY CENTRE

B-WaterSmart

Brine valorisation for disinfectants production through selective electrodialysis

Eric Santos
Project Manager and Researcher
Water & Resource recovery

Membrane technologies in wastewater treatment
ULTIMATE workshop – 6 March 2023

CETAQUA

Main activities

1 R&D

WATER RESOURCES MANAGEMENT

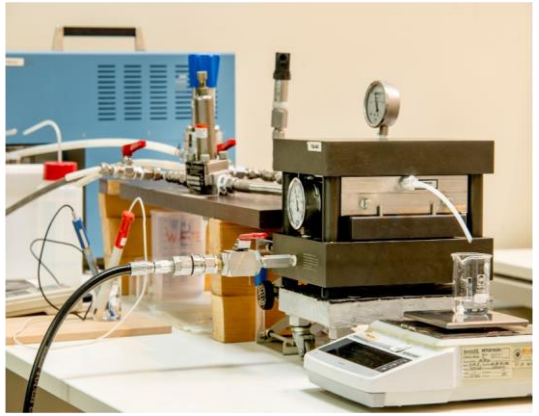
ENVIRONMENTAL, ECONOMIC AND SOCIAL SUSTAINABILITY

BIOFACTORY AND RESOURCE RECOVERY

WATER 4.0

CRITICAL INFRASTRUCTURE MANAGEMENT AND RESILIENCE

2 Knowledge-based services



3 Digital services



What we do. R&D

Research lines / BIOFACTORY AND RESOURCE RECOVERY

BIOFACTORY AND RESOURCE RECOVERY

Solutions for transforming treatment plants into biofactories: efficient facilities for obtaining water, energy and materials.



- Efficient **treatments** for urban and industrial wastewater, drinking water and reclamation and reuse
- Recovery and production of high added value **materials** from urban and industrial waste effluents
- Recovery and storage of **green energy** from urban and industrial waste effluents

B-WaterSmart

B-WaterSmart accelerates the transformation to water-smart economies and societies in coastal Europe and beyond

Key Data:

Partners: 36 organizations

Total Budget: **17.3 M€**
Total EC contribution: **15.0 M€**
EC H2020 GA Number: **869171**

Duration: **Sep 2020 – Aug 2024**

Coordinator: **IWW Water Centre**

B-WaterSmart project partners

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B-WaterSmart

B-WaterSmart accelerates the transformation to water-smart economies and societies in coastal Europe and beyond

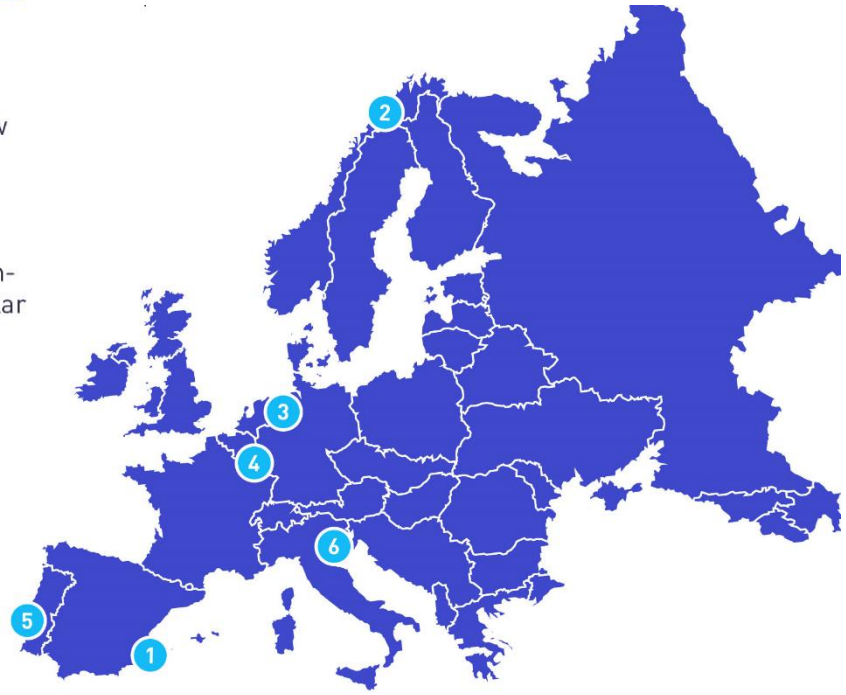
The project is:

- Grounded on **6 coastal European cities and regions** as 6 interconnected **Living Labs (LLs)**
- Supported by Communities of Practice (**CoPs**) and **a European Innovation Alliance** (INALL)
- Promoted by the Aqua Research Collaboration **ARC** – A Network of European Water Research Institutes

1 Alicante

Challenges
Water scarcity, limitations to water reuse due to high salinity/nitrates, limitations to water reuse due to low acceptance.

Innovation & Demonstration
Improve water-smartness in the municipality of Alicante by incrementing water reuse and boosting circular economy opportunities.



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Living Lab Alicante - ambition

A regional Living Lab to boost water reuse and resource recovery in the territory

Demonstration of a set of technologies in Rincón de León WRP:

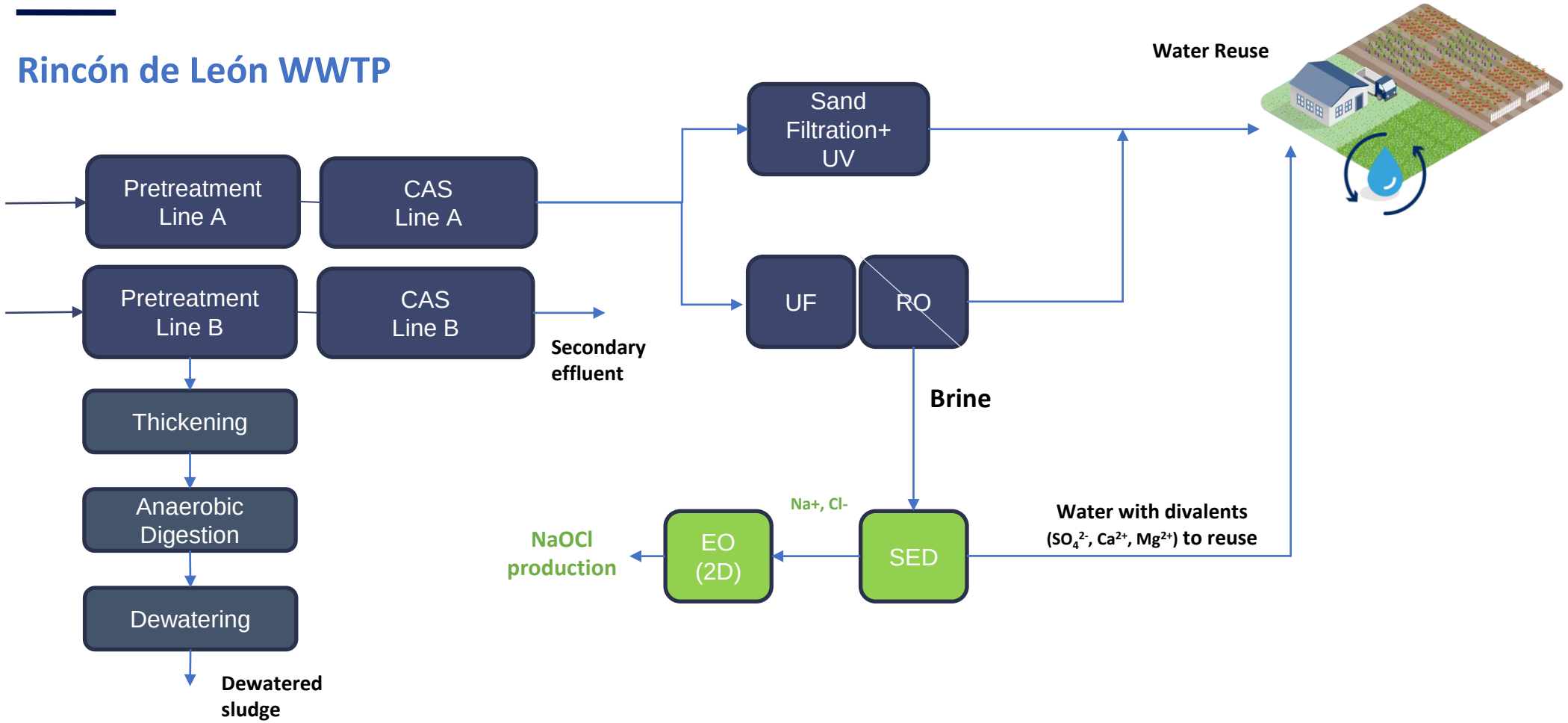
- **Valorisation of RO brines**
- **Energy recovery**
- **Nutrients recovery**

Physical-virtual space for co-creation, supported by RE-ACTOR Tool to assess reuse opportunities, demonstrate the benefits of increased water reuse and raise awareness between stakeholders



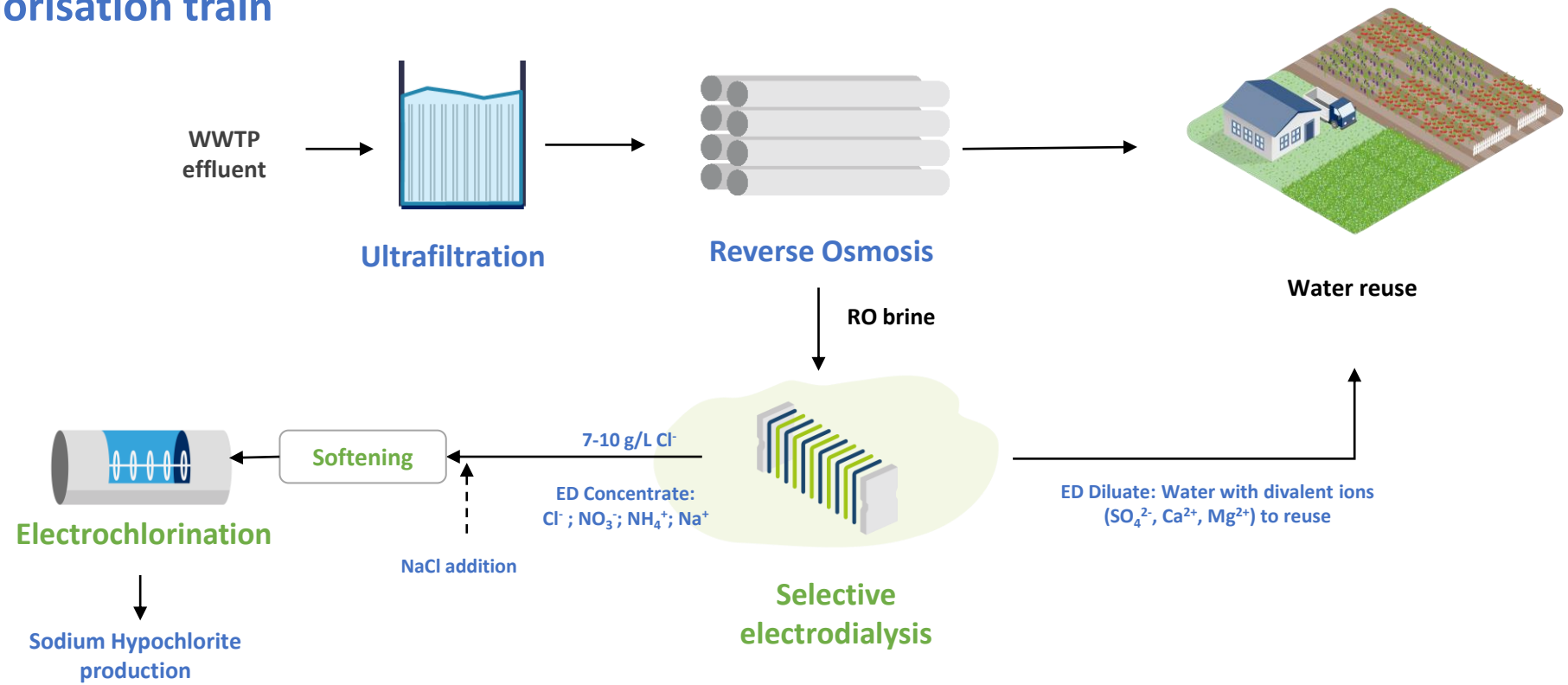
Valorisation of RO brines in Rincón de León WWTP

Rincón de León WWTP



Valorisation of RO brines in Rincón de León WWTP

Brine valorisation train

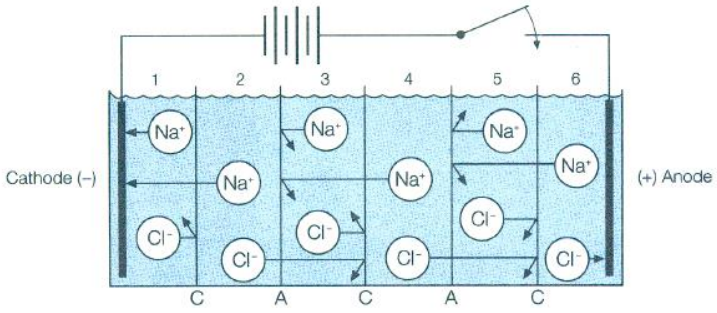


AGUAS DE ALICANTE
CETAQUA WATER TECHNOLOGY CENTRE
B-WaterSmart

Valorisation of RO brines in Rincón de León WWTP

Selective electrodialysis

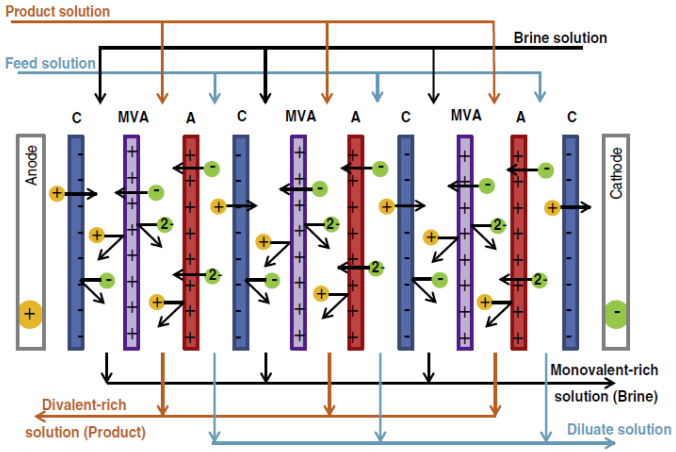
Conventional electrodialysis



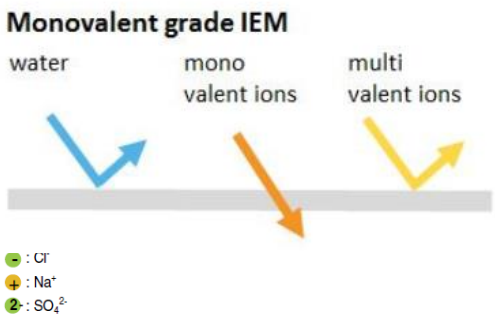
Source: American Water Works Association, 1999



Selective electrodialysis



Source: M.Reig, 2016- Integration Of Electrically Driven Membrane Separation Processes For Water Treatment And Resources Recovery



Valorisation of RO brines in Rincón de León WWTP

Selective electrodialysis

Main characteristics of the ED pilot plant

- 80 cell pairs
- Total membrane area: 8 m2
- 3 tanks: concentrate, dilute, electrode rinse solution
- Feed & bleed / batch operation



Valorisation of RO brines in Rincón de León WWTP

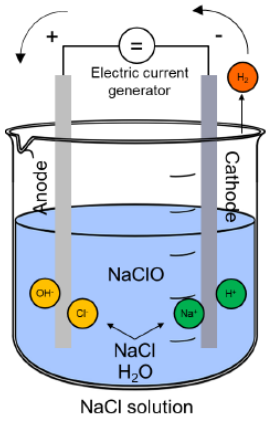
Electrochlorination

EC will allow to produce NaOCl from concentrated brine obtained in SED

A mix-oxidant (NaOCl + H2O2) EC unit was selected → lower Cl- concentration is needed for an equivalent disinfection capacity (13.5 g NaCl/L needed or 8.19 g Cl-/L)

Characteristics of the ECU

- 13.6 kg FAC/day (aprox. 0.5 kg/h)
- 12.5% bleach equivalent: 113.5 L/day
- 3 kg NaCl/kg FAC
- 6.6 kWh/kg FAC
- FAC concentration: 4500 mg/L ± 1000 mg/L
- Operation in batch



NaCl solution

Reaction at the Anode:
$2Cl^- \rightarrow Cl_2 + 2e^-$ (chlorine generation in the electrolyzer)

Reaction at the Cathode:
$2H_2O + 2e^- \rightarrow H_2 + 2OH^-$ (hydrogen evolution from electrochlorinator)

Chemical Reaction in Electrolyzer:
$\underline{Cl_2 + 2OH^- + 2Na^+ \rightarrow 2NaClO + H_2}$
(hypochlorite generation)



Valorisation of RO brines in Rincón de León WWTP

Brine valorisation pilot plant integration





Expected benefits: SED + EC

Water reclamation market

- ❑ **Increase** overall **reclaimed water** production
- ❑ **Reduce costs** in brines disposal
- ❑ Reduce costs in chemical consumption (NaClO)

- ❑ Own-production of NaClO: **protection against shortages** or market changes
- ❑ Boosting of **biofactory** and **circular economy** concept

- ❑ Improve the **environmental footprint** of WRP plants: lower waste disposal & consumption of chemicals
- ❑ **Recovery of divalents ions** useful for agricultural fertilization: lower chemical fertilizers consumption



CONCLUSIONS

- During the lab scale tests, different ionic compositions were assessed to evaluate the effect of brine composition variability in the valorization process. **Lab tests** demonstrated that SED was able to **concentrate NaCl 5 to 10 times**
- Average energy consumption of the overall process, including SED and electrochlorination was **10.3 kWh/kg of active chlorine** produced
- The produced **dilute** had a **low conductivity** below 3 mS/cm, enabling its use for **reclaimed water** applications.
- The proposed process appears to be a **cost-effective alternative** to conventional brine management, **reducing the environmental impact** of nitrate-rich brines while producing sodium hypochlorite that can be used on-site
- The results obtained in the laboratory tests will be validated in a **semi-industrial prototype** that is being installed in the water reclamation plant of Alicante and will be operated until December 2023

CETAQUA
WATER TECHNOLOGY CENTRE

Thank you!

Eric Santos
Project Manager and Researcher
eric.santos@cetaqua.com

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ULTIMATE PROJECT WORKSHOP



Water reuse in Sicily within WiderUptake Project

Prof. ing. Giorgio MANNINA

Full Professor of Sanitary and Environmental Engineering, Palermo University

27 February 2023, Online

1

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The wastewater treatment is an issue or an opportunity/deal?

Achieving wider uptake of water-smart solutions

Wider Uptake

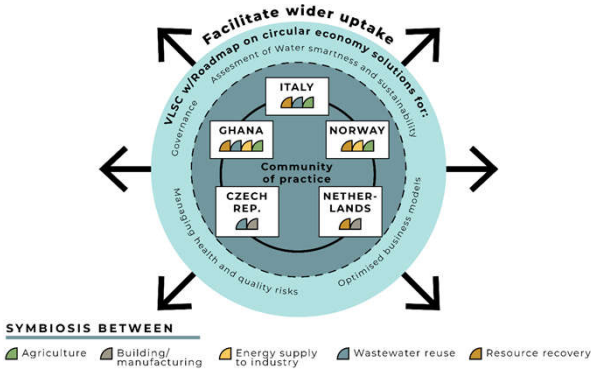
wider uptake

2

Wider Uptake – main goals

Transform WWTPs in **water resource recovery facilities**

Facilitate industrial symbiosis by co-development of a roadmap towards wider uptake of water-smart solutions for wastewater reuse and resource recovery



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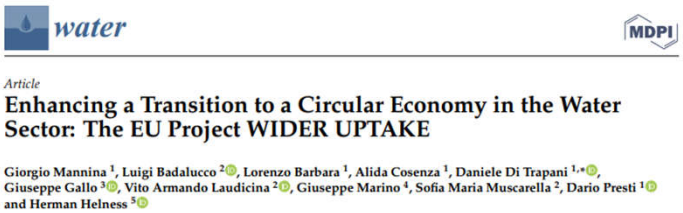
Wider Uptake – how to achieve the goals


water

MDPI

Article

Enhancing a Transition to a Circular Economy in the Water Sector: The EU Project WIDER UPTAKE

Giorgio Mannina [1], Luigi Badalucco [2], Lorenzo Barbara [1], Alida Cosenza [1], Daniele Di Trapani [1,*], Giuseppe Gallo [3], Vito Armando Laudicina [2], Giuseppe Marino [4], Sofia Maria Muscarella [2], Dario Presti [1] and Herman Helness [5]

4

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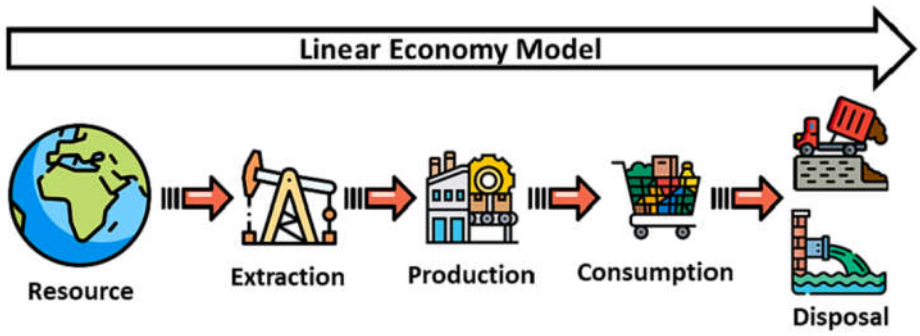
Linear vs circular economy model …



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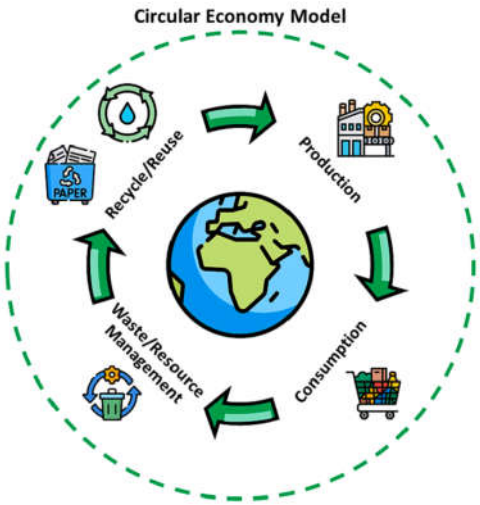
Linear vs circular economy model …



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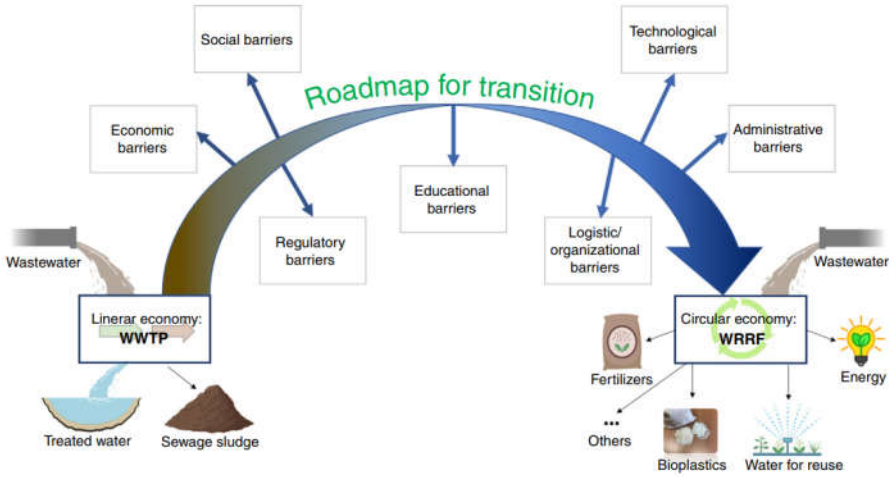
Need of a “tool” for the transition… breaking barriers



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Bioresource Technology 363 (2022) 127951

Contents lists available at ScienceDirect

Bioresource Technology

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

Review

Water reuse from wastewater treatment: The transition towards circular economy in the water sector

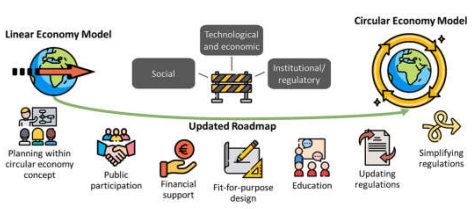
Giorgio Mannina [a,*], Hazal Gulhan [a,b], Bing-Jie Ni [c]

[a] Engineering Department – Palermo University, Viale delle Scienze, Ed. 8, 90128 Palermo, Italy
[b] Environmental Engineering Department, Civil Engineering Faculty, Istanbul Technical University, Ayazaga Campus, Maslak, 34469 Istanbul, Turkey
[c] Centre for Technology in Water and Wastewater, School of Civil and Environmental Engineering, University of Technology Sydney, Sydney, NSW 2007, Australia

HIGHLIGHTS

- Roadmaps are strategic tools in the realization of systemic transitions.
- Water reuse is crucial in the transition from a linear to a circular economy.
- Current roadmaps toward a circular economy overlook water reuse.
- An updated roadmap to widen water reuse applications is proposed.
- The results on resource recovery from the University of Palermo are promising.

GRAPHICAL ABSTRACT



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Demonstration Case studies - UNIPA

wider uptake

1. Palermo University: bioplastic, water reuse, low release fertilizers; sewage sludge reuse (composting)

2. Marineo WWTP –bioplastic production & low realise fertilizers – deviation line

3. Corleone WWTP: water reuse; sewage sludge reduction and minimization

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Multidisciplinary Team within UNIPA

WP6 Leader–multidisciplinary team:

- ✓ Ingegneria
- ✓ Scienze Agrarie, Alimentari e Forestali
- ✓ Giurisprudenza
- ✓ Scienze e Tecnologie Biologiche Chimiche e Farmaceutiche

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Water Resource Recovery Facility at Palermo University Campus

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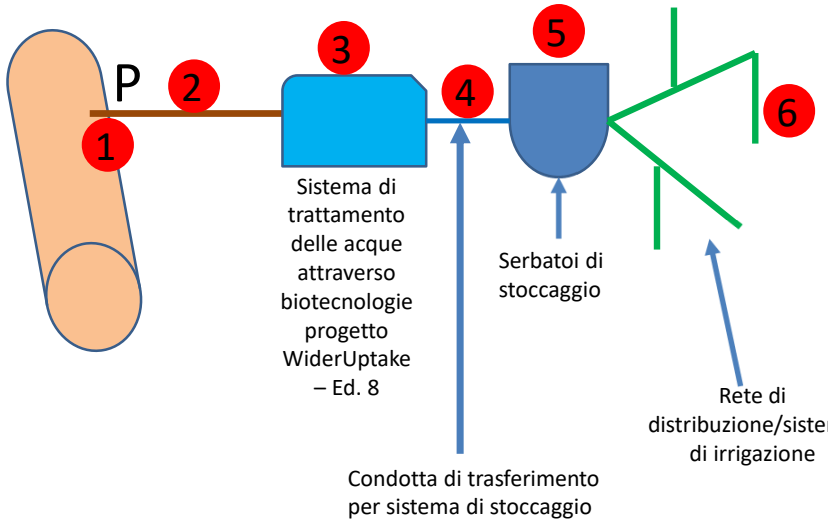
Water Resource Recovery Facility at UNIPA



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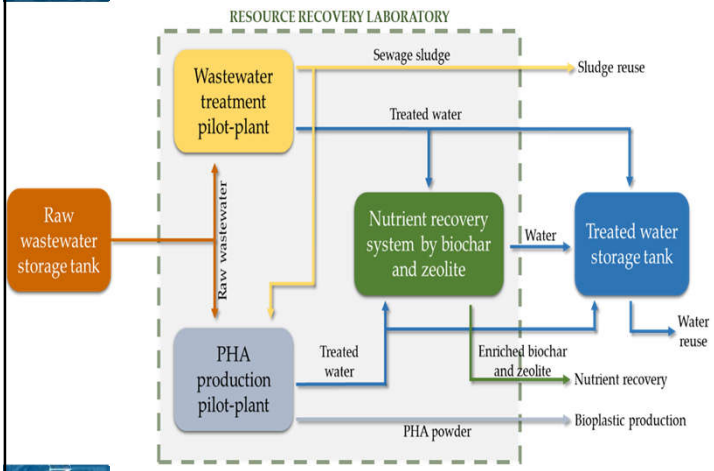
WRRR - UNIPA Case study







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WRRR - UNIPA Case study



Wastewater pipeline:
Length: 520 m
Suction height: 36 m a.s.l.
Discharge height: 45 m a.s.l.
Diameter: 60 mm

Treated water and irrigation pipeline
Length: 775 m
Suction height: 45 m a.s.l.
Discharge height: 40 m a.s.l.
Diameter: 40 mm

1 – Pumping station
2 – Wastewater line
3 – Water tratment pilot-plant
4 – Trated water line for reuse
5 – Water storage tank
6 – Irrigation system
7 – Composting area
8 – Greenhouse and experimental field

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LAVORI IN CORSO
AMAP S.p.A.

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Prof. Giorgio Mannina – Università di Palermo
Achieving wider uptake of water-smart solutions - WIDER UPTAKE – GA No. 869283

18


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LAVORI IN CORSO
LAVORI IN CORSO

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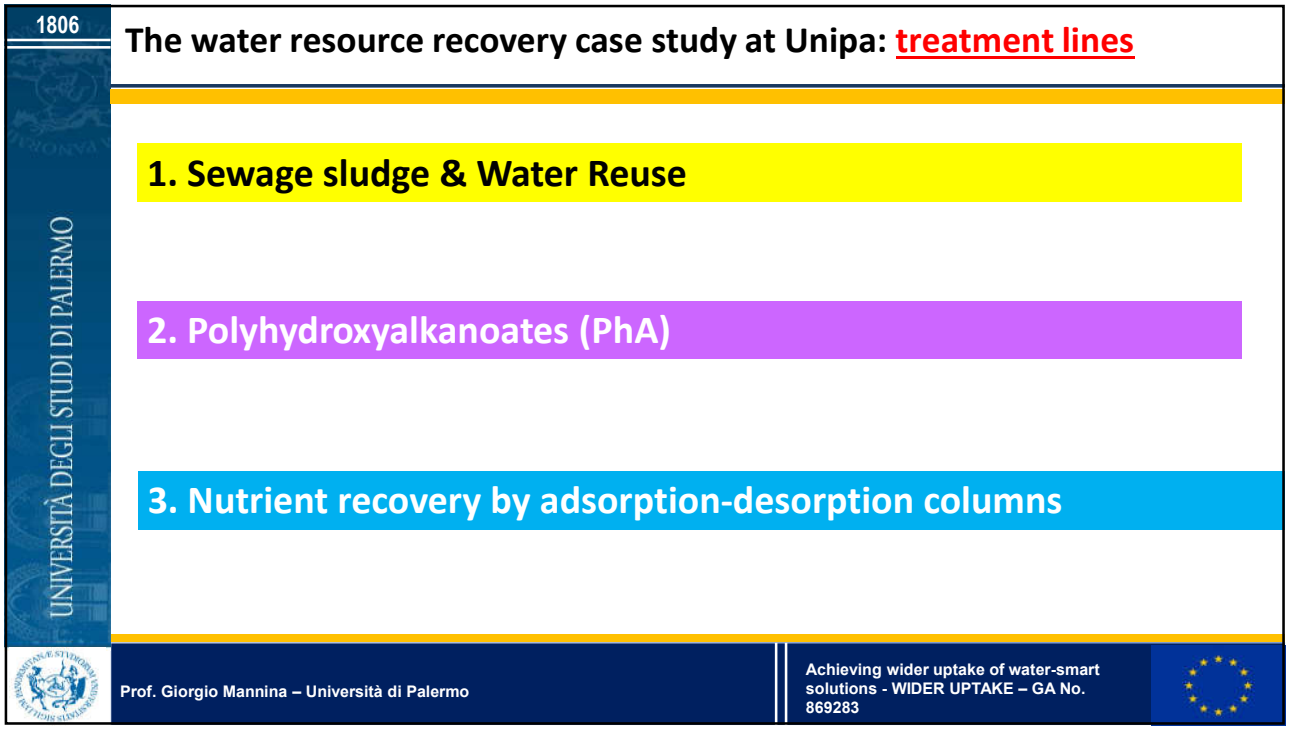
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The water resource recovery case study at Unipa: treatment lines
1. Sewage sludge & Water Reuse
2. Polyhydroxyalkanoates (PhA)
3. Nutrient recovery by adsorption-desorption columns
Prof. Giorgio Mannina – Università di Palermo
Achieving wider uptake of water-smart solutions - WIDER UPTAKE – GA No. 869283

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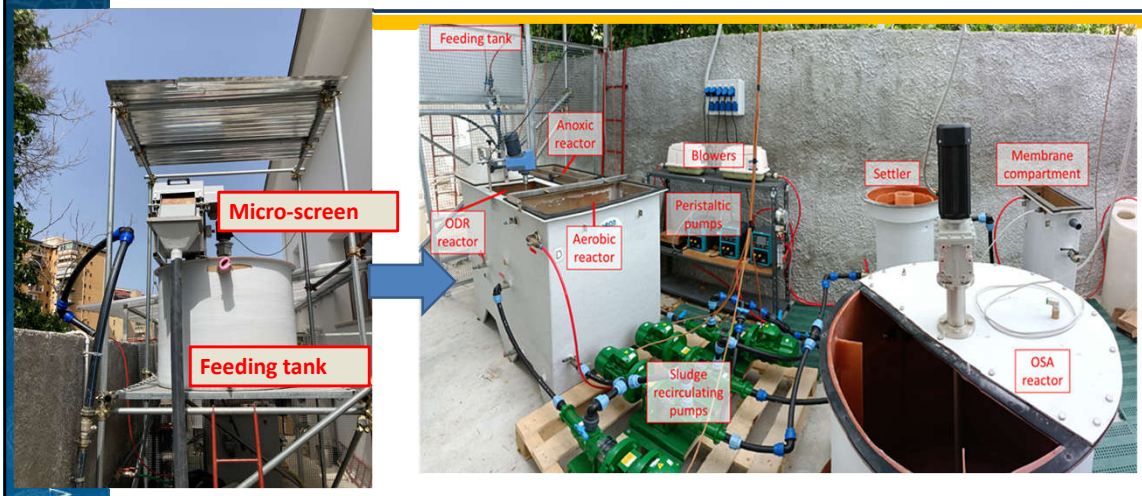
Sewage sludge & Water Reuse: 1st treatment line



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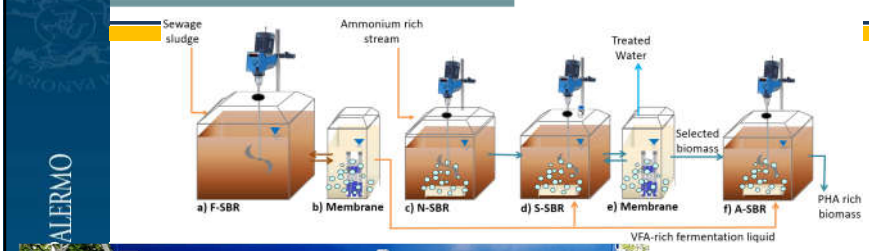
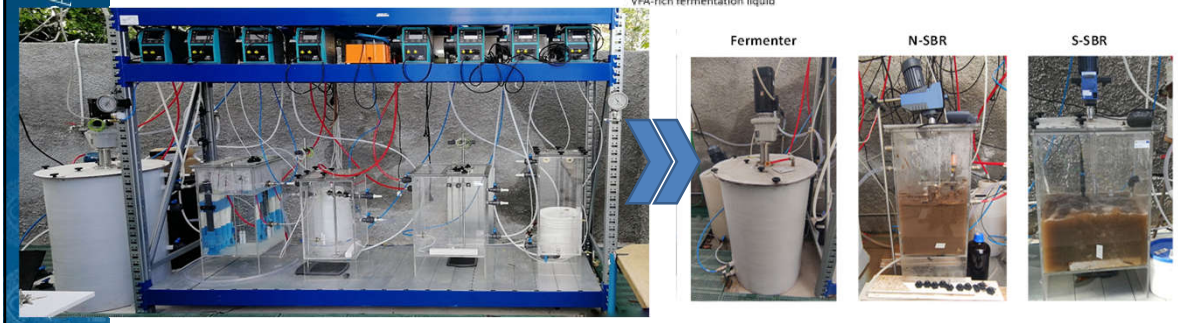
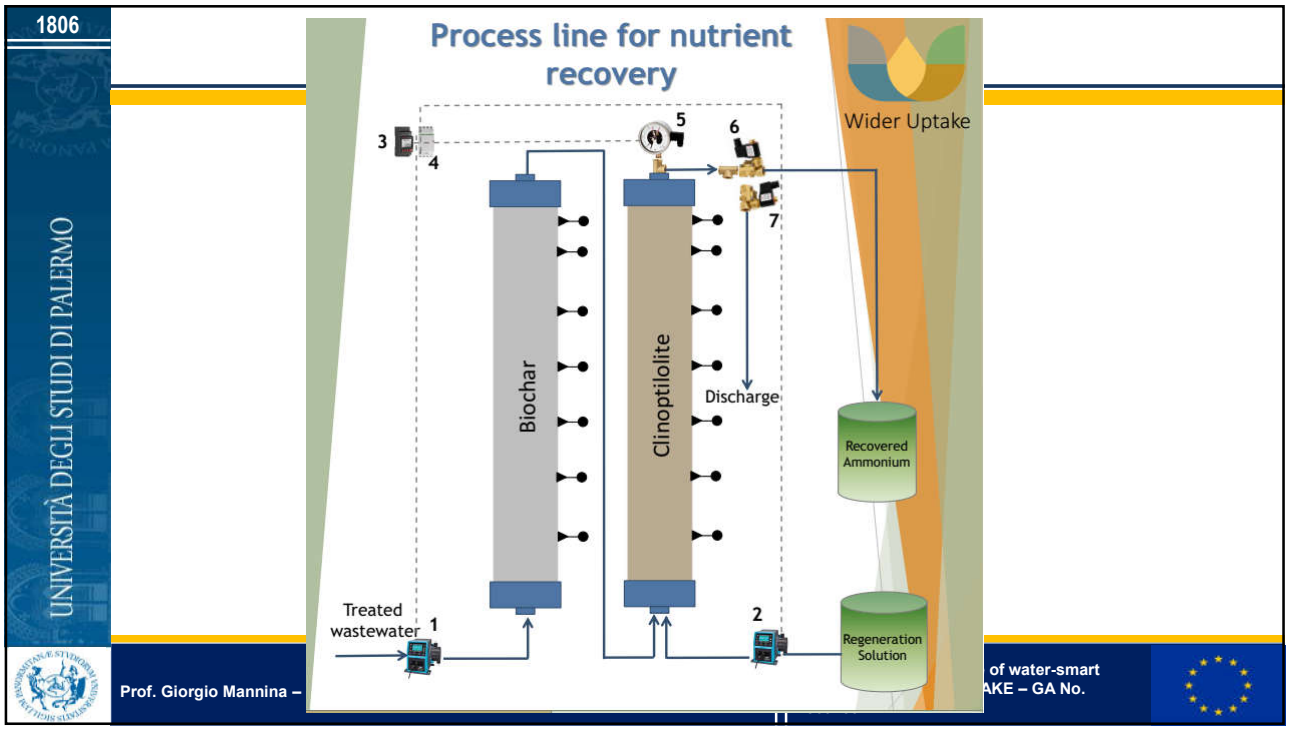
Bioplastic (PhA) production: 2nd treatment line



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Process line for nutrient recovery
Wider Uptake
Biochar
Clinoptilolite
Discharge
Recovered Ammonium
Regeneration Solution
Treated wastewater
1
2
3
4
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6
7
Prof. Giorgio Mannina –
of water-smart
AKE – GA No.

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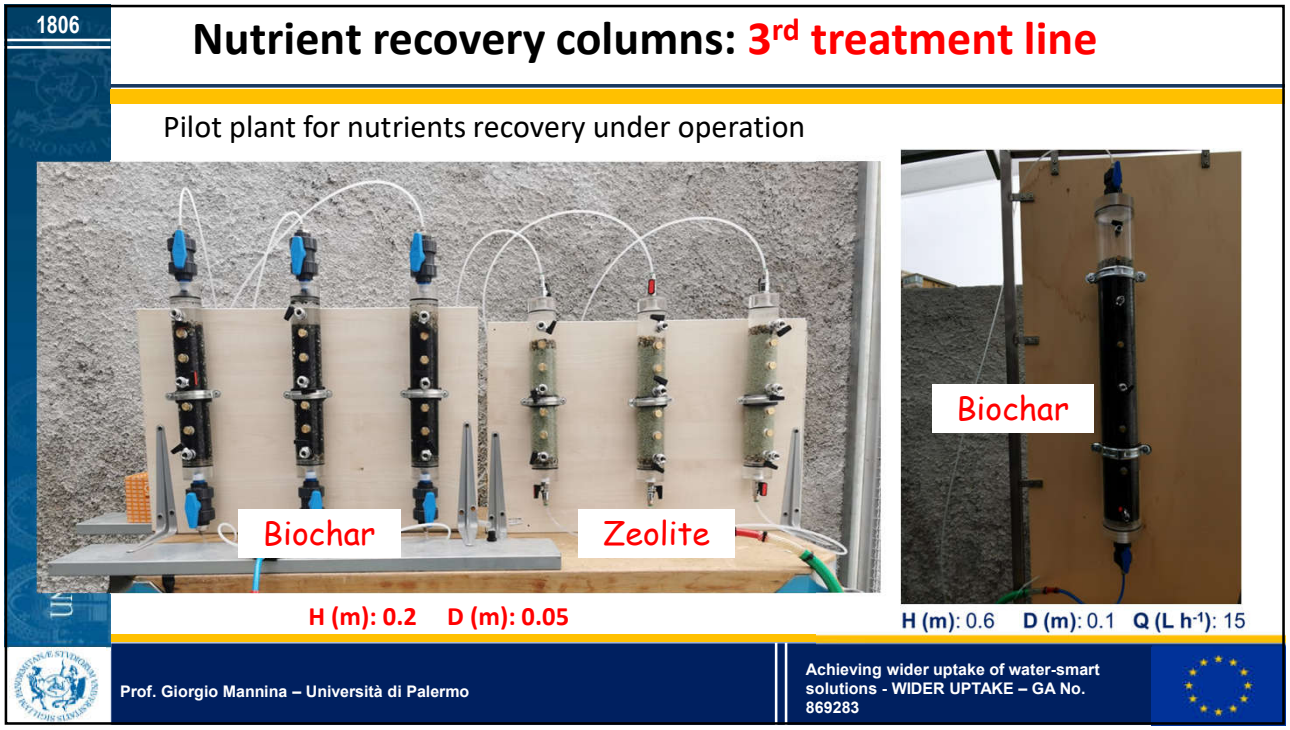
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Nutrient recovery columns: 3rd treatment line
Pilot plant for nutrients recovery under operation
Biochar
Zeolite
H (m): 0.2 D (m): 0.05
Biochar
H (m): 0.6 D (m): 0.1 Q (L h-1): 15
Prof. Giorgio Mannina – Università di Palermo
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Water Resource Recovery Lab







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New Water Resource Recovery lab

Before……

Work in progress…..



…..ready!



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New Water Resource Recovery lab



Respirometric/PHA accumulation batch test



Vacuum pump and other equipment



Ionic chromatograph



Gas chromatograph



Optical IPC

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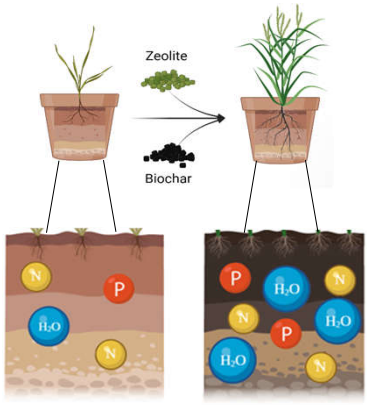
Running activities



15 x 8.5 m



Reuse experiments at Unipa











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water

MDPI

Article

Water Resource Recovery Facilities (WRRFs): The Case Study of Palermo University (Italy)

Giorgio Mannina [1,*], Rosa Alduina [2], Luigi Badalucco [3], Lorenzo Barbara [1], Fanny Claire Capri [2], Alida Cosenza [1], Daniele Di Trapani [1], Giuseppe Gallo [2], Vito Armando Laudicina [3], Sofia Maria Muscarella [3] and Dario Presti [1]

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[2] Department of Biological, Chemical and Pharmaceutical Sciences and Technologies, University of Palermo, Viale delle Scienze, 90128 Palermo, Italy; rosa.alduina@unipa.it (R.A.); fannyclaire.capri@unipa.it (F.C.C.); giuseppe.gallo@unipa.it (G.G.)
[3] Department of Agricultural, Food and Forest Science, University of Palermo, Viale delle Scienze, 90128 Palermo, Italy; luigi.badalucco@unipa.it (L.B.); vitoarmando.laudicina@unipa.it (V.A.L.); sofiamaria.muscarella@unipa.it (S.M.M.)
* Correspondence: giorgio.mannina@unipa.it; Tel.: +39-091-23896556

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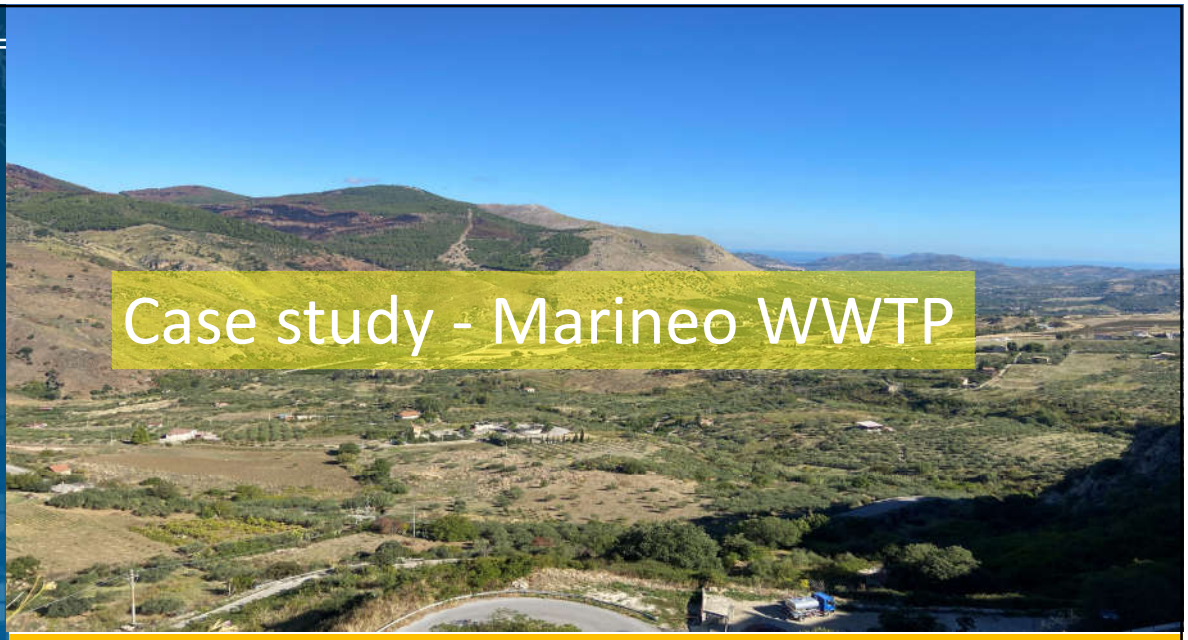
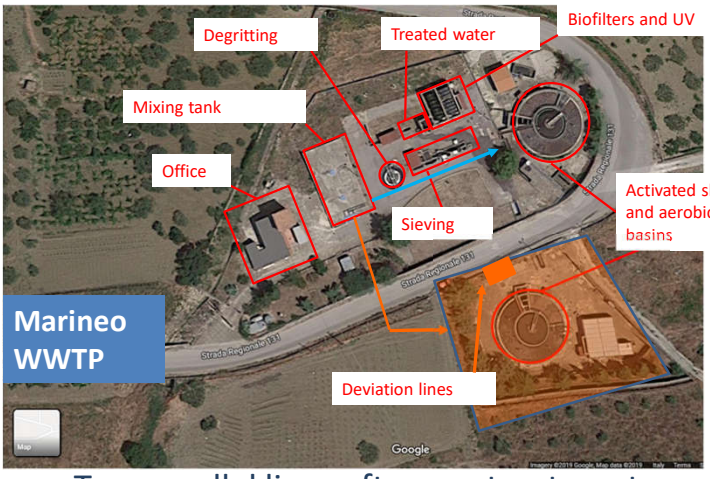


Case study - Marineo WWTP

34

Case study – Marineo WWTP



Two parallel lines after pre-treatment

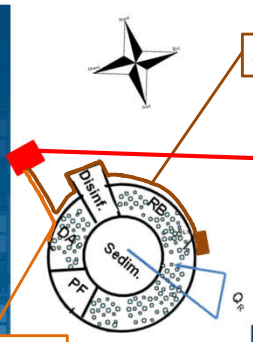
Case study – Marineo WWTP

Deviation line for Polyhydroxyalkanoates (PHA) production





Sludge line



Water line

Design and realization of a deviation line for PHA

Case study – Marineo WWTP



Case study – Corleone WWTP

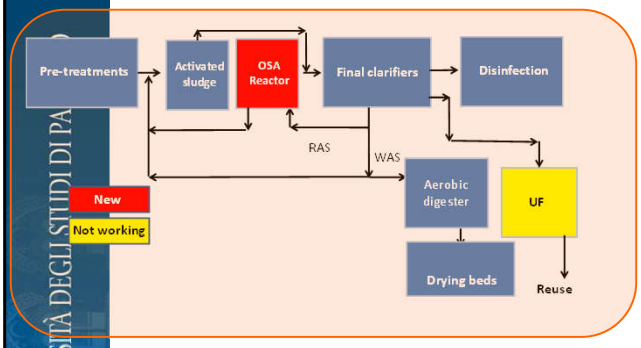
Case study – Corleone WWTP



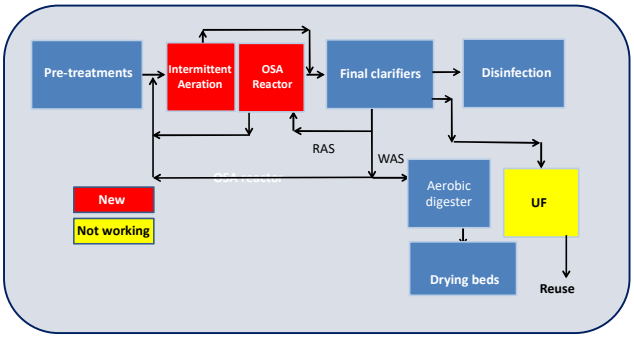
Activities - Corleone WWTP

New WWTP configuration for sludge minimization

Scheme 1



Scheme 2



OSA reactor: anaerobic reactor for sludge reduction

OSA reactor: Corleone WWTP – reduction of sewage sludge production



New aeration system under operation



Mechanical mixers installation





Arrangement of new electric line for mixers

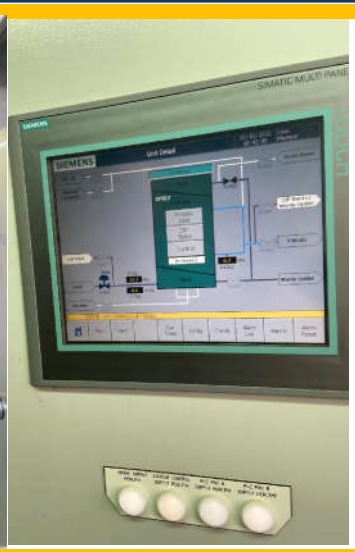


New flow meters installed

Reuse ultrafiltration system – revamping

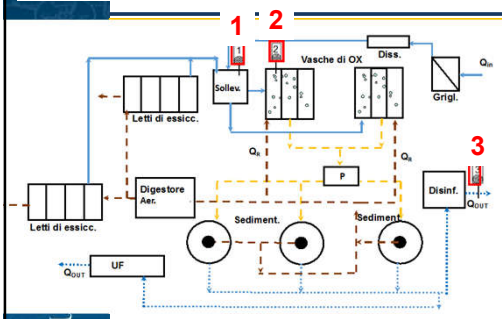


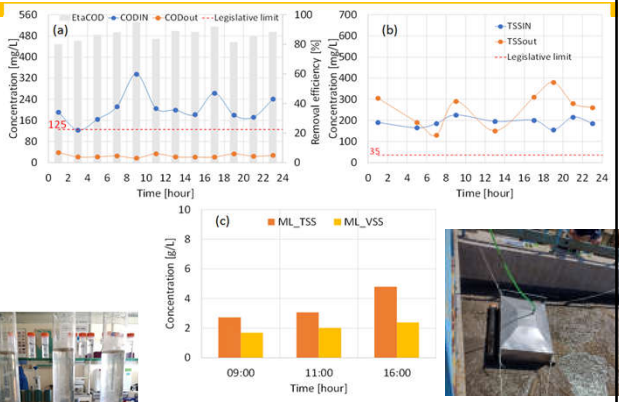




Activities - Corleone WWTP

Monitoring campaign at full scale plant





- **Section 1-** inlet to activated sludge reactor
- **Section 2-** mixed liquor inside biological reactor
- **Section 3-** outlet of settled water from secondary clarifier





1806

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Think globally & act locally

Great opportunity for innovation of the Water-wastewater infrastructures in Sicily.
WRRF from WiderUptake can be drawn as «model» for Sicily offering great opportunities also in terms of economy, new employmnets, sustainability

Smart Solutions for Wastewater: Road-mapping the Transition to Circular Economy

New books – Elsevier, September 2022



Chapter 1	Introduction
	This chapter will present general information about the smart solutions for wastewater.
Chapter 2	Sewage sludge from wastewater in a circular economy prospect
	This chapter deals with the fundamental aspects of sewage sludge production from wastewat focusing on circular economy perspectives
Chapter 3	Polyhydroxyalkanoates production from wastewater organic carbon
	PHA production and treatment schemes will be discussed focusing on advances and perspecti
Chapter 4	Production of volatile fatty acids from sewage sludge fermentation
	VFA production and treatment schemes will be discussed focusing on advances and perspecti
Chapter 5	Zeolite for the recovery of nutrients from treated wastewater
	This chapter will discuss advances in zeolite medium for adsorb and then desorb nitrogen in vi resource recovery
Chapter 6	Selecting bulking agent for Sewage sludge composting
	This chapter deals with the production of compost from sewage sludge in view of a circular ec scale
Chapter 7	Advances in technologies for sewage sludge management
	Sewage sludge management is crucial and will be the main goal of this chapter. The new trenc perspettive will be discussed
Chapter 8	Energy and valuable product recovery through anaerobic digestion processes
	This chapter will discuss anaerobic digestion processes in wastewater sector in view of an optimization fro circular economy application
Chapter 9	Life cycle assessment as a tool for resource recovery facilities in wastewater sector
	LCA can foster the circular economy model in water sector. This chapter will discuss the main advances in LCA and application to water sector
Chapter 10	Water reuse in the frame of circul
	Water reuse from wastewater treatment will be discussed reporting main pro and cons and the limits that hamper a wider application
Chapter 11	Drivers and barriers to wider uptake of water smart solutions
	This chapter will highlight the main drivers and bottleneck for the transition from linear to circular economy model in water sector
Chapter 12	Advances in environmental bioprocess technology for an effective transition to a green circular economy
	This chapter will deal with advances in bioprocess technology in wastewater treatment
Chapter 13	Advanced technologies for a smart and integrated control of odour emissions from wastewater treatment plant
	This chapter will discuss smart water systems to minimize odour emissions from wastewater treatment plant
Chapter 14	Microbial biotechnology diverts wastewater treatment to circular economy
	Microbial biotechnology advances applied to wastewater treatment will be discussed
Chapter 15	Biological nutrients recovery from wastewater for circular economy

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wider uptake

https://wideruptake.unipa.it/



Full Prof. Giorgio Mannina, Ph.D.
Sanitary Environmental Engineering
Engineering Department
Università di Palermo
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@giorgiomannina

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CTG meeting:

Adsorption and advanced oxidation processes (AOP) technologies in wastewater treatment

When: 10th July 2023 (14:30-16:30h)

Where: Online meeting

14:30 h **Opening and welcome.** Andrea Naves (EURECAT).

14:40 h **ULTIMATE: Ammonium adsorption on zeolites for reclaimed water production for the chemical and petrochemical industrial sector (CS1).** Andrea Naves (EURECAT, Spain).

15:00h **ULTIMATE: Innovative sensors and alternative materials for the removal of organic matter and micropollutants by adsorption and AOP technologies in ARETUSA (CS3).** Cecilia Bruni (Università Politecnica delle Marche, Italy).

15:20h **ULTIMATE: Coupling technologies in recovery methodologies in industrial water by-product treatment (CS4).** Dimitri Iossifidis (Greener than Greener, Greece).

15:40 h **Break**

15:55 h **ULTIMATE: MET 3D printing of catalytic membranes and supports for cleaning AOPs in water (CS5).** Pablo Ortega (Colfeed4Print).

16:15 h **Discussion and closure.**

ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

Adsorption and advanced oxidation processes (AOP) technologies webinar

A. Naves, S. Casas

July, 10th 2023



ULTIMATE- Adsorption and advnaced oxidation processes (AOP) technologies workshop

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

Agenda

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Key Ultimate information

Call	2017 - H2020 – Greening the economy in line with the Sustainable Development Goals (SDGS) - H2020-SC5-2018-2019-2020
Topic	CE-SC5-04-2019 - Building a water-smart economy and society
Budget	**TOTAL:** Budget 16.614.814€
Duration	53 months (01/06/2020 – 31/10/2024)
Partners	27 (12 private companies; 8 non-profit/private centers; 7 public centers) from 11 countries
Coordinator	KWR WATER (NL)

Web del proyecto: https://ultimatewater.eu/

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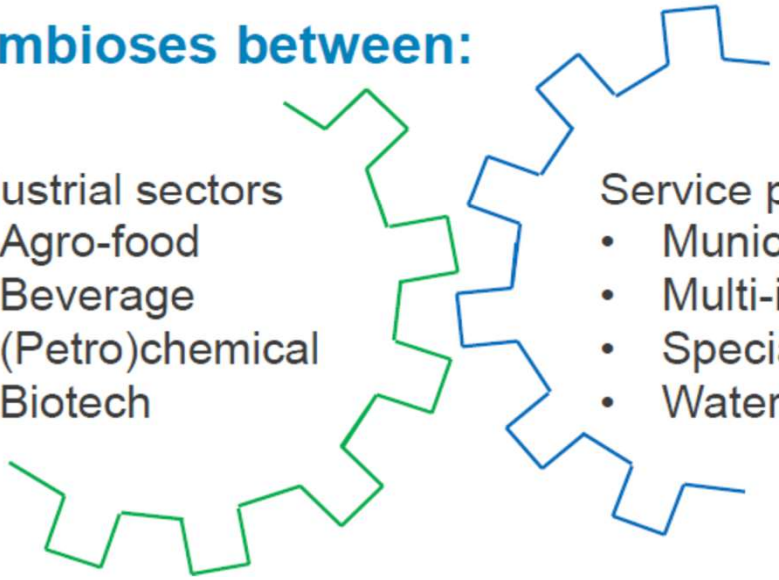
Ultimate (June 2020 – May 2024):

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

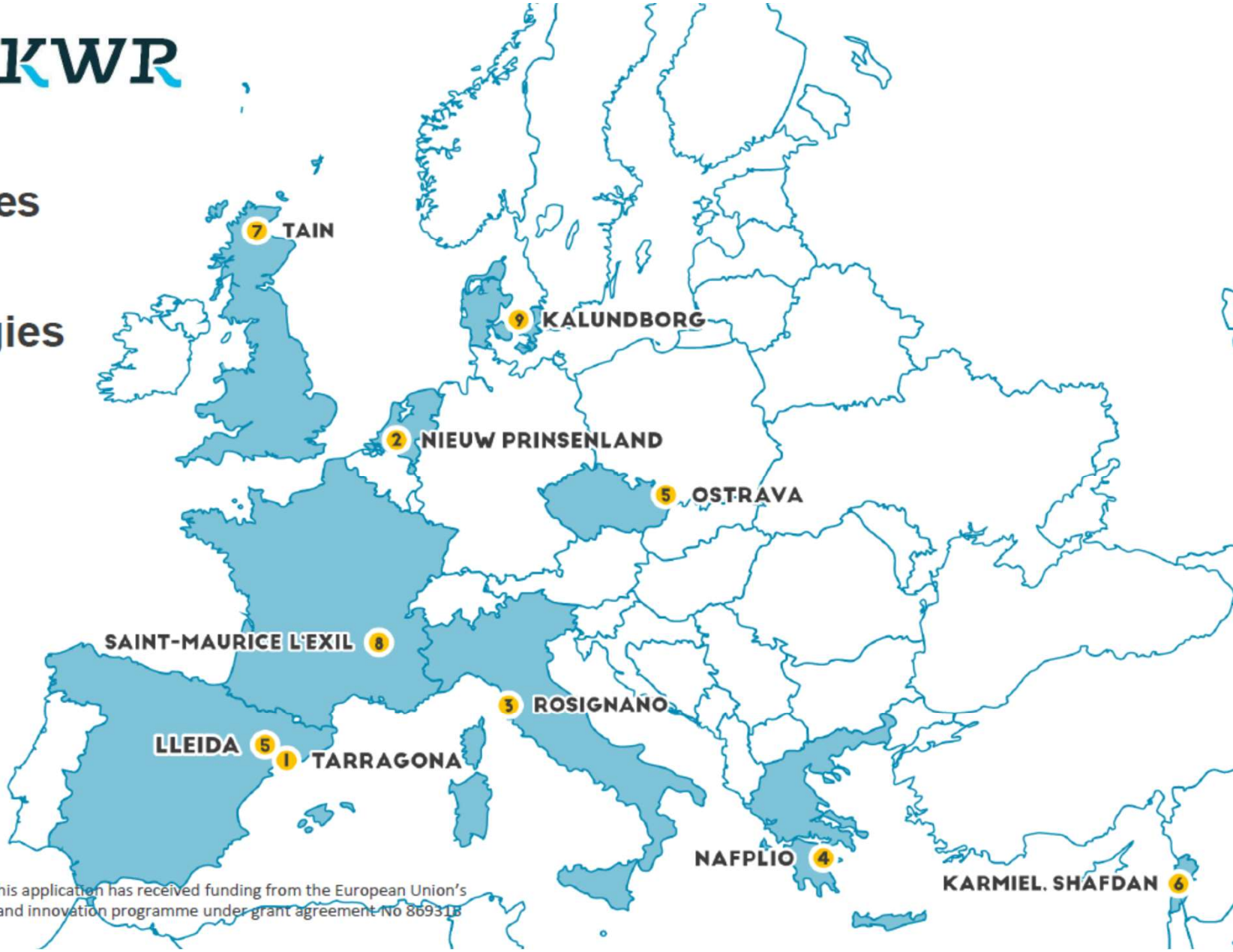
Service providers
- Municipal utility
- Multi-industry utility
- Specialized SME
- Water services provider

Coordinator: KWR

9 Case Studies

27 Partners

37 Technologies



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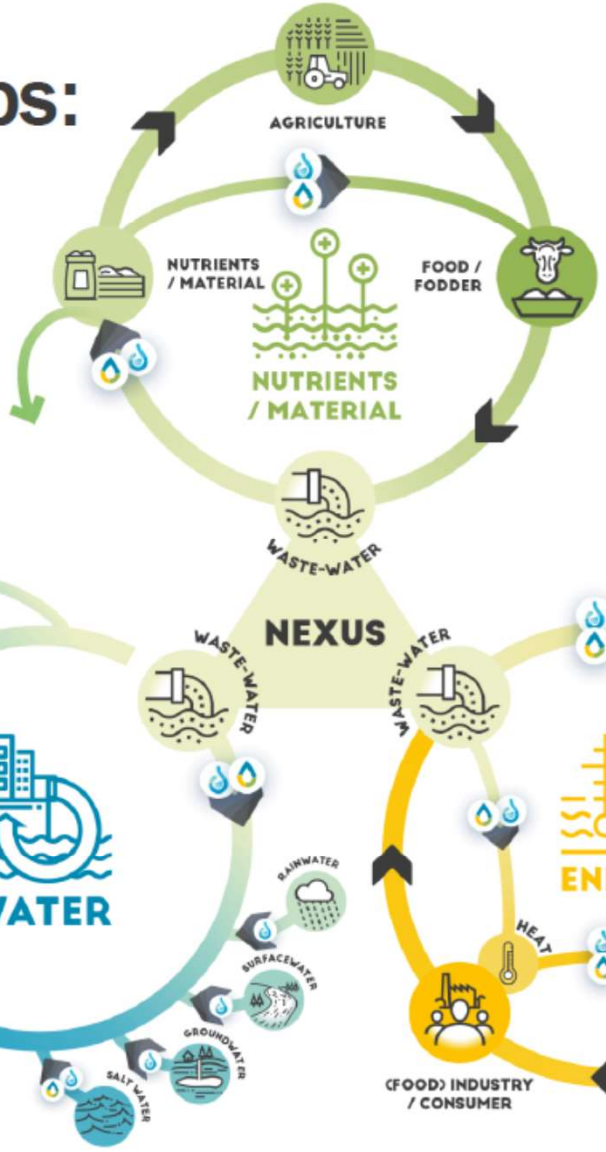
3 Cross-cutting Technology Groups: 9 Topics





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



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

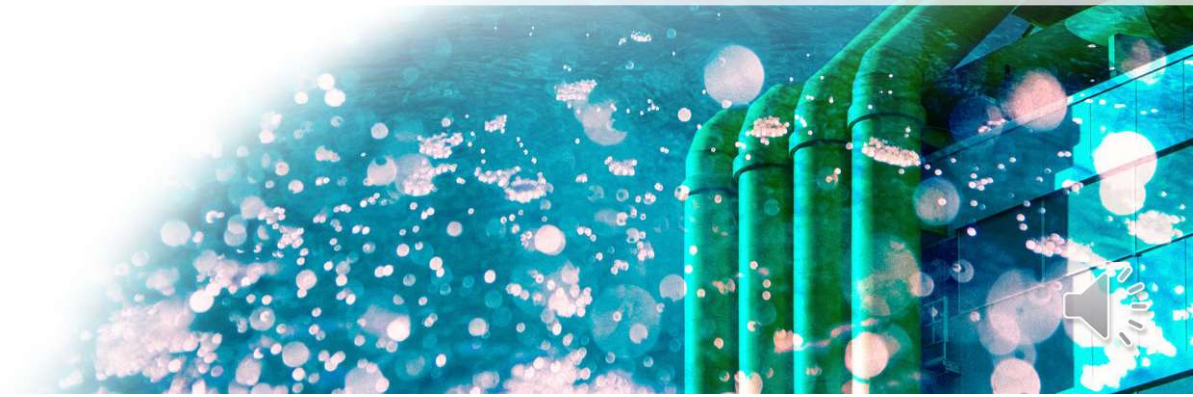
ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

Ammonium adsorption on zeolites for reclaimed water production for the chemical and petrochemical industrial sector (CS1)

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

S. Casas, A. Naves (EURECAT)



Petrochemical Complex of Tarragona (Spain): CS1

AITASA (Aguas Industriales de Tarragona) 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.

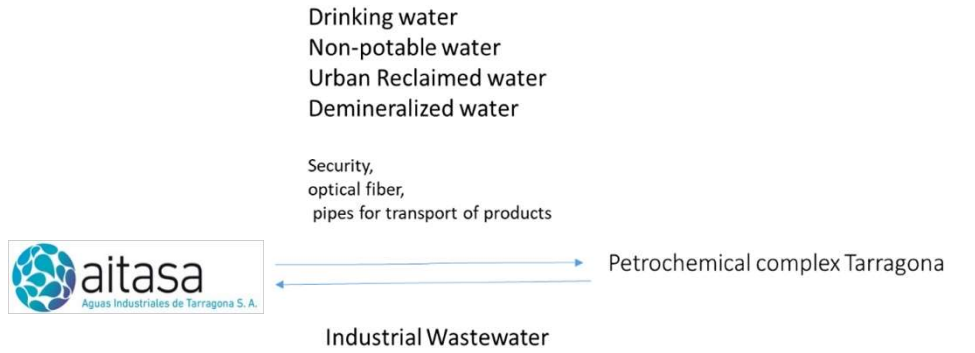
More than 30 companies operate in the petrochemical complex focusing on production of chlorine, alkaline salts, oxygen gas, fertilizers, insecticides, fuels, plastics and synthetic essences.

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

Partners:

eurecat
Centre Tecnològic de Catalunya

aitasa
Aguas Industriales de Tarragona S. A.





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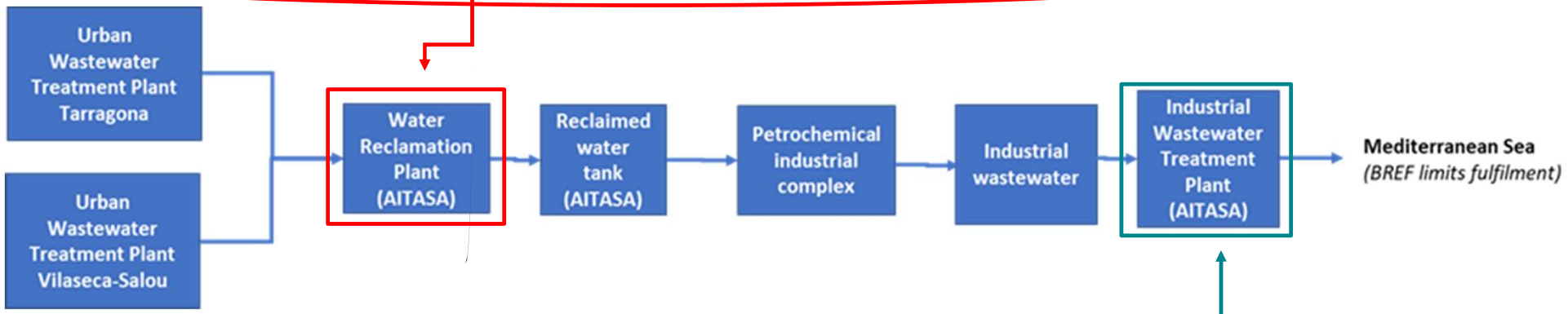
Objectives of the Ultimate solutions

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

→ **Water Reclamation Plant**:
- → Increase water recovery of the current WWRP with nZLD technologies
- → Remove the ammonium with low-cost technology (zeolite adsorption)



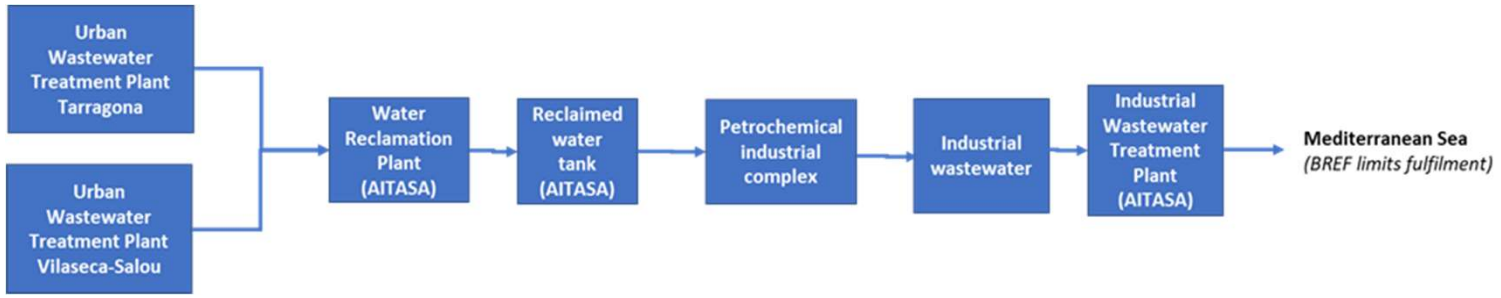
→ **Industrial Wastewater Treatment Plant**:
- → Defining a novel tertiary treatment with nZLD technologies (reverse osmosis and membrane distillation) to obtain reclaimed water

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

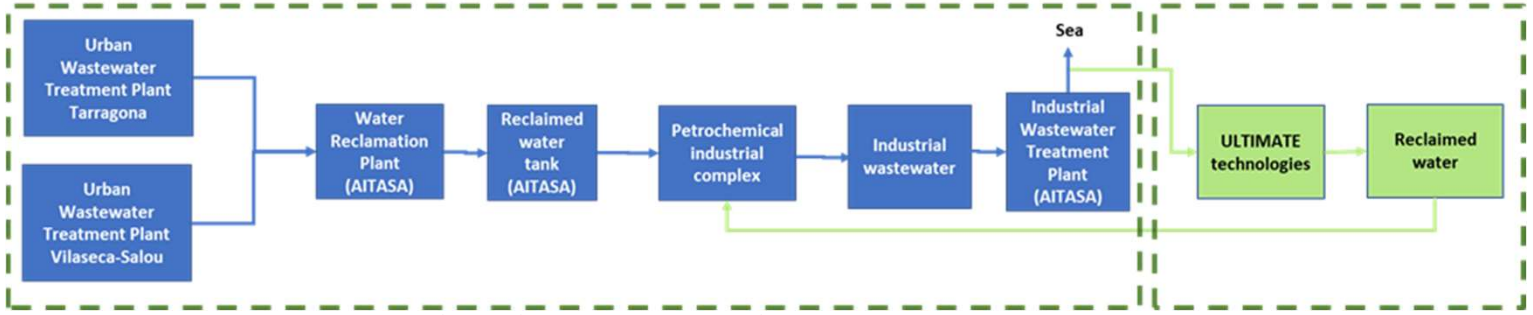
Increase reclaimed water production capacity

Phase 1:19,000 m^3/day (current)→ **Phase 2:** 29,000 m^3/day

Option 1: to increase reclaimed water production capacity in the current Water Reclamation Plant



Option 2: to produce reclaimed water treating the outlet of the Industrial Wastewater Treatment Plant→ ULTIMATE Project (Case Study 1)



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Camp de Tarragona Advanced Water Reclamation Plant

RECLAIMED WATER QUALITY

Since 2012, AITASA operates the Water Reclamation Plant (WRP) of Camp de Tarragona producing reclaimed water for boilers and cooling towers of the industry. Reclaimed water has to fulfil with Spanish Royal Decree 1620/2007 that includes the water requirements to be reused in the industry.

Parameter	Requirement	Units
Legionella	Absence	CFU/1 L
Nematode eggs	<1	Eggs/10 L
Escherichia coli	Absence	CFU/100 mL
Suspended solids	<5	mg/L
Turbidity	<1	TNU

Additionally, some restrictions are established for the reclaimed water at the outlet of the WRP to be reused in cooling towers.

Parameter	Requirement	Units
Ammonium	< 0.8	mg/L
Ortho-PO_4	<3	mg/L
BOD_5	<4	mg/L
TOC	< 15	mg/L
Conductivity	20-40	µS/cm

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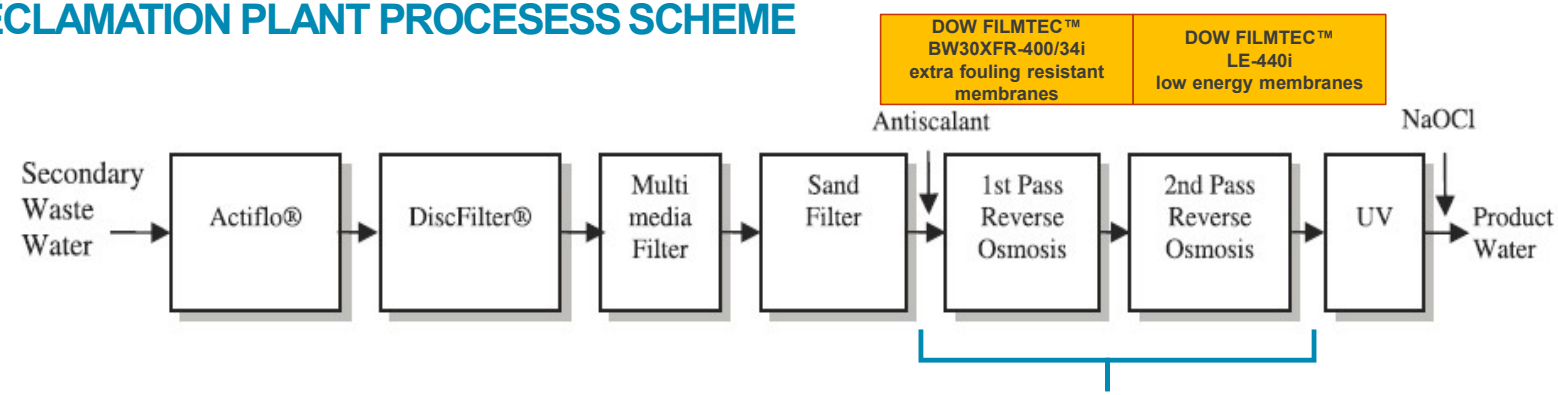
Camp de Tarragona Advanced Water Reclamation Plant

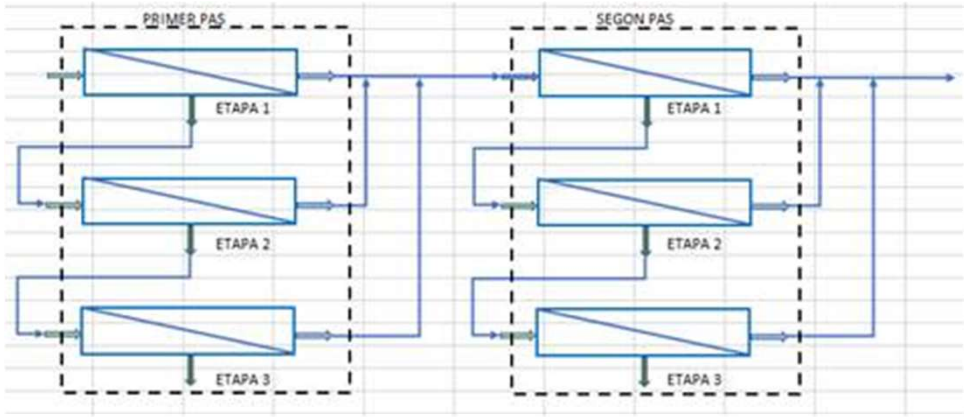
WATER RECLAMATION PLANT PROCESESS SCHEME



AMMONIUM REMOVAL ALTERNATIVE TECHNOLOGIES

- 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

AITASA CURRENT AMMONIUM REMOVAL PROCESS (RO)



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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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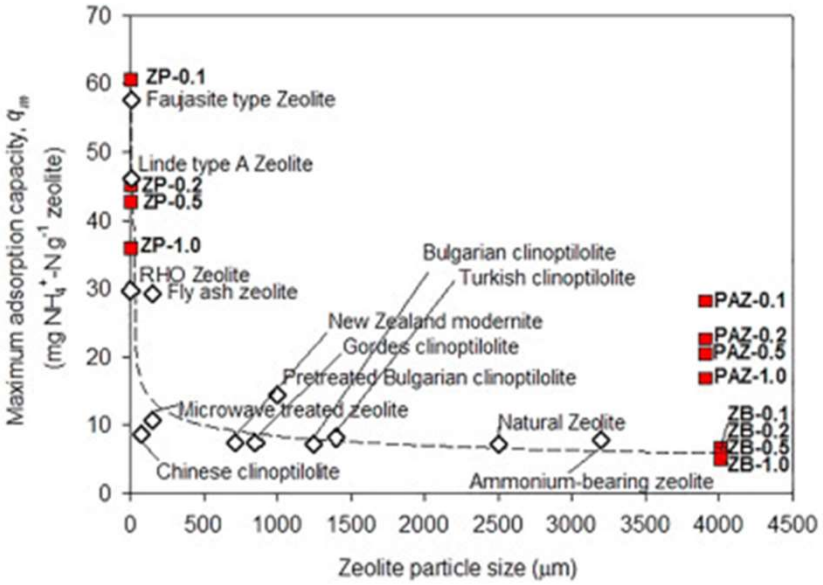
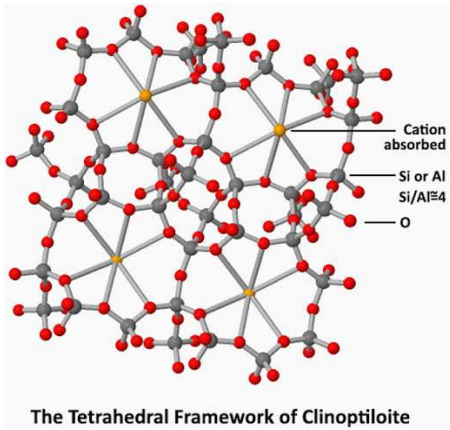
Ammonium removal from water by adsorption with zeolites

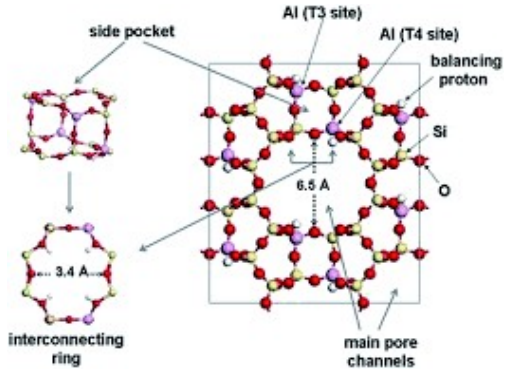
ZEOLITES SELECTION

- 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	—	—	5.5

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Ammonia removal by adsorption with zeolites

BENCH SCALE TESTS

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

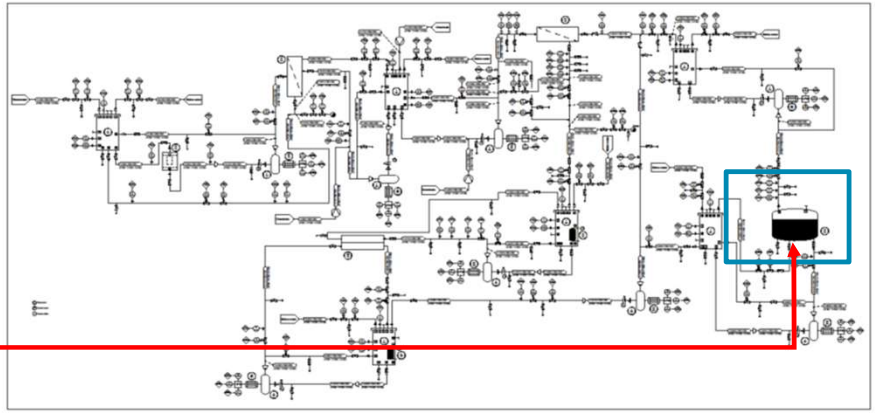
Experimental set-up



- **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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Pictures of the technologies at lab scale

Optimal operation conditions obtained experimentally at bench scale→ Pilot plant design

UF bench scale experimental set-up

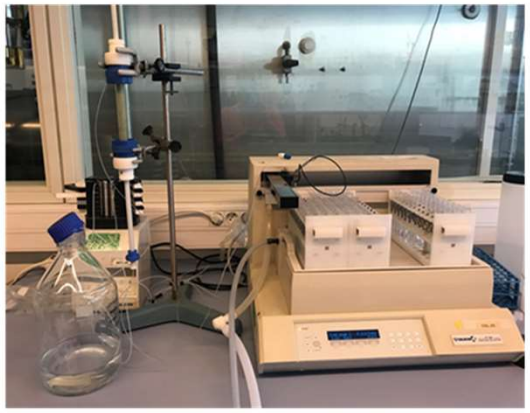




RO bench scale experimental set-up

MD bench scale experimental set-up





Zeolite adsorption bench scale experimental set-up

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Ammonium adsorption on zeolite: experimental plan

General remarks:

- Tests were carried out with permeate from RO previous tests at laboratory scale
- This permeate was doped with ammonium to obtain ~35 mg NH_4/L at the inlet (ammonium concentration at the inlet of the RO process in WWRP)

Experimental plan:

1.- Zeolite selection: batch tests to determine adsorption capacity
2.- Break-through curves: ammonium adsorption capacity in continuous operation
3.- Regeneration

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Ammonium adsorption on zeolites: zeolite selection in batch tests

- Three different comercial zeolites were tested:
  - Zeolite 4 A(IQE) and Zeolite 13X (IQE)→ synthetic zeolite
  - Zeolita ZN Aqua (Zeocat)→ natural zeolite
- (*) Batch tests carried out with real water doped to 35 mg NH_4/L
- 2,5 g zeolite in 50 mL water
- Test duration=3h





Feed water		Zeolite		Outlet NH_4, mg/L	Adsorption capacity, mg NH_4^+/g zeolite
Type	NH_4, mg/L (*)	Type	Granulometry, mm		
Real water	35	Zeolite 4 A	0,003-0,005	19,7	0,31
Real water	35	SiOLITE 13X	0,002-0,006	7,1	0,56
RO permeate (70% recovery)	35	Zeocat ZN Aqua	0,5-1	3,5	0,63

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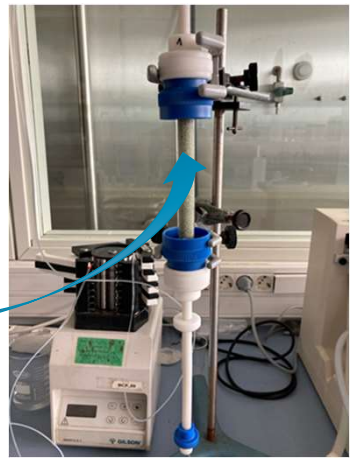
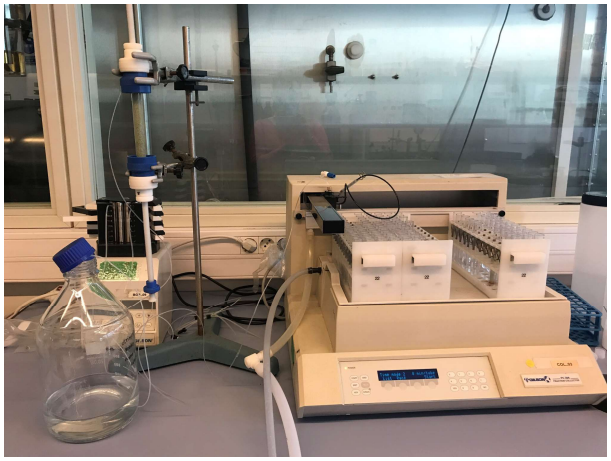
Ammonium adsorption on zeolites: experimental set-up







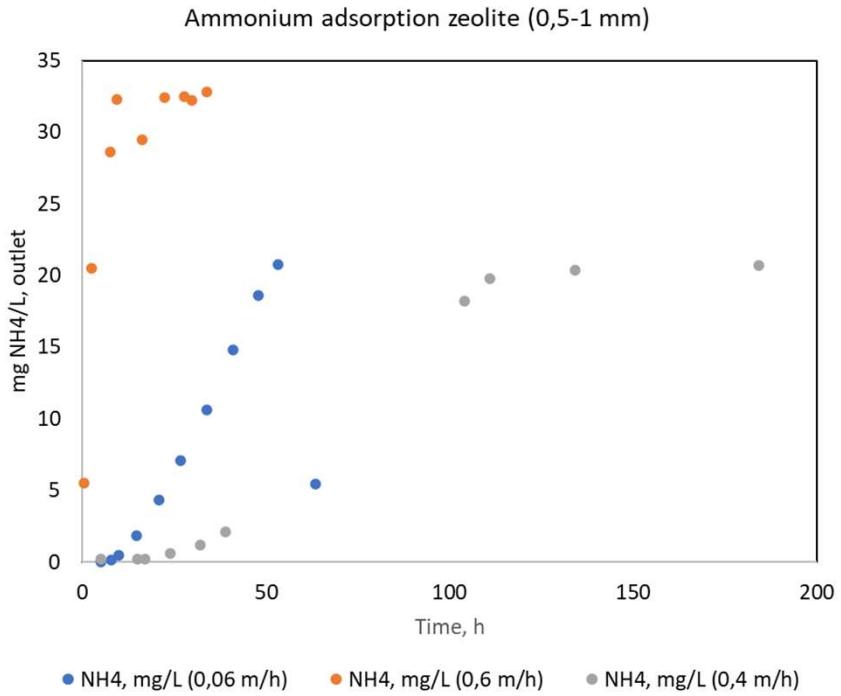
Column diameter=1 cm

Column height=10 cm

Zeolite Zeocat ZN Aqua (technical data sheet)	
Granulometry, mm	0.5-1
Composition	Clinoptilolite, 82-86%
Ammonium adsorption capacity	1,2-1,5 meq NH4/g media (21.6-27 mg NH4/g 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

Ammonium adsorption on zeolites: breakthrough curves (continuous operation)

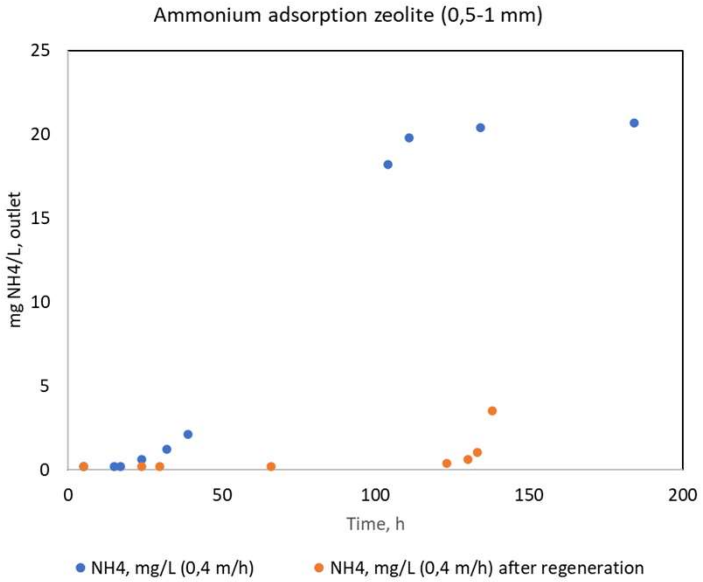


- Tests carried out with RO permeate obtained in previous tests and doped with ammonium
- Downflow operation
- Breakthrough time was calculated when NH_4 at the outlet was 0,8 mg NH_4/L.
- Three different bed contact times were tested (1,10 and 15 min)
- New zeolite was used in each experiment

Experimento	Column diameter, m	Column height, m	Zeolite weight, g	Water flow rate, mL/min	Water linear velocity, m/h	Hydraulic time, min	Break-through time, h	Initial concentration, mg NH4/L	Adsoprtion capacity, mg NH4/ g zeolita
1	0,01	0,1	7,74	0,78	0,60	10,1	11,1	41	2,8
2	0,01	0,1	7,68	7,86	6,00	1,0	0,07	36,7	0,2
3	0,01	0,1	7,68	0,5	0,38	15,7	26,7	28	2,9

Ammonium adsorption on zeolites: regeneration

- Regeneration with NaCl 10%
- Higher ammonium adsorption capacity after zeolite regeneration



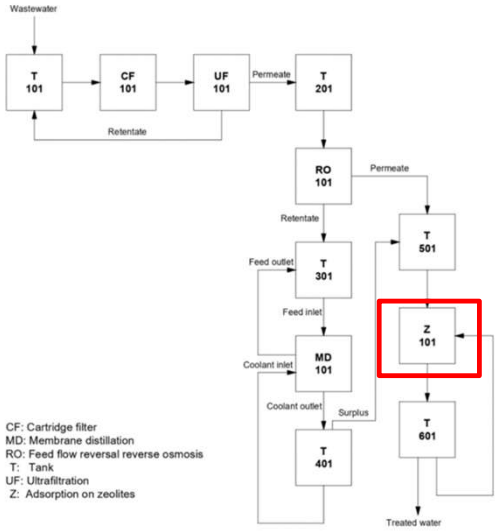
Experimento	Column diameter, m	Column height, m	Zeolite weight, g	Water flow rate, mL/min	Water linear velocity, m/h	Hydraulic time, min	Break-through time, h	Initial concentration, mg NH4/L	Adsoprtion capacity, mg NH4/ g zeolita
1-adsorption	0,01	0,1	7,74	0,78	0,60	10,1	11,1	41	2,8
2-adsorption-	0,01	0,1	7,68	7,86	6,00	1,0	0,07	36,7	0,2
3-adsorption	0,01	0,1	7,68	0,5	0,38	15,7	26,7	28	2,9
4-regeneration	0,01	0,1	7,68	1	0,76	7,9			0,0
5-adsorption	0,01	0,1	7,68	0,5	0,38	15,7	131,3	28,76	14,8

Technologies at pilot plant scale

Process	Treatment capacity
Cartridge filter (pre-treatment)	12 m^3/day
Ultrafiltration	12 m^3/day
Reverse Osmosis	12 m^3/day
Membrane Distillation	1 m^3/day
Zeolite adsorption	1 m^3/day



Maritim container and tanks





UF unit (left) and RO unit (right)



Membrane distillation



Adsorption with zeolites column

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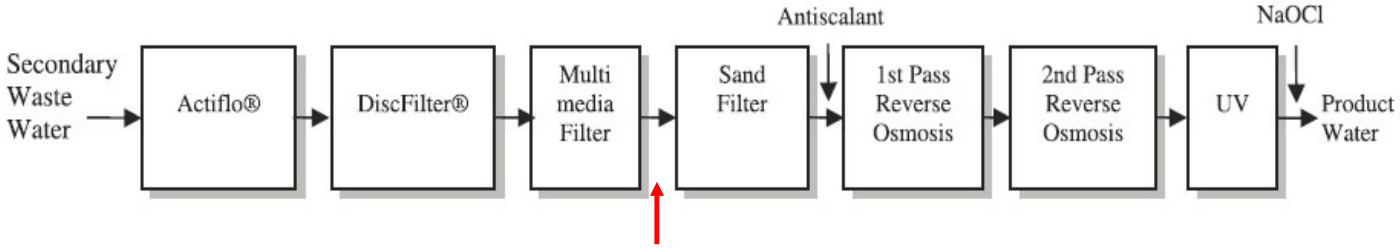
Pilot plant scale results

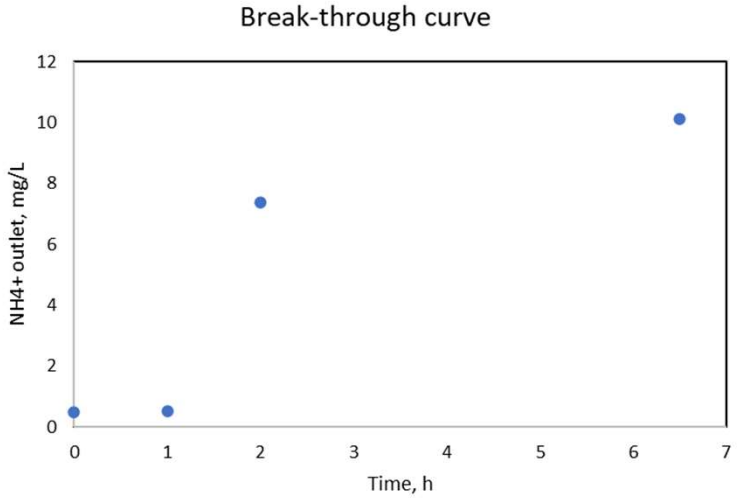
WATER RECLAMATION PLANT PROCESESS SCHEME





Pilot plant test was carried out with water at the inlet of the sand filters (before sodium hypochlorite)

Zeolita mass, kg	14.7
NH4 inlet water, mg/L	64.7
Linear velocity, m/h	5.5
EBCT, min	6.8
Adsorption capacity, mg NH4/g zeolite	0.7



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Pilot plant scale next steps

- To determine ammonium adsorption capacity at different linear velocities and EBCT
- To determine ammonium adsorption capacity at different ammonium inlet concentration
- To assess regeneration process and reuse of the regeneration solution and ammonium recovery
- To estimate operational costs: energy, regeneration solution, etc

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Thank you!

Sandra Casas, Andrea Naves

Sandra.casas@eurecat.org

Andrea.naves@eurecat.org



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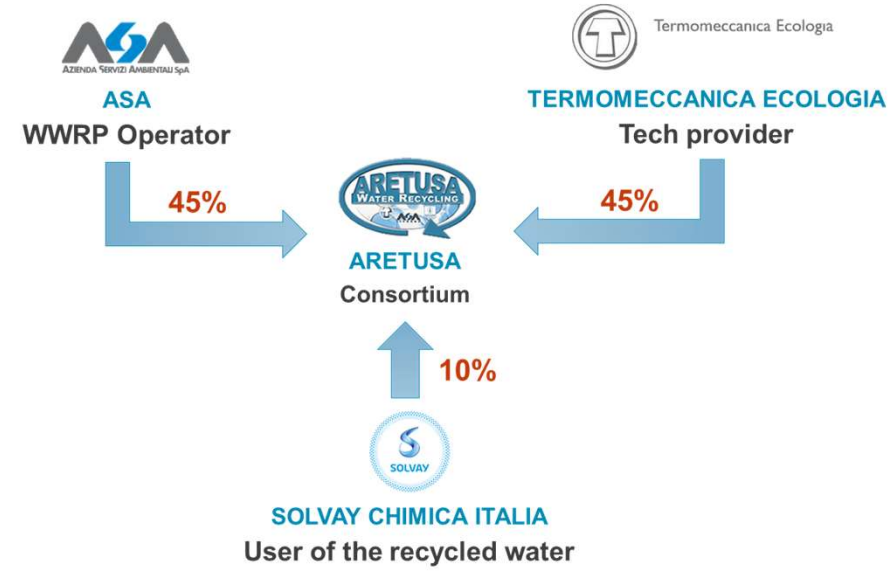
Innovative sensors and alternative materials for the removal of organic matter and micropollutants by adsorption and AOP technologies in ARETUSA (CS3).

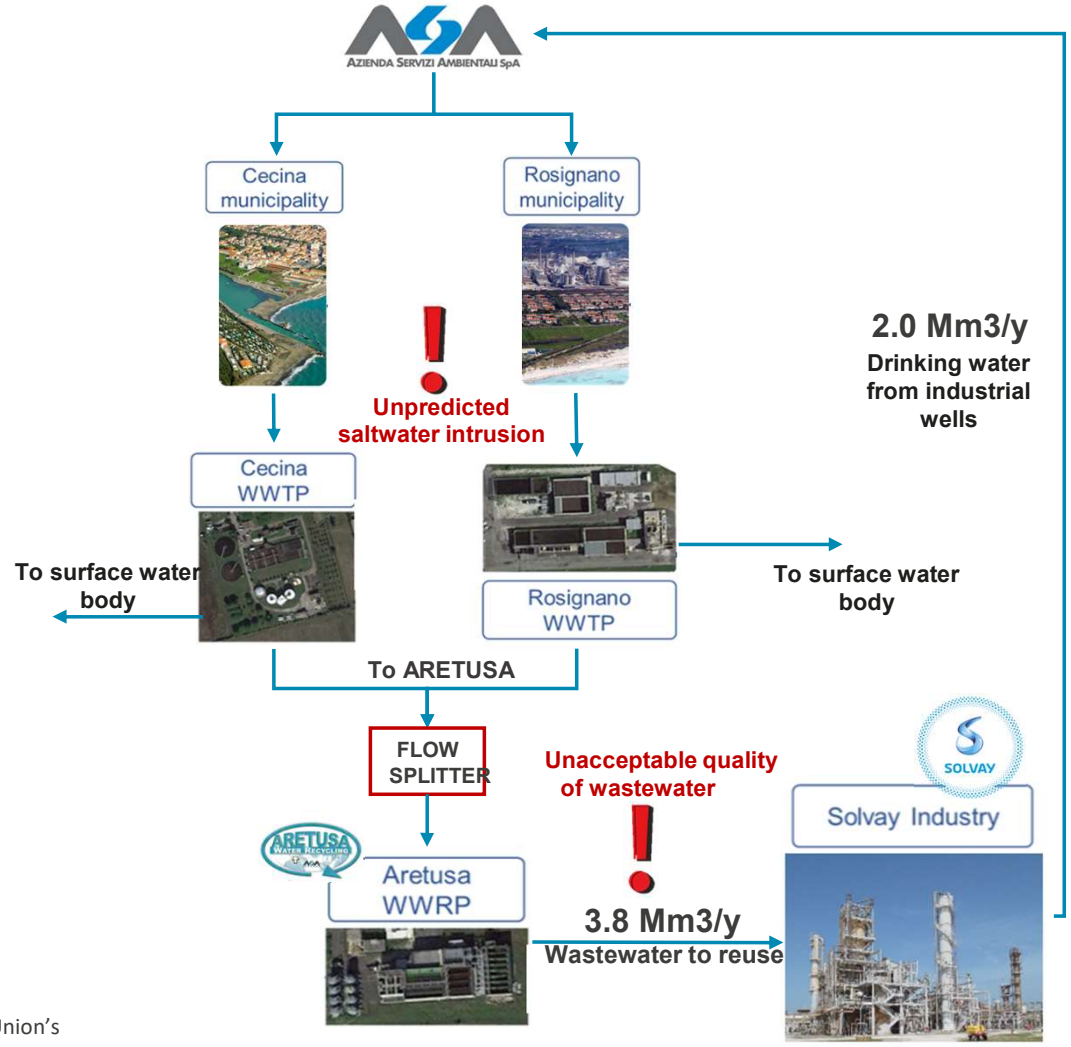
C. Bruni, M. Parlapiano, M. Sgroi, F. Fatone



July, 10th 2023.

ARETUSA urban-industrial symbiotic system





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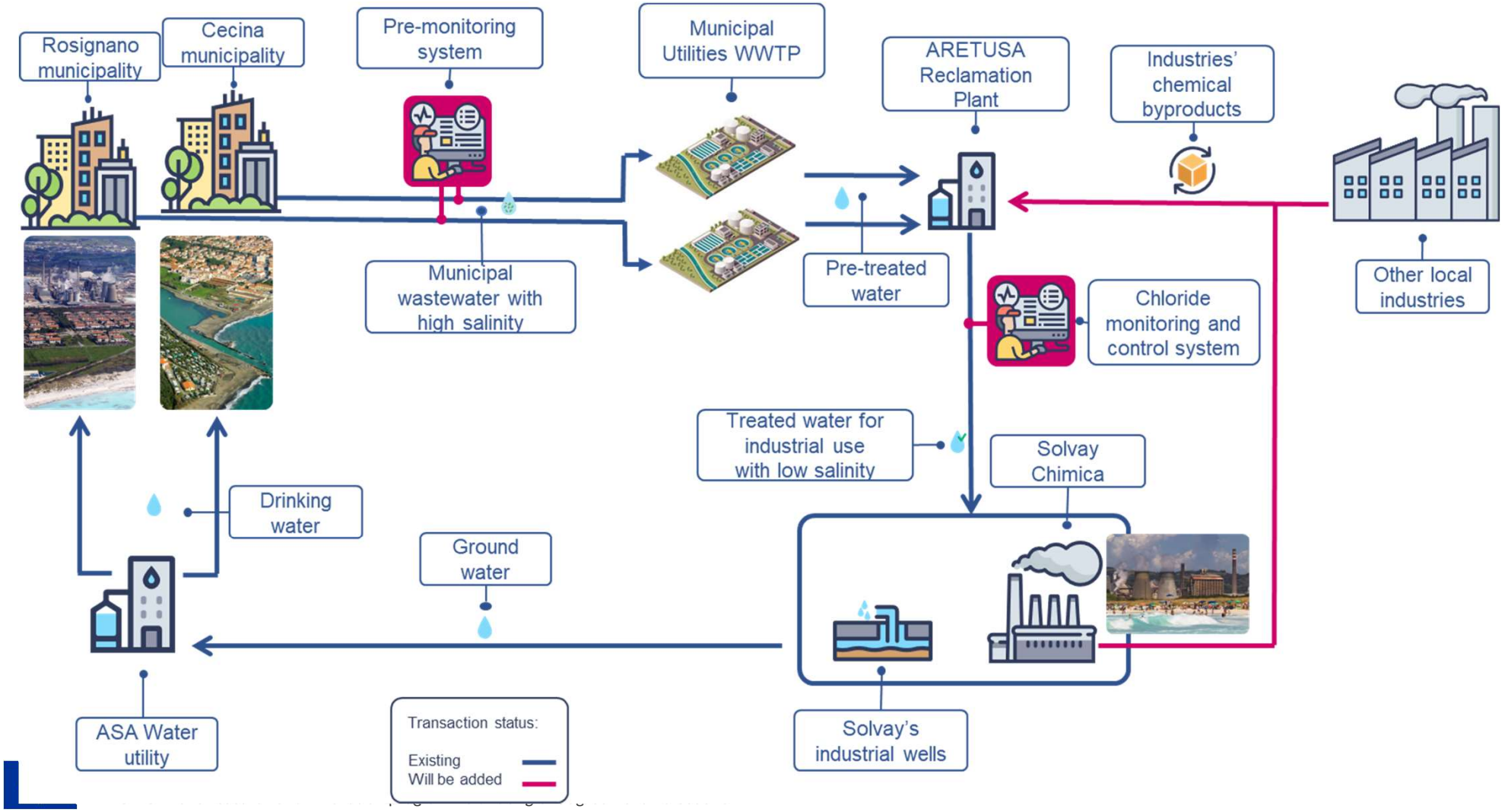
ARETUSA urban-industrial symbiotic system



Hydrochar for adsorption process

Hydrochar (HC) produced from sewadge sludge



	HC
F-	54.2
Cl-	44.4
Br-	< 0,1
NO3-	1.3
PO4---	38.5
SO4--	147.3
COD	4200

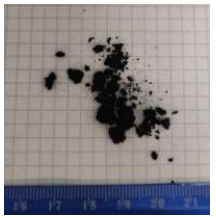
COD Leaching

Chemical activation

*Activation performed in CPTM laboratories

- Mixing of char pellets with KOH in flakes (KOH to char ratio: 1:1).
- Heating up to 600°C (5°C/min), isotherm for 1 hr and cooling (5°C/min) with N2 purging.
- Washing with 5M HCl and demi water (up to pH 7).
- Drying at 105°C until constant weight.

AH
Activated Hydrochar



	AH
F-	< 0,1
Cl-	1.7
Br-	< 0,1
NO3-	< 0,1
PO4---	8.4
SO4--	103.4
COD	< 15

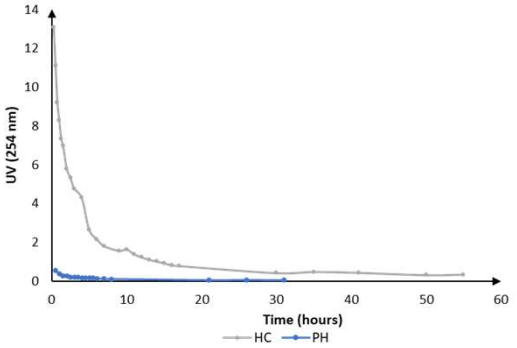
Optimal (chemical) activation of Hydrochar at pilot/demo scale is difficult → Pyrolysis was tested as more feasible alternative

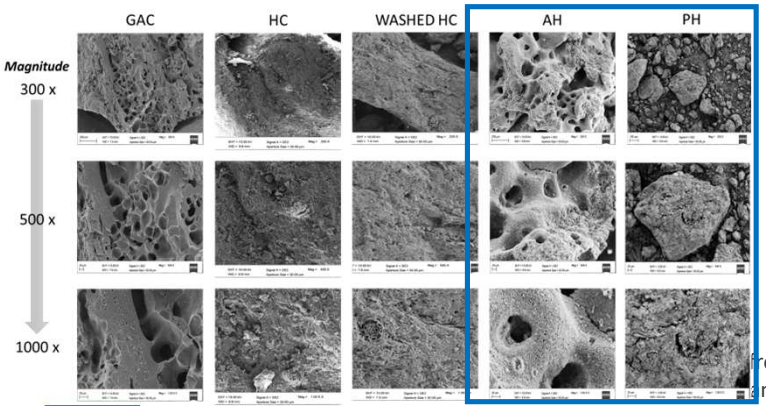
Slow Pyrolysis

Material was produced by TGA under Nitrogen Flux (N2) at 450°C for 2 hours with a heating rate of 20°C/min.

PH
Pyrolyzed Hydrochar

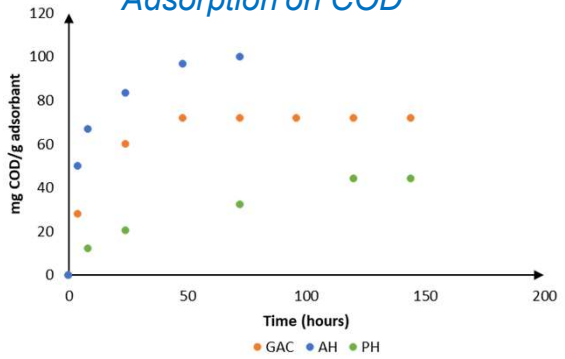






	BET Surface Area
	m²/g
HC	ND
AH	751.7
PH	100.42
GAC	1100-1150

Adsorption on COD



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Hydrochar for adsorption process

Process scale-up

Slow Pyrolysis of Hydrochar at Pilot scale

Temperature (°C)	450
Flowrate of hydrochar (kg/h)	40
Residence time (min)	90



100 kg





25-30 kg



Granular Activated Carbons

STANDARD SPECIFICATIONS - CSC5			
Specifications	Unit	Values	Methods
BET Surface area	m2/g	500 ± 50	BET N2
Ash content	%	< 10	CEFIC 1986
Bulk density	g/cm3	0,50-0,55	CEFIC 1986
Humidity	%	< 2	CEFIC 1986
Grain size:			Wet sieving
> 5 mm	%	0.5	
< 2 mm	%	1.5	

STANDARD SPECIFICATION - GBC 8x30			
Specifications	Units	Values	Method
Surface Area (BET)	m2/g	1000 ± 50	BET N2
Ash content	%	12 ± 2	CEFIC 1986
Bulk density	g/cm3	0,50 ± 0.05	CEFIC 1986
Moisture (as packed)	%	< 5	CEFIC 1986
Iodine index	mg/g	950 ± 50	CEFIC 1986
Hardness	%	> 95	On request
Half-length chlorination	cm	> 2.2	On request
Grain Size			Sieving
> 8 mesh (2.4 mm)	%	< 5	
< 30 mesh (0.6 mm)	%	< 5	

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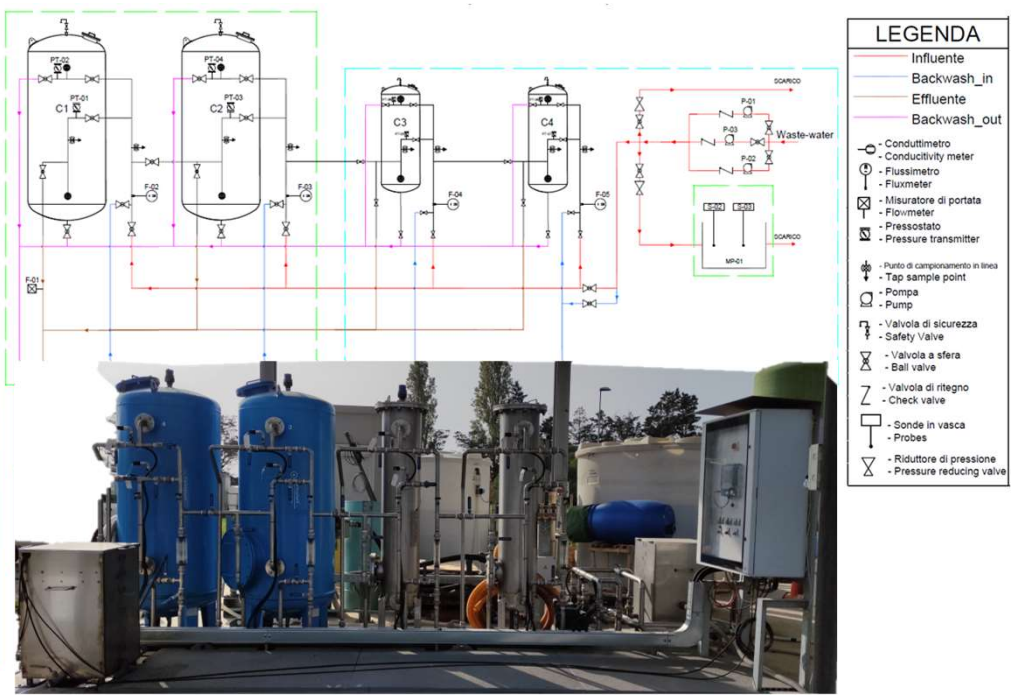
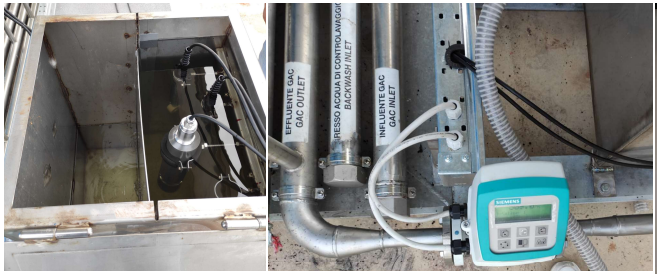
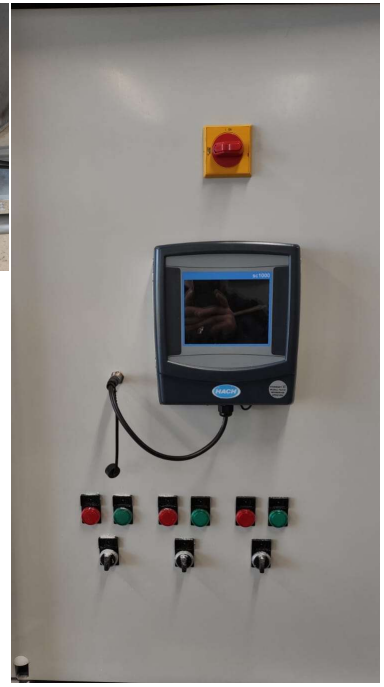
Pilot plant implementation – adsorption process



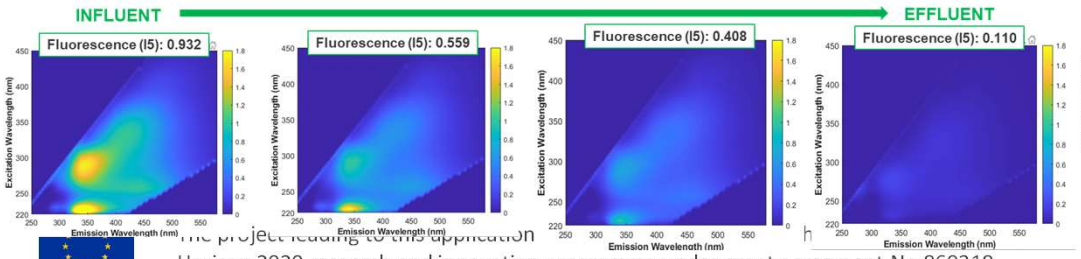
Monitoring system

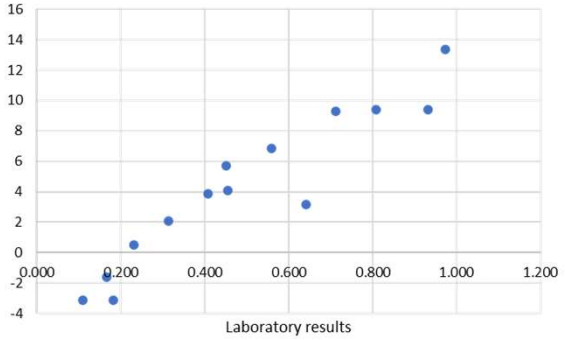
- ✓ Conductivity
- ✓ pH
- ✓ UV absorbance sensor reading at 254 nm
- ✓ Fluorescence sensor reading at the excitation/emission couple of 325/445 nm
- ✓ Flowmeter





Fluorescence sensor calibration





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Adsorption pilot plant

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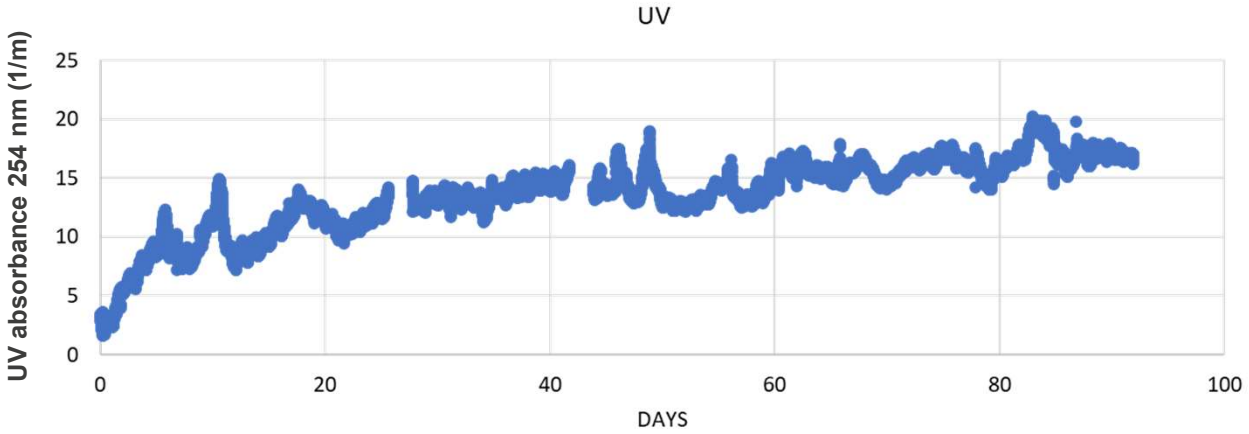
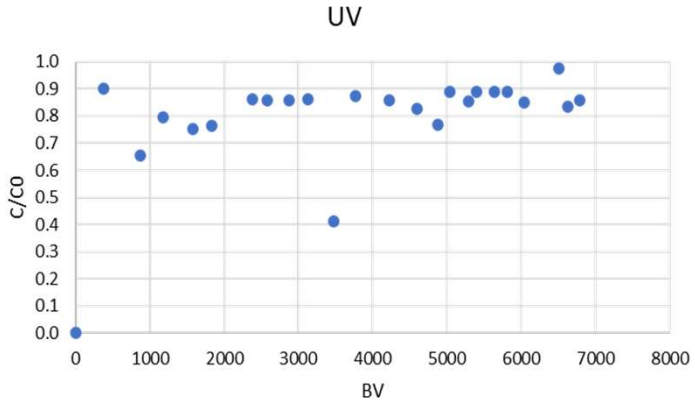
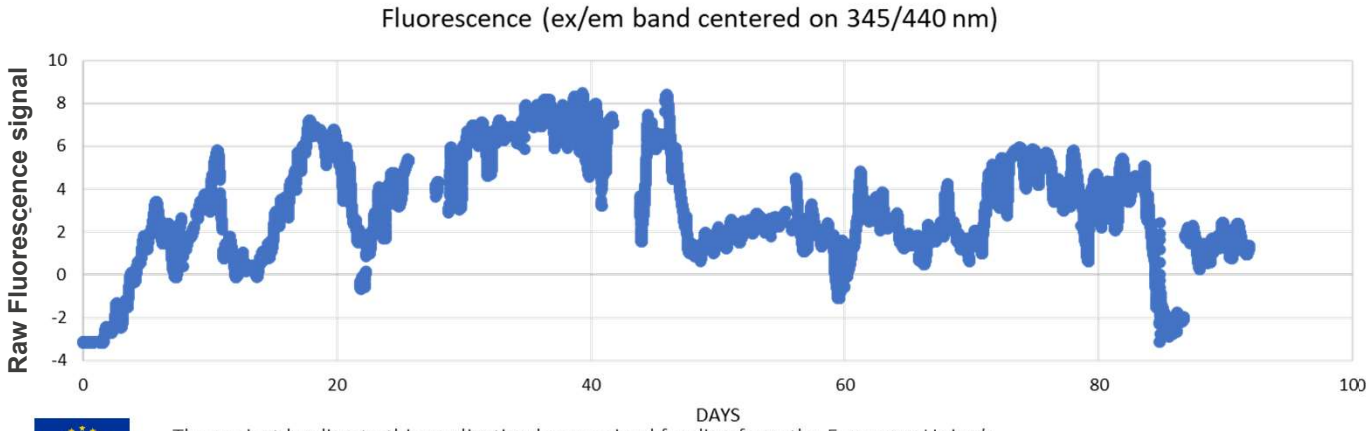
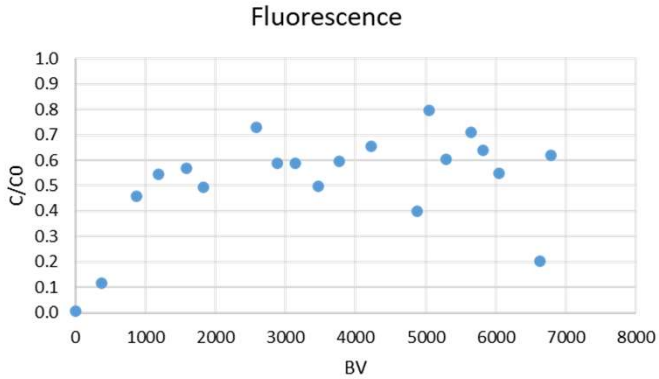
Pilot test: adsorption with GAC grain size 2-5 mm









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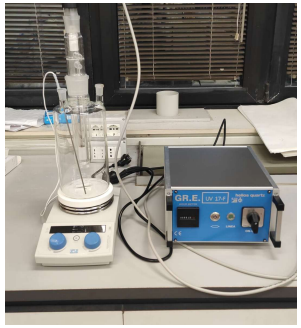
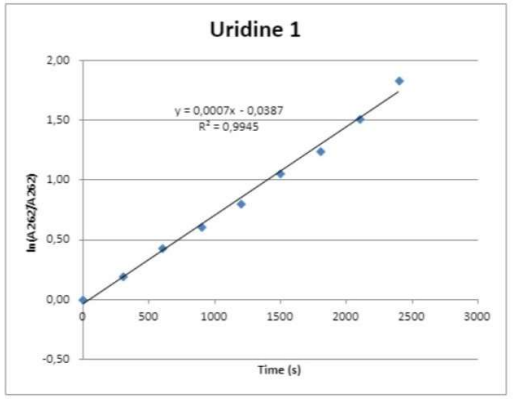
AOP Laboratory set-up and experimentation

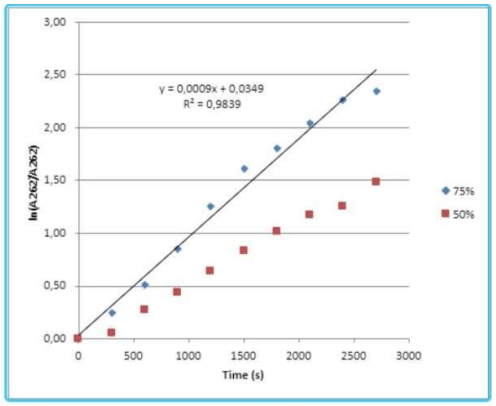




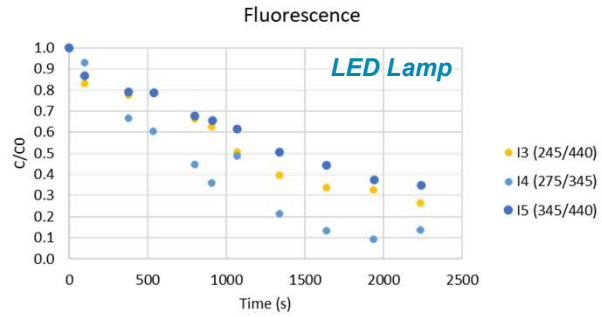
Actinometry test

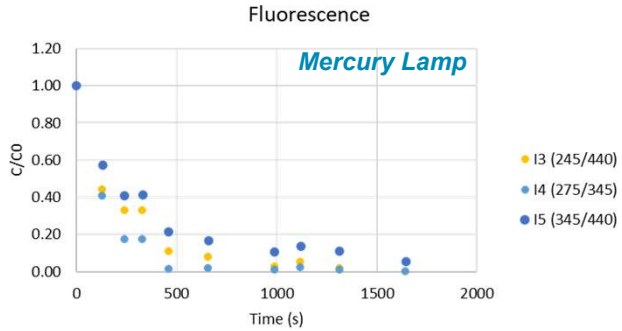


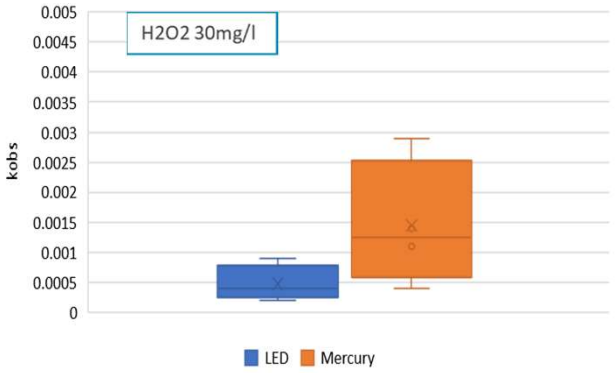
MERCURY

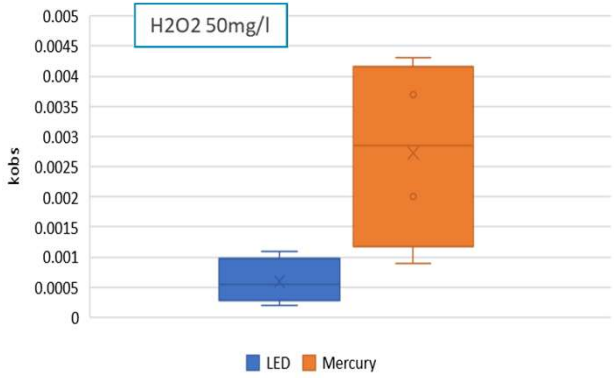


LED









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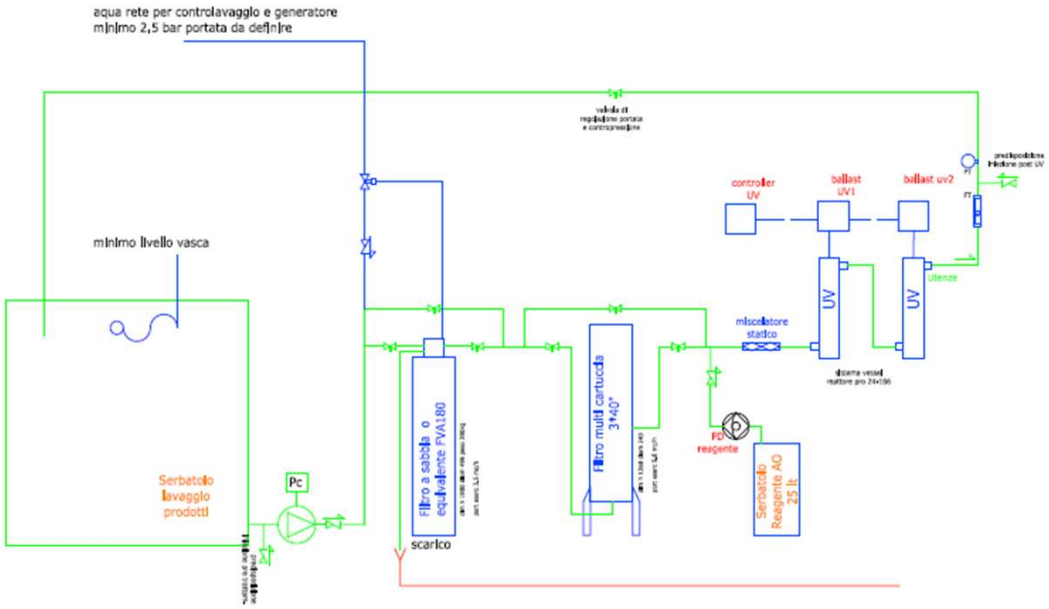
AOP Pilot plant







SKID EQUIPPED WITH:

- ✓ pressurization pump: 60 l/min, 1.9 bar
- ✓ sand filter: 3.5 mc/h 250 kg of sand
- ✓ multi-cartridge filter
- ✓ electromagnetic dosing pump
- ✓ static mixer
- ✓ Viqua PRO 24-180mJ UV system
- ✓ electrical panel

Fluorescence meter

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indUstry water-utiLiTy symbiosis for a sMarter wATEr society



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Case Study 4

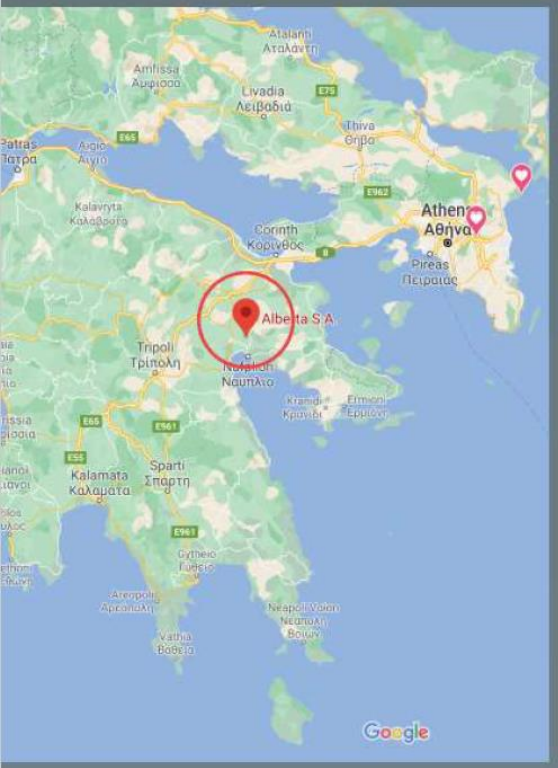
- Fruit processing industry

- 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

Recovery of Value-added compounds

AOP

SBP

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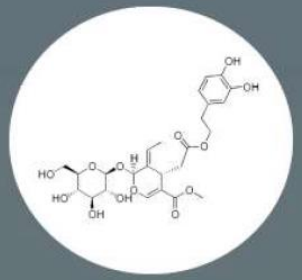
Case Study 4 Goals

- 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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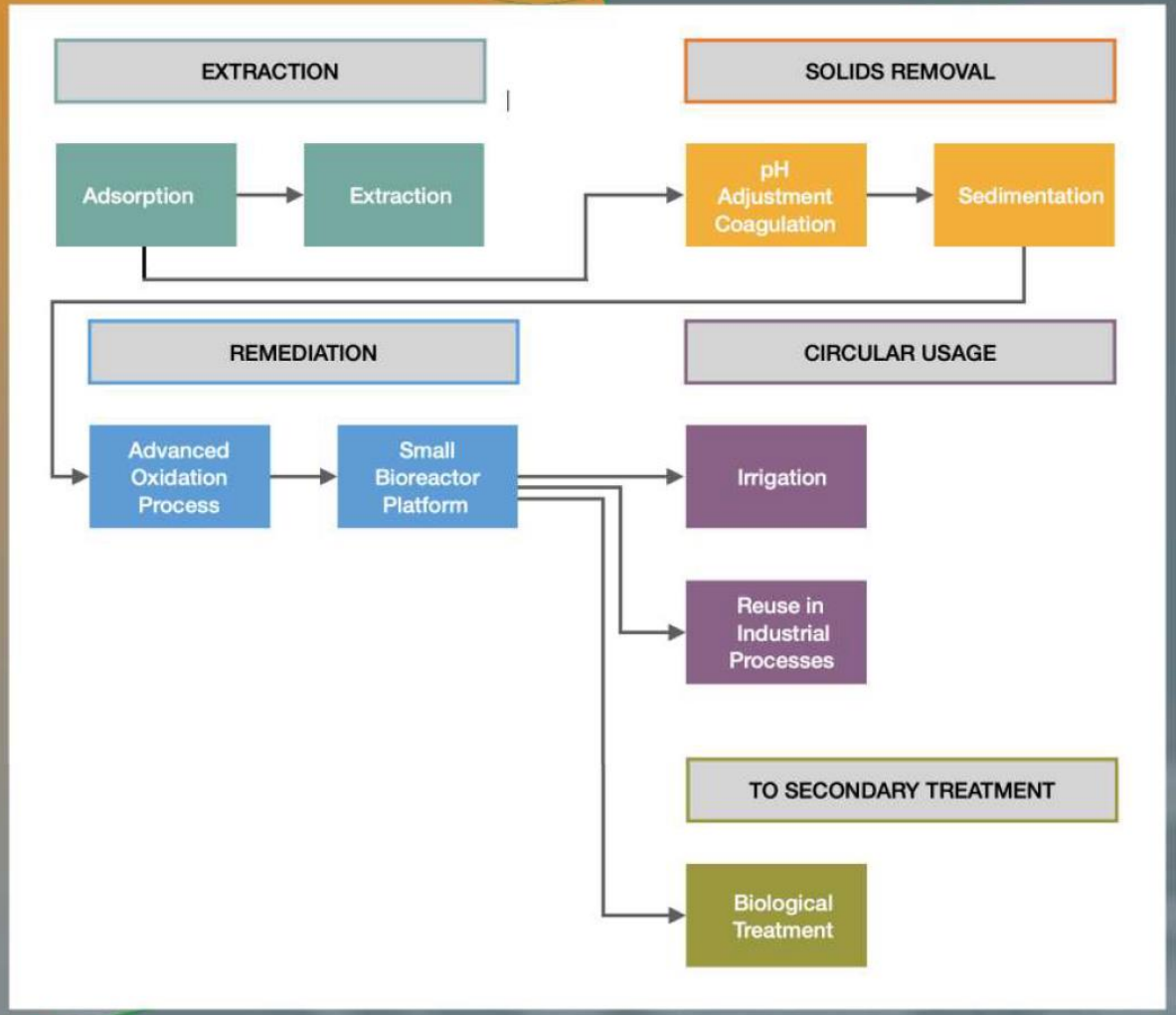
Unit Design



Cross-section

P&ID



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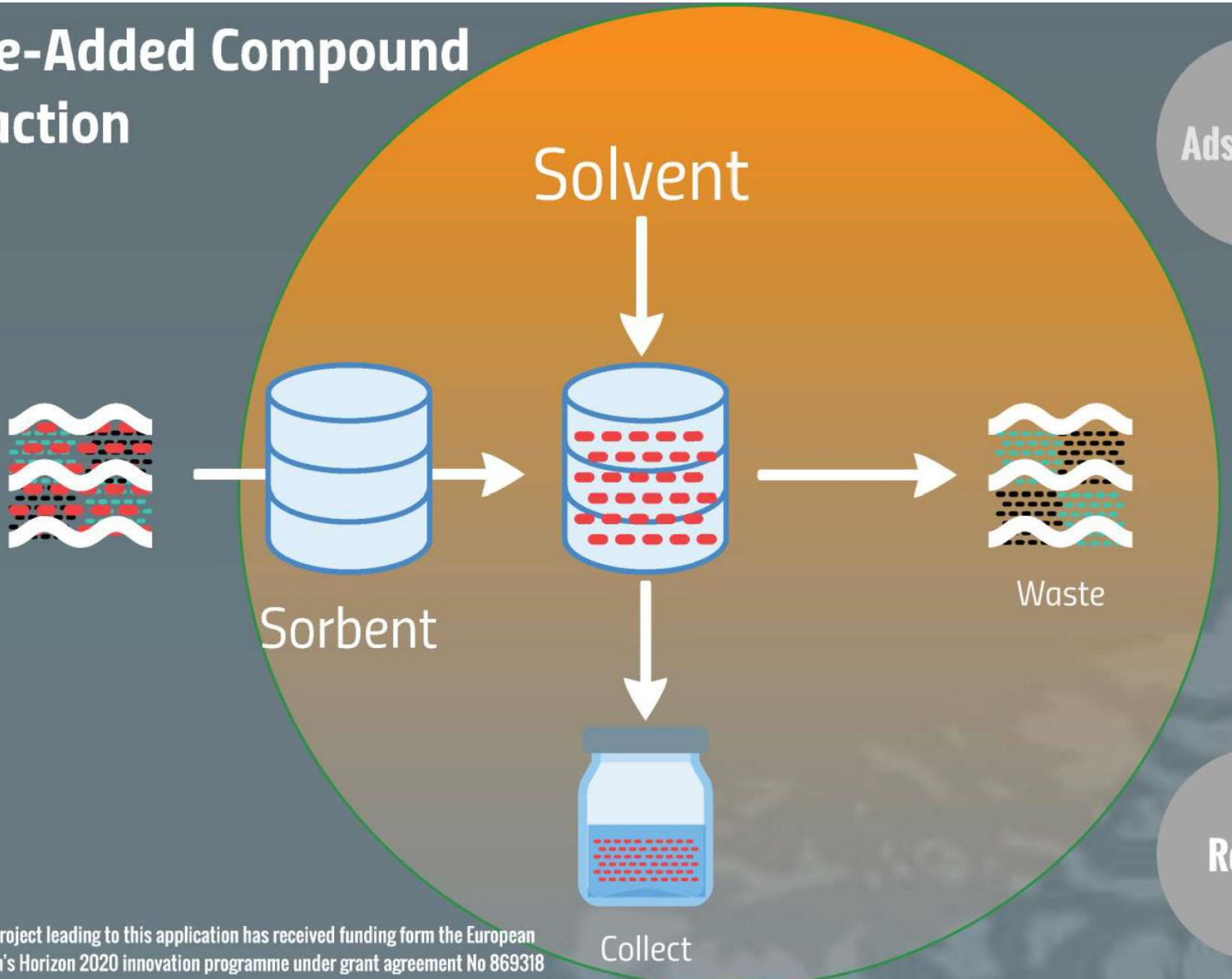
Value-Added Compound Extraction



Adsorption

Recovery

Value-Added Compounds

Results

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Adsorption considerations

Selectivity

preferentially bind a specific class of compounds

Hydrophobicity/ Hydrophilicity bias

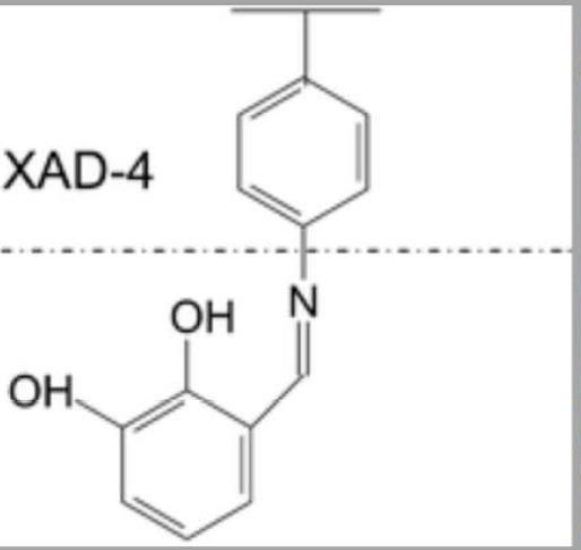
retain also almost hydrophobic compounds

Materials

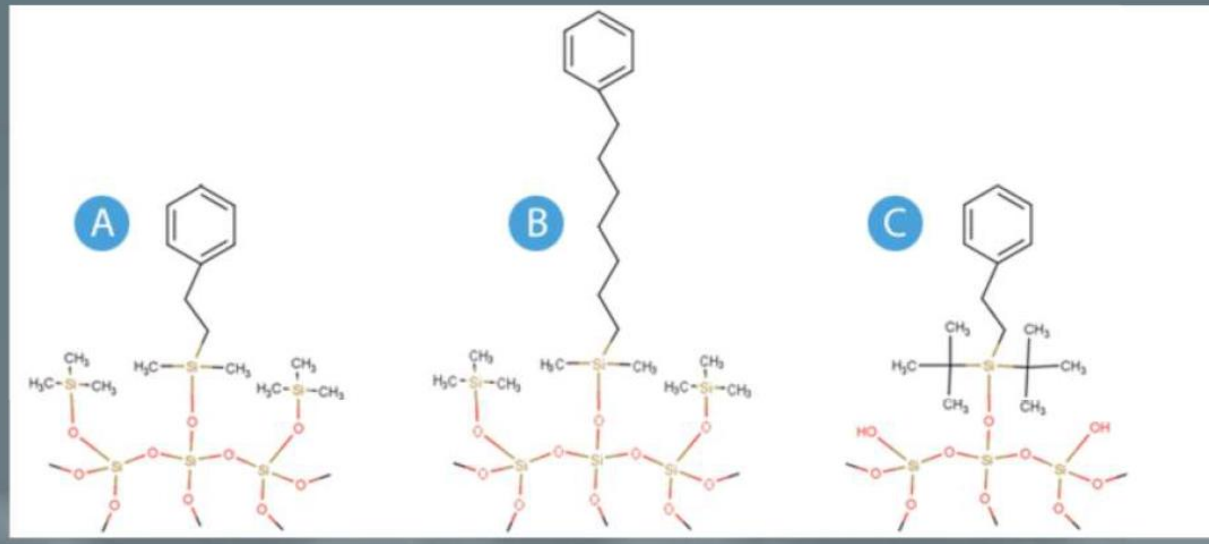
Sorbents

Beyond

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









Biosorbents

agro-industrial solid wastes can be used as sorbents

- cheap
- eco-friendly
- upcycling
- waste reduction







Recovery

Recovery attributes

- Efficiency
- Environmental hazards
- Cost effectiveness
-
- Ease

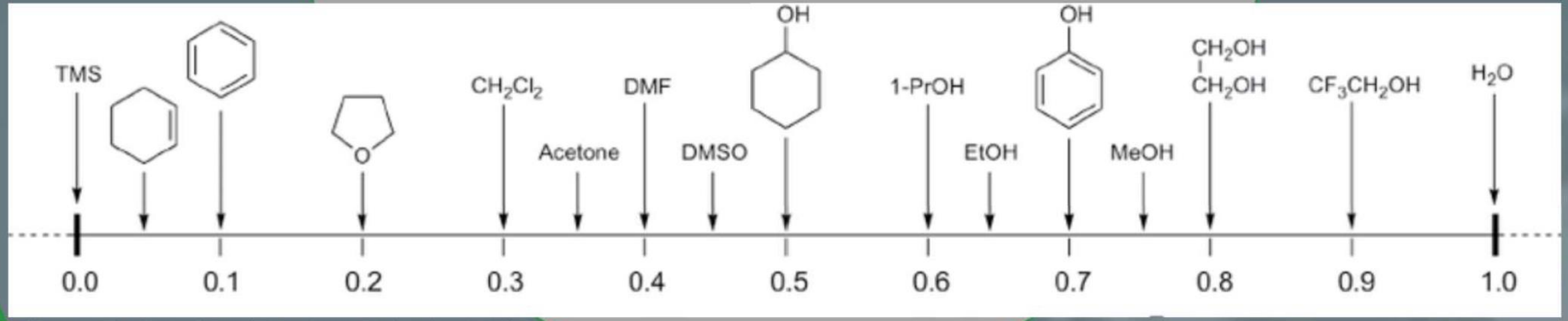
Extraction Solvents

Subcritical Water Extraction

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

Extraction Solvents

Water - cheap, inefficient, non-toxic
Methanol - high cost, increased toxicity
Ethanol - very high cost, lower toxicity



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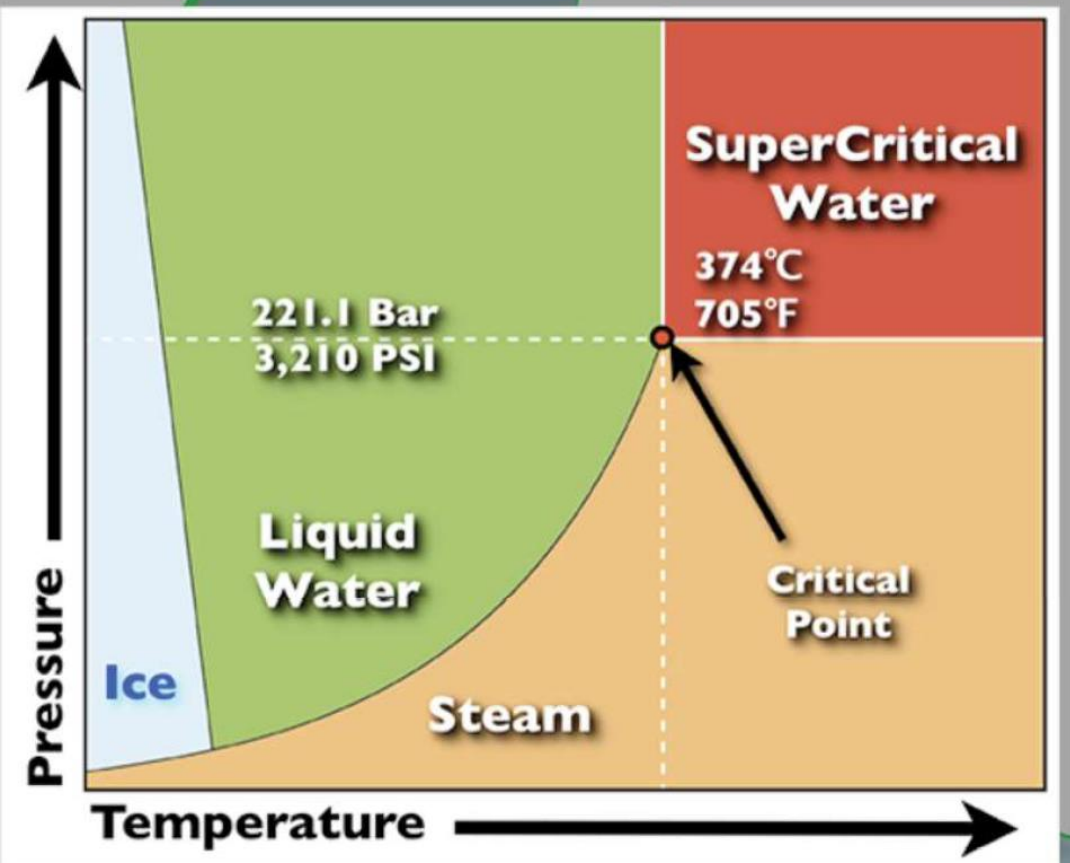
SubCritical Water Extraction (SCWE)

- 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

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

Results



Static Adsorption

Static Adsorption Methodology

Static Adsorption Results



Dynamic Adsorption

Dynamic Adsorption Methodology

Dynamic Adsorption Results

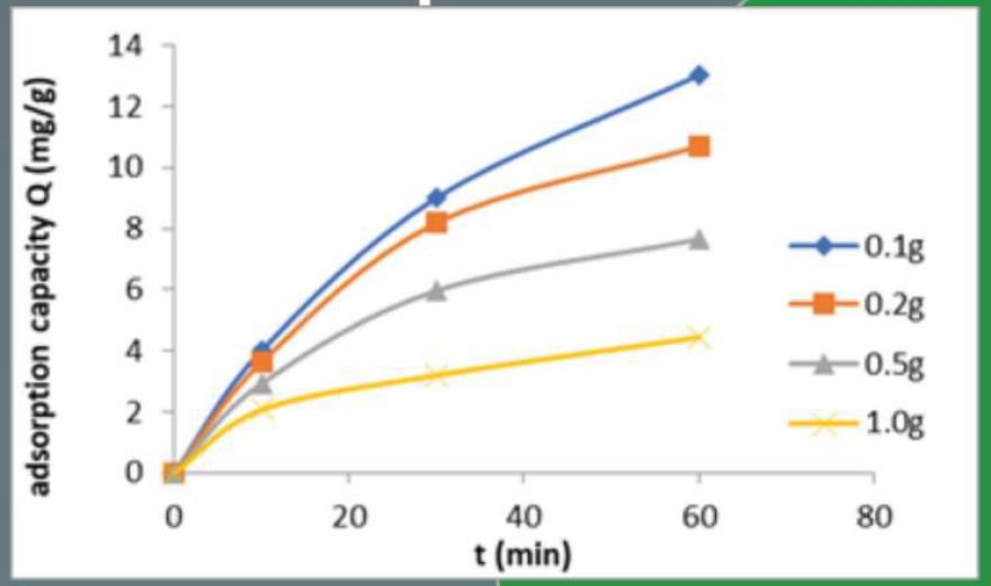


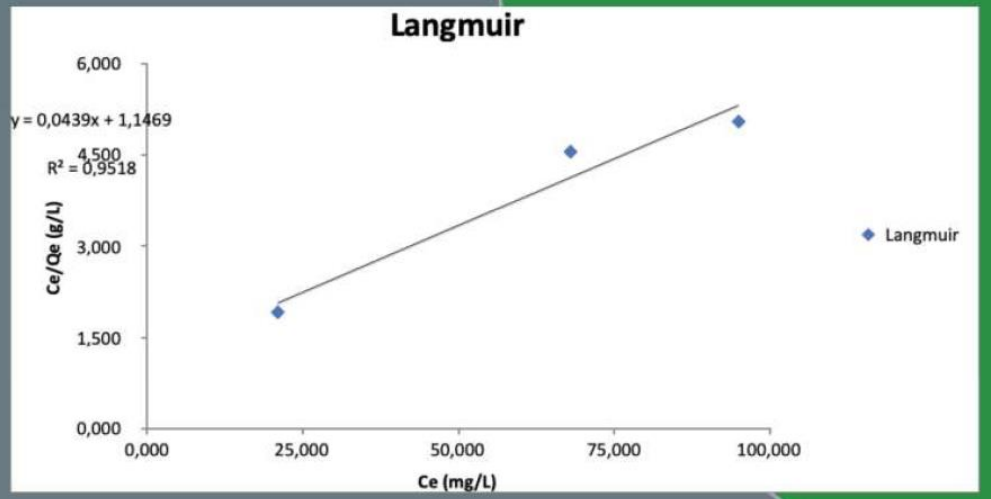
Recovery

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 Results





Maximum capacity 22,78 g/kg
(g of polyphenol per kg of resin)

Contact time vs Adsorption %

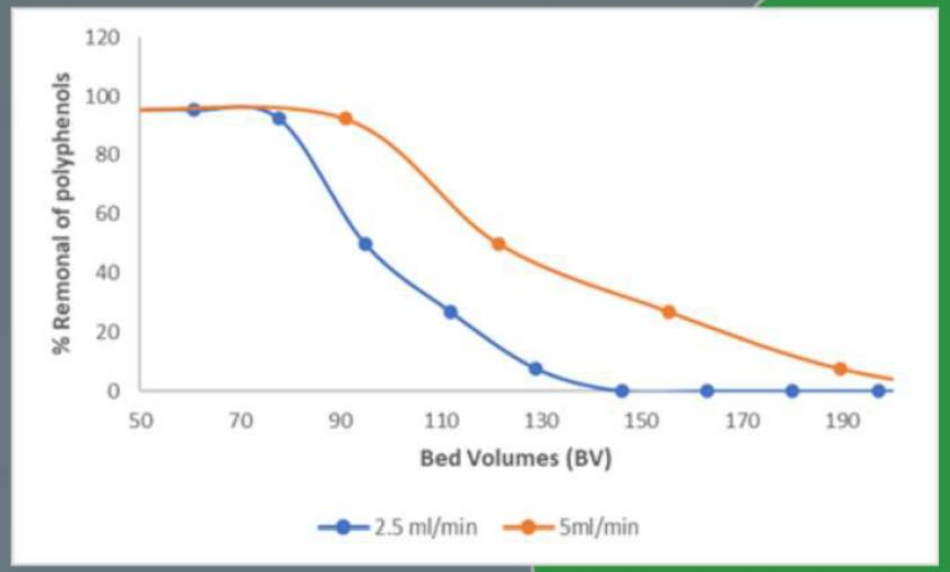
60 min 95%

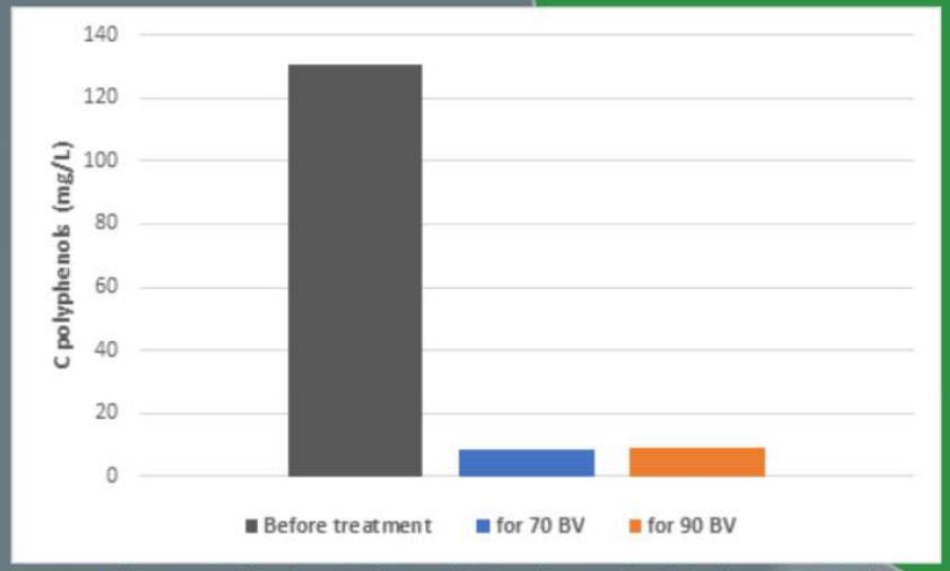
30 min 60%

Yield = 130 g/m3
(mg of polyphenol per L of wastewater)

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

Dynamic Adsorption Results





Unit

- 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

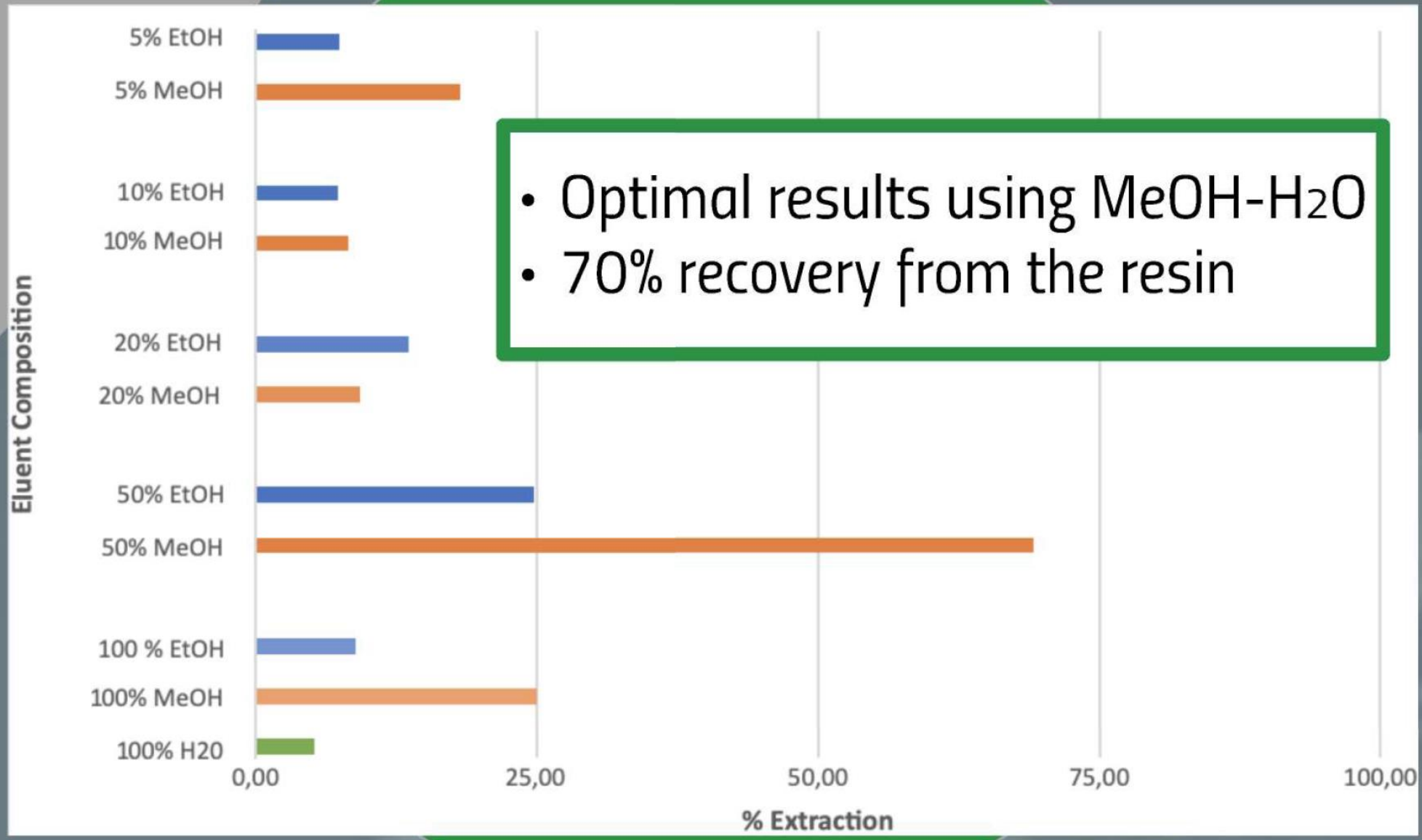
The project leading to this application has received funding form the European Union's Horizon 2020 innovation programme under grant agreement No 869318

Pilot Plant Adsorption Results

- Continius flow dynamic adsorption adsorbes over 80% of the polyphenols present in orange juice by-product
- This step has 20% contribution in the reduction of the overall Total Organic Carbon (TOC) of the orange juice by-product



Recovery



- Optimal results using MeOH-H_2O
- 70% recovery from the resin

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Advanced Oxidation Process

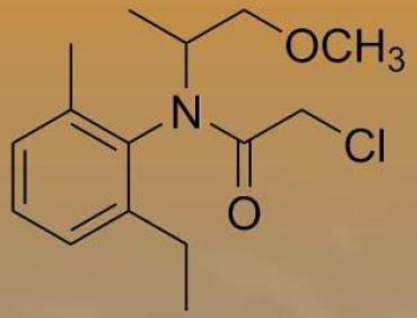
Catalyst
or
Oxidant

+UV



OH•

Hydroxyl radical



Pollutant





CO_2



Design

Model Compound Selection

Results

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

The CPC photocatalytic reactor

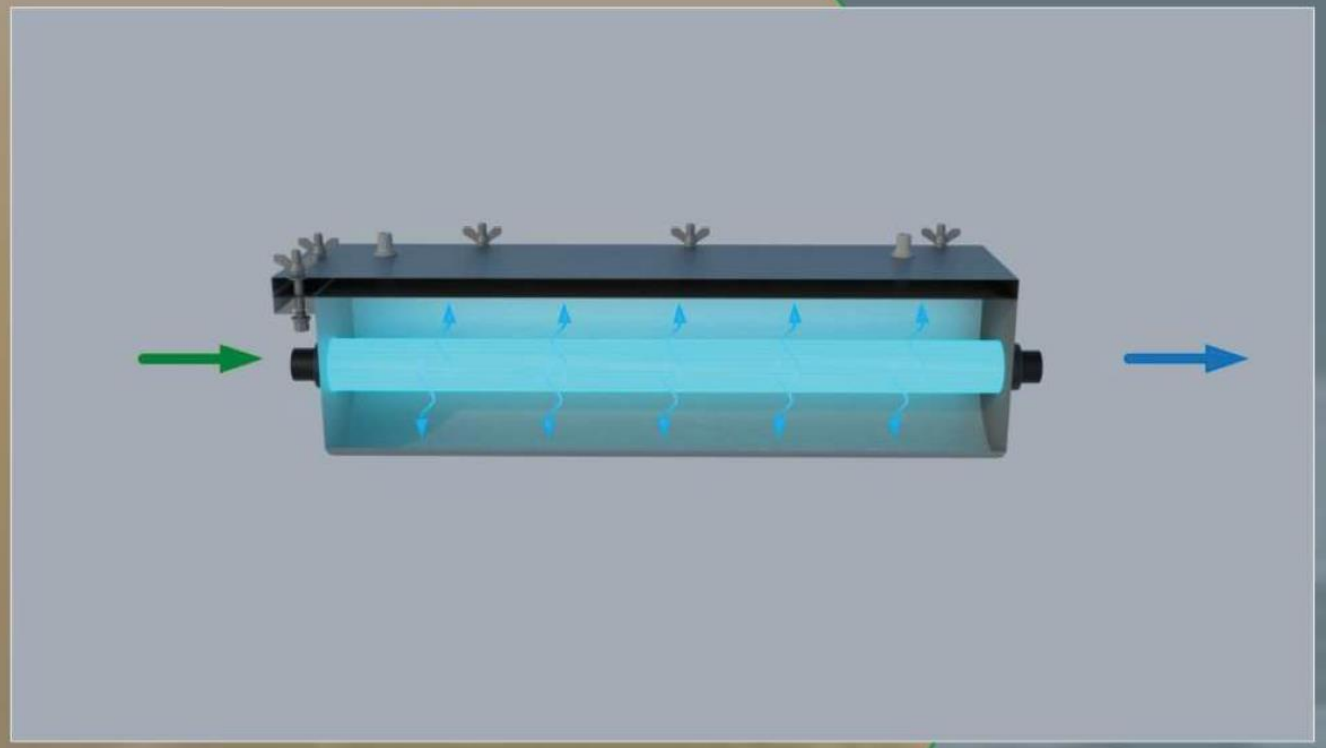
Annular



- Continuous flow
- Operates under either solar or artificial UV light

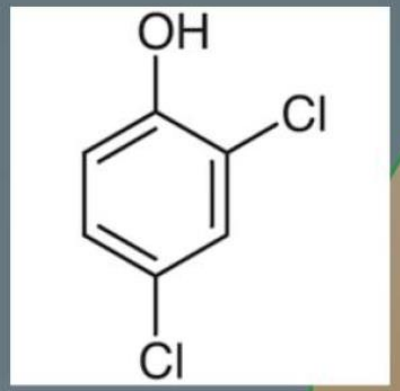
The annular photocatalytic reactor





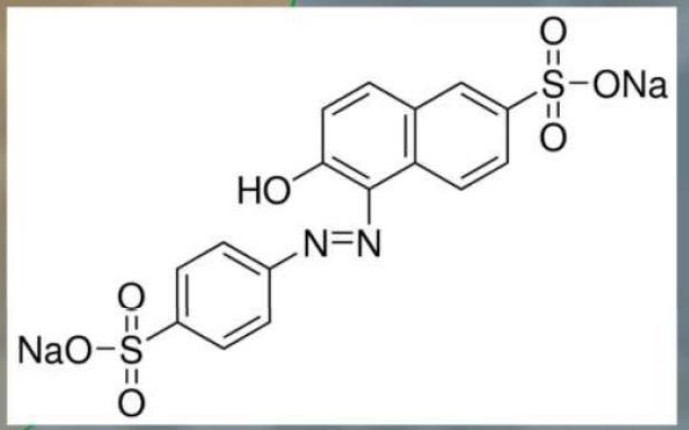
- Continuous flow
- Operates under artificial UV light

Model Compound Selection

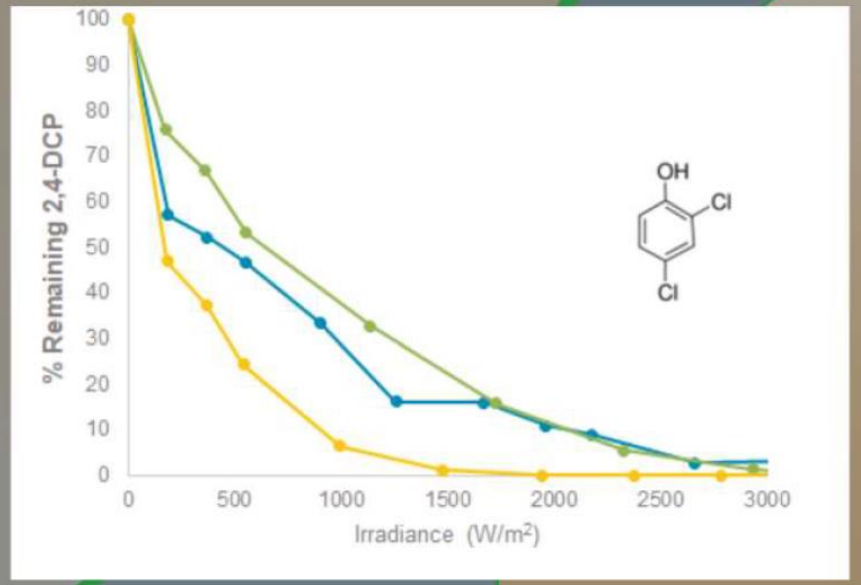


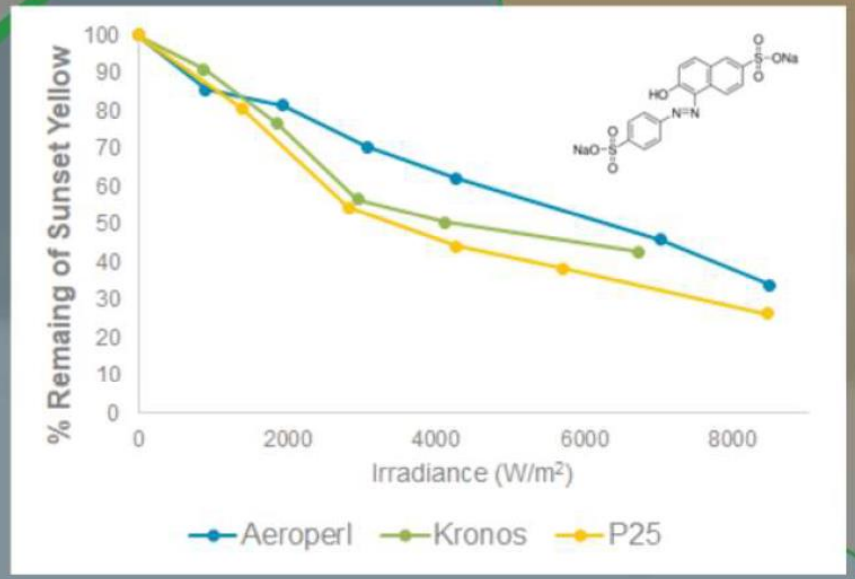
Lab tests:
2,4-Dichlorophenol

Pilot scale tests:
Sunset Yellow



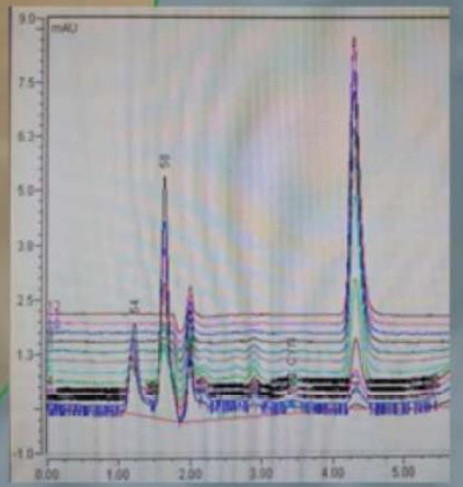
Degradation of model compounds





Demonstrated ability to remove 90% of organic pollutants





ULTIMATE

indUstry water-utiLiTy symbiosis for a sMarter wATEr society



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COLFEED4Print

MTE 3D printing of catalytic membranes and supports for cleaning AOPs in water

Pablo Ortega Columbrans
Junior Research Assistant (PhD Candidate) / Production
pablo.ortega@colfeed.com



ULTIMATE WATER SMART INDUSTRIAL SYMBIOSIS

COLFEED 4PRINT

WHO ARE WE?



ICV Instituto de Cerámica y Vidrio · CSIC · colloidal processing

INNOVATIVE SME

Valid until Mar 8th 2026

GOBIERNO DE ESPAÑA · MINISTERIO DE CIENCIA E INNOVACIÓN

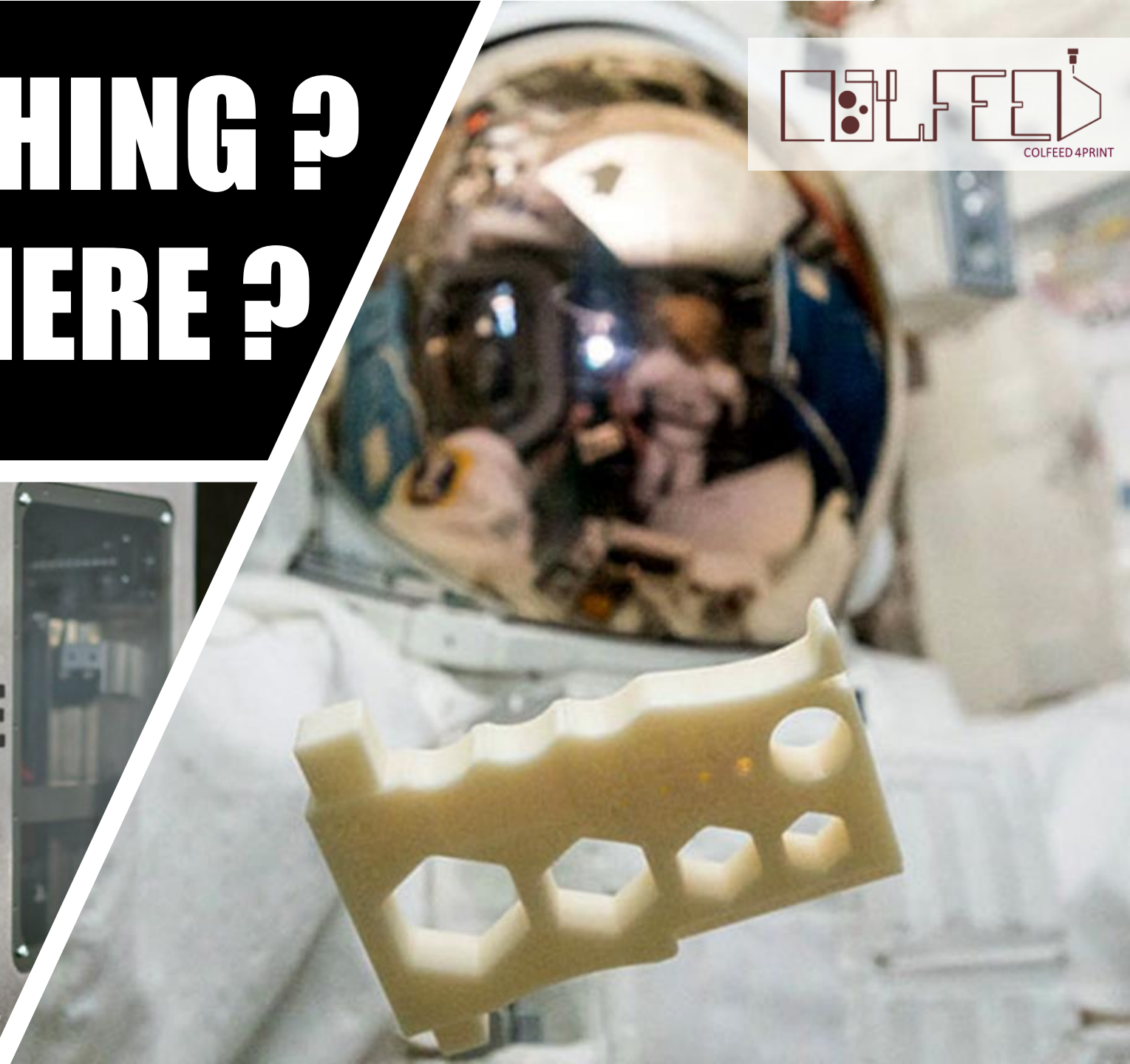
COLFEED4Print

We are a CSIC technology-based firm, TBF-CSIC, founded in February 2020, with the aim of providing (solutions of) innovative products for 3D printing in markets with high technological impact

We manufacture filaments/ granules of **functional materials** for 3D printing by material thermal extrusion (MTE).

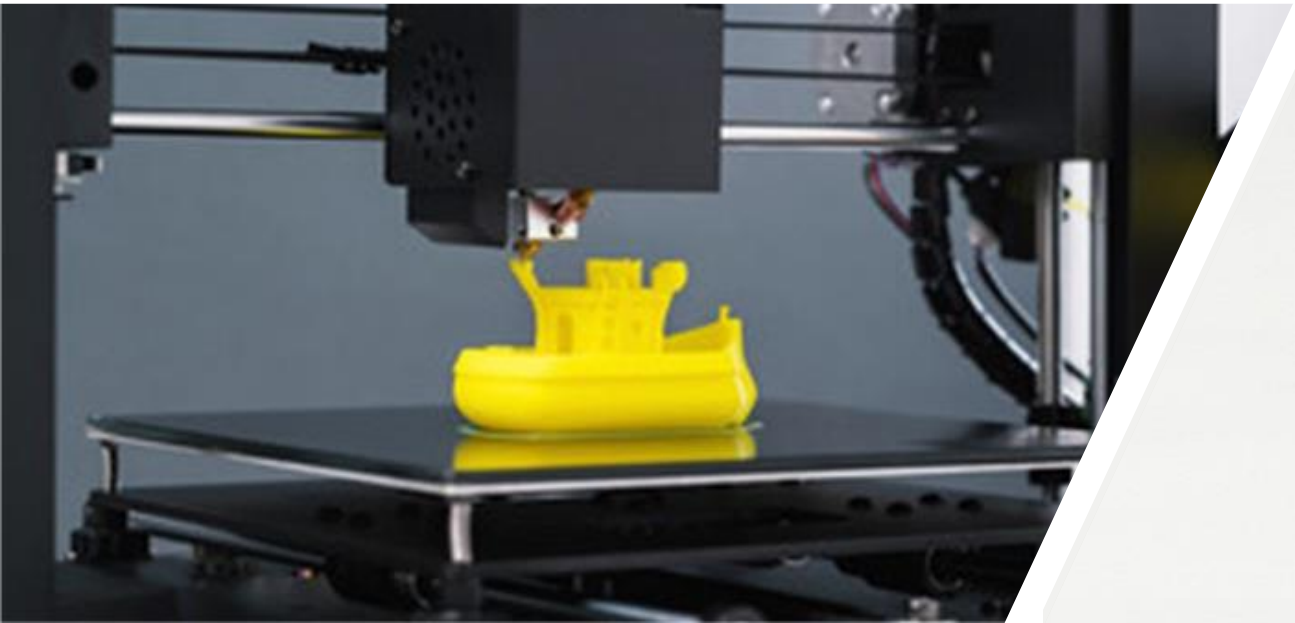
DESIGN ANYTHING ?
MAKE ANYWHERE ?





COLFEED 4PRINT

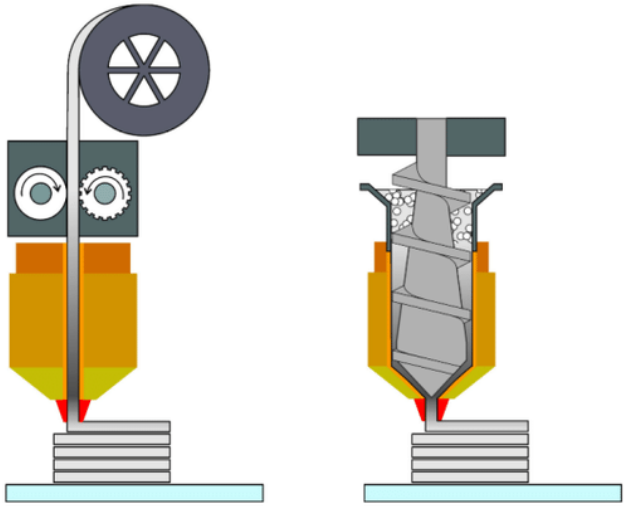
DESIGN ANYTHING
MAKE ANYWHERE
MAKE ANYTHING

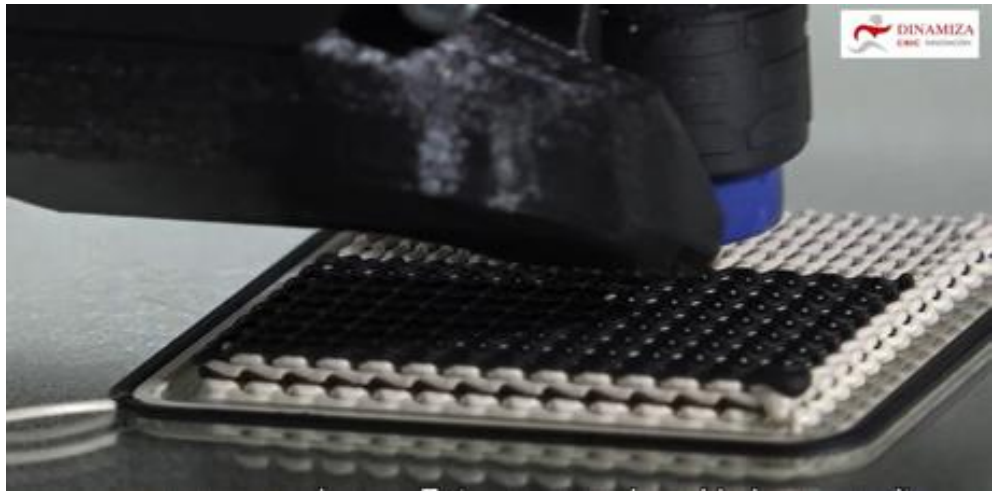


COLFEED 4PRINT

Material Thermal Extrusion

Additive Manufacturing



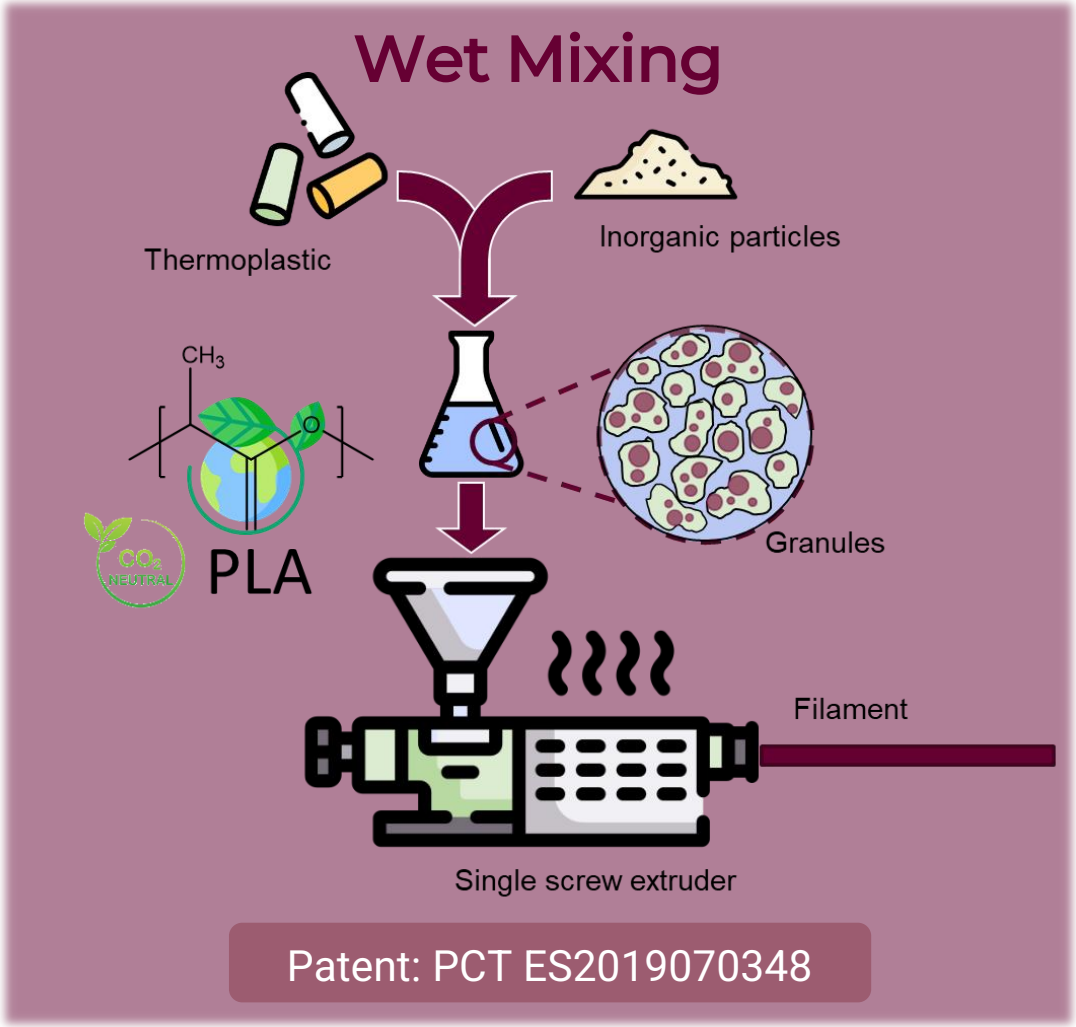


✔ Advantages vs. other 3D Printing Technologies

- Economical and accessible
- Less materials restrictions
- Easy to change material
- Room conditions printing
- MultiPrinting and Printing of different final 3D parts
- Low know-how requirements for digital designs
- Expanded in the medical sector (hospital and clinical)

What makes us UNIQUE

Our patented technology allows us to obtain feedstock to print any material



Patent: PCT ES2019070348

Unique Features

- Functional Composites & 100% Inorganic Pieces
- Easy to print
- High resolution
- Unique 3D components
- Added value

Ecological Commitment

- Low energy production
- Recyclable Filaments
  Circular Economy – Zero Waste
- We use Biomass,
  Our process is Zero Carbon Footprint

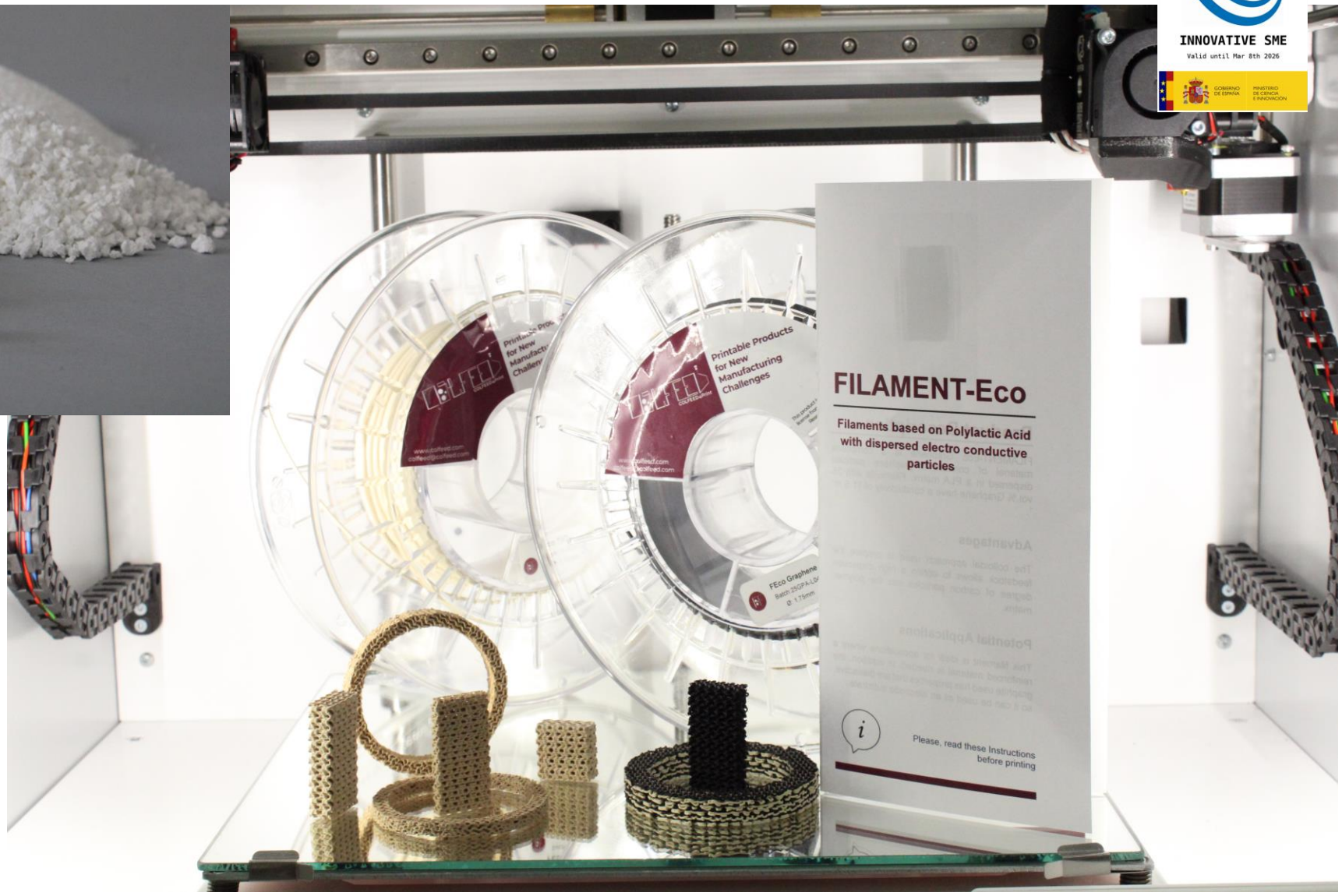
Our Catalogue



PRINTABLE PRODUCTS FOR NEW MANUFACTURING CHALLENGES

CATALOGUE 2023





INNOVATIVE SME
Valid until Mar 8th 2026

Our Catalogue

FILAMENT-Eco

Photo- and electroactive materials for catalytic and energy applications

- Photocatalytic TiO_2/ZnO
- Conductive Graphite/Graphene
- Reinforced/Conductive FC-composites





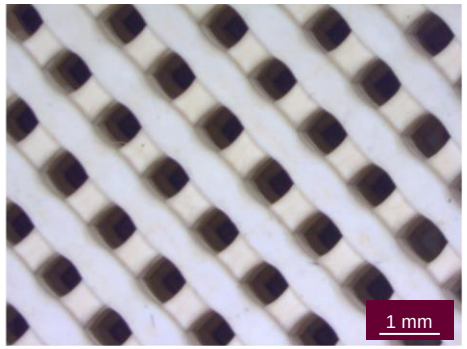
INNOVATIVE SME
Valid until Mar 8th 2026

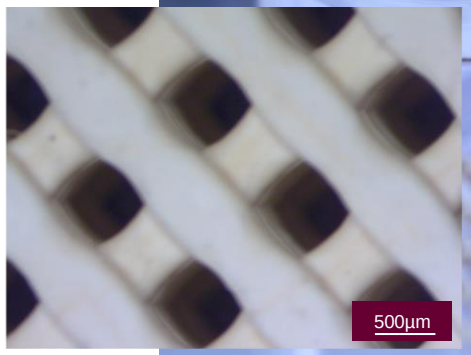
Our Catalogue

FILAMENT-Cer

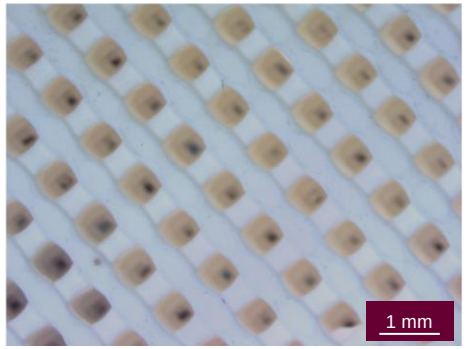
Ceramics for high temperature and abrasive conditions

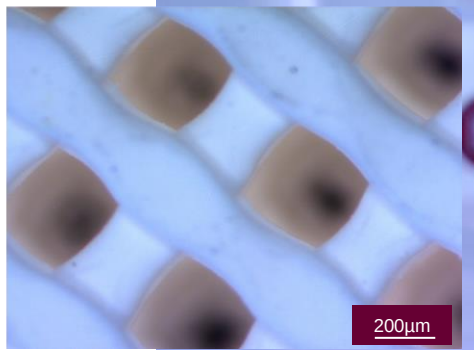
- High Al_2O_3/ZrO_2 content (44 vol.%)
- Conventional debinding/sintering
- 100% ceramic parts





Printed

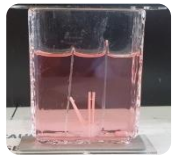


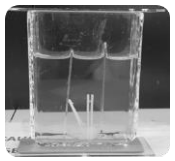


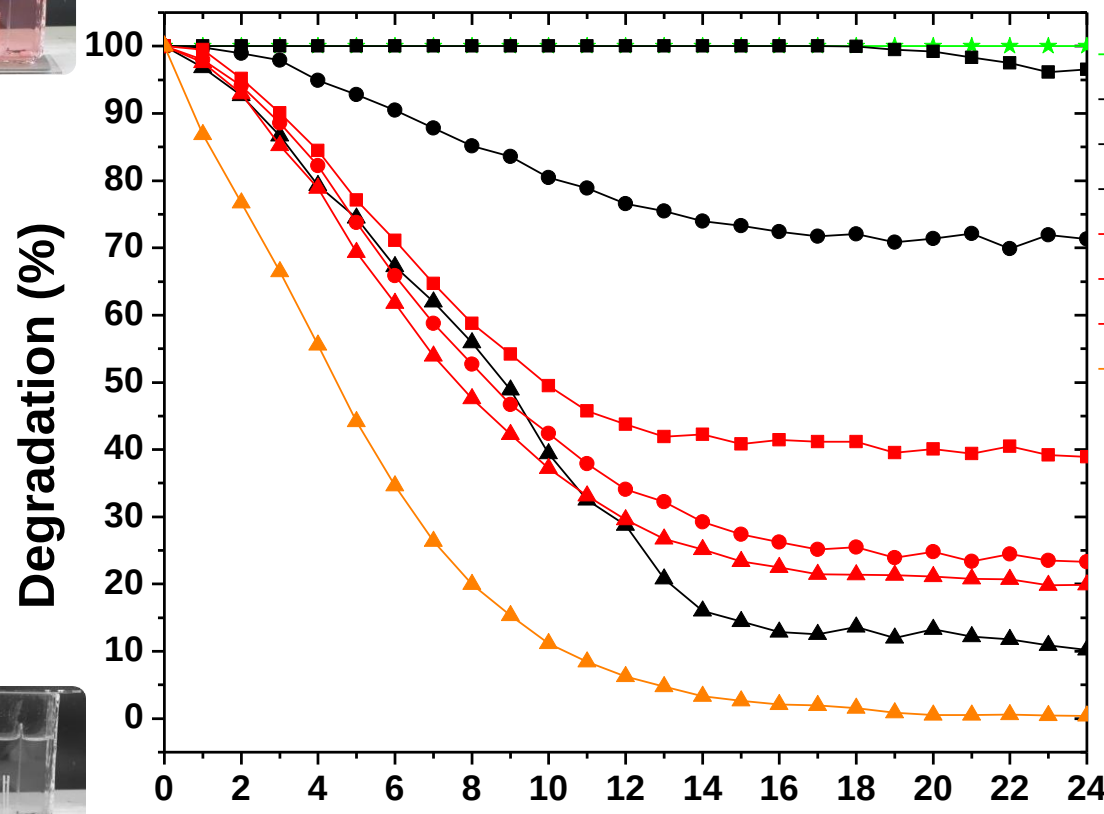
Sintered

AM & Colloidal Materials: Inks for Filament Fabrication

Material Extrusion: **FFF of Photoactive composites**



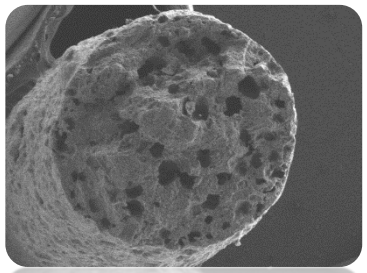


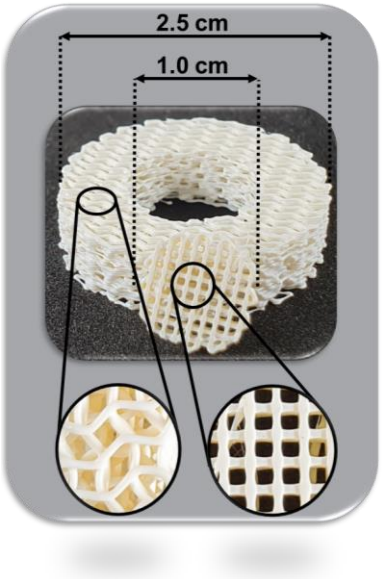


PLA
5vol.% TiO2
10vol.% TiO2
15vol.% TiO2
Filaments
5vol.% TiO2
10vol.% TiO2
15vol.% TiO2
Membranes
15vol.% TiO2 +nanoCellulose
Filaments (+nanoCellulose)









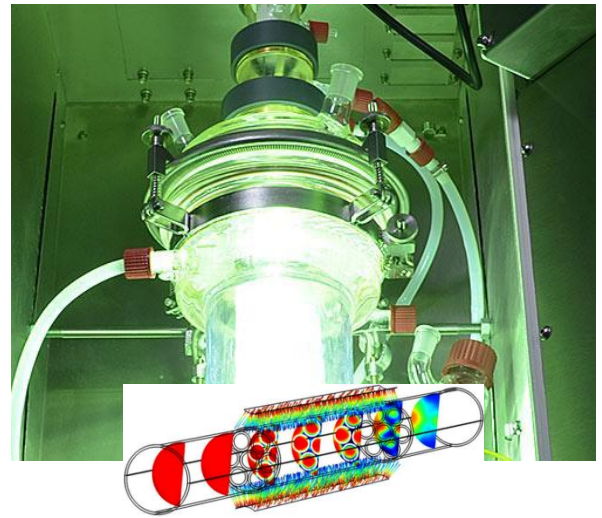
Photocatalysis tests MO (C_0 = 3ppm || pH =2)

P. Ortega-Columbrans, A. Ferrandez-Montero, J. Yus, A.J. Sanchez-Herencia and B. Ferrari. Processing of membranes and 3D scaffolds based on n-TiO2 colloidally dispersed on a thermoplastic matrix for photocatalytic pollutant removal. Catalysis Today. Manuscript number: CATTOD-D-23-00122

Double Green H_2 Production

The Challenge of Flow Reactors Engineering, with immobilized photocatalysts, fabricated through an Environmentally Friendly Technology

- Represents 1.7% of the world's annual energy consumption
- Only 1% is generated from green energy sources
- Most of it is obtained from natural gas and coal, emitting **830 million tons CO_2/year**
- Alternative: **membrane photoreactors** (PMR) for water splitting under sunlight



Photoreactor from Peschl Ultraviolet GmbH
COMSOL predictive model

Problem

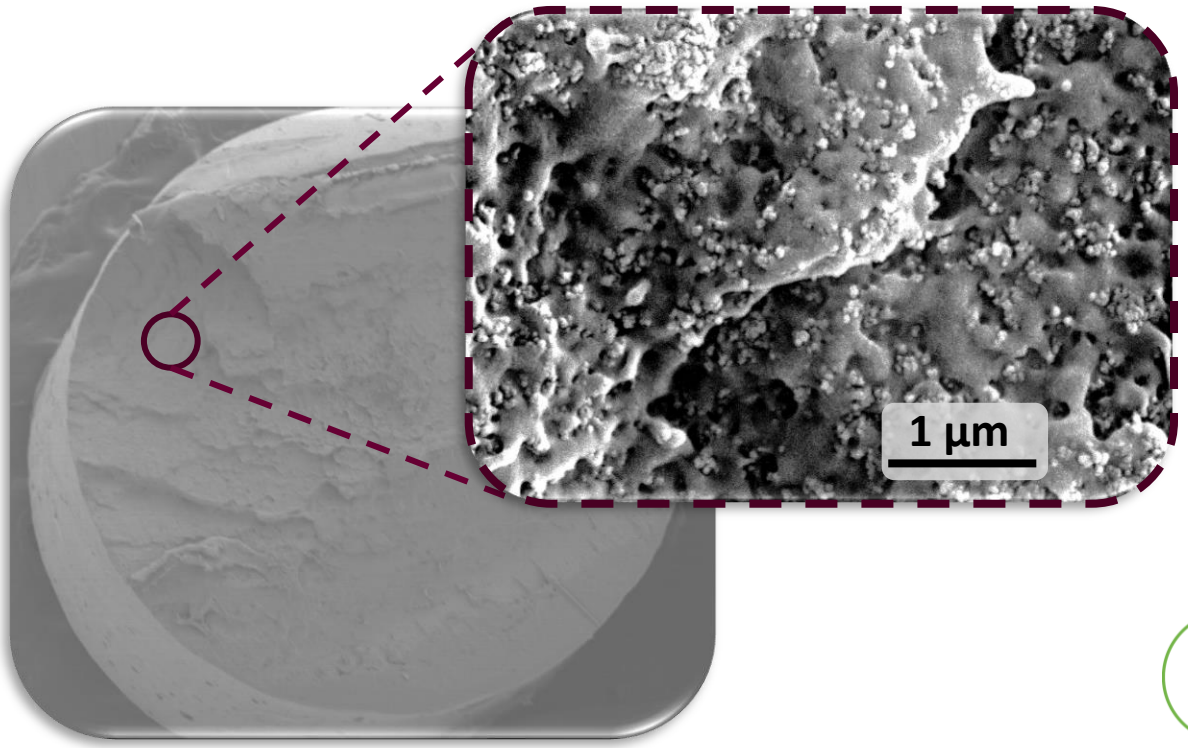
- ✗ PMR configurations are not resolved yet
- ✗ New materials are still under study
- ✗ Photocatalyst dosage and light exposition is limited
- ✗ Low surface to volume ratio of membranes
- ✗ Limited performance

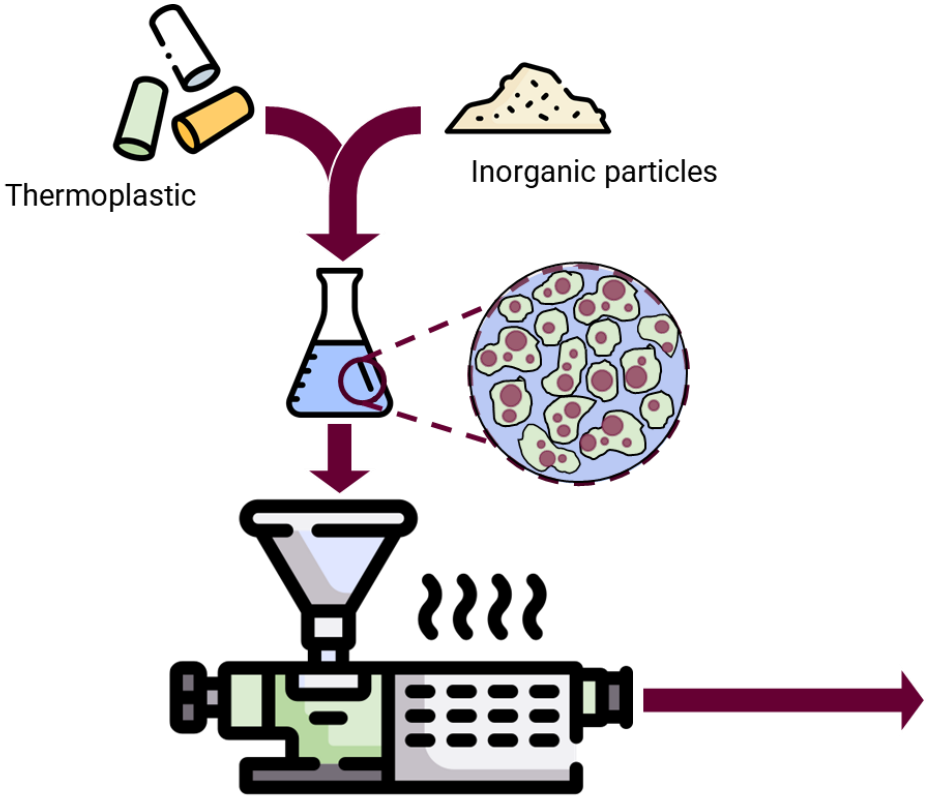
Need

- ✓ Geometries and Porosities to assure the contact with fluids
- ✓ **Configurations of self-standing membranes, able to favor light exposure and fluid flux**
- ✓ Testing bench for extremely efficient materials and compositions

COLFEED4Print: Feedstock & 3D printing of heterostructures in self-supported membranes for DOUBLE green H_2 generation

We are the only company able to introduce large quantities of **nanoparticles** in printing feedstock, maximizing photocatalytic activity or sintering 100% inorganic parts for full-solid-state based technologies (PEM & SOEC).





By a zero-carbon footprint and low energy **production process**, integrated in the circular economy frame

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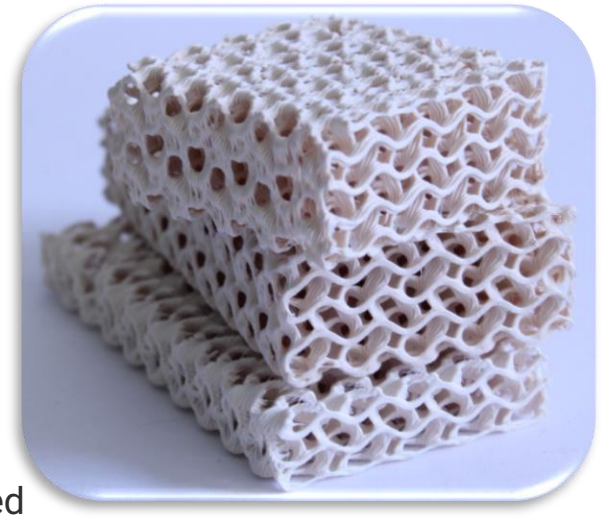
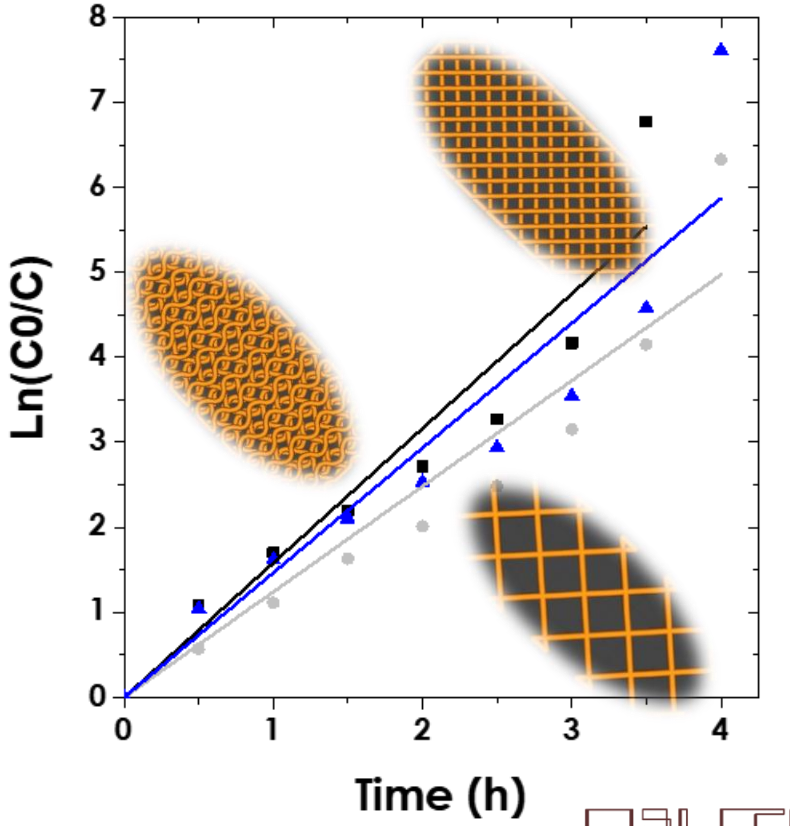
CAD-Designed porosities & configurations of components for **multiprinted structures** with different functional materials: photocathode/anode + collectors and/or heterojunctions for H_2 generation.



By a zero-carbon footprint and low energy **production process**, integrated in the circular economy frame

Membranes with designed geometries and photocatalytic activity

FEco TiO_2 / FEco ZnO



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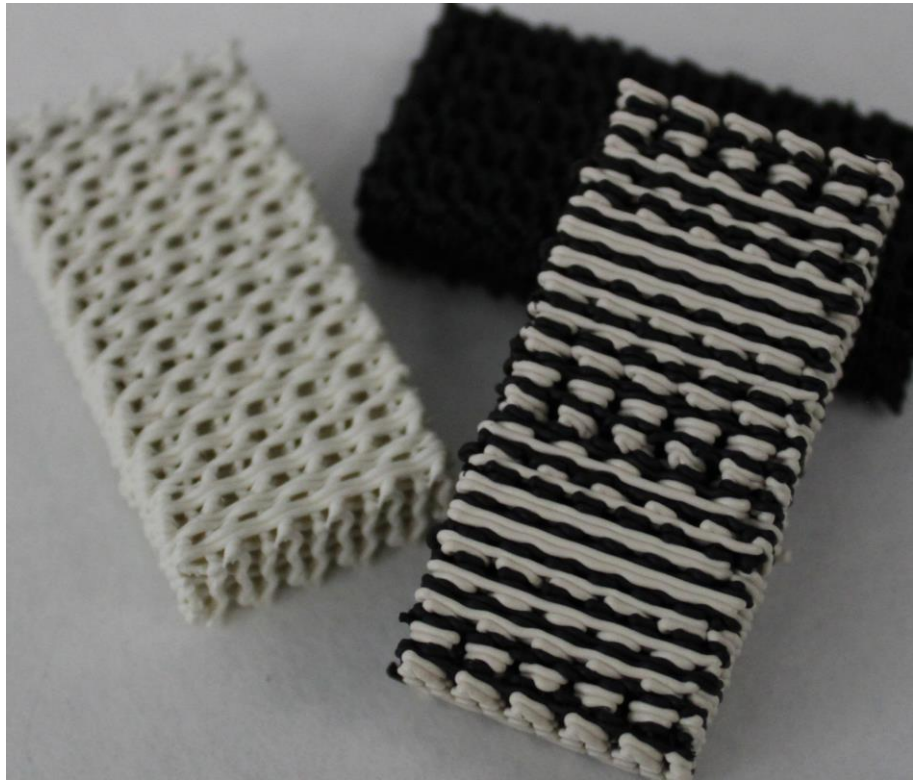
Small batches for testing **nanoengineered compositions** improved with synthesis particles that increase photocatalysis performance as well as electrical conductivity

By a zero-carbon footprint and low energy **production process**, integrated in the circular economy frame

Membranes where photocatalysts joint adsorbents lead to excellent results

FEco TiO_2 / FEco ZnO / FEco Graphene / FEco Al_2O_3 / FEco ZrO_2



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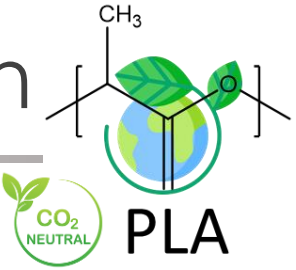
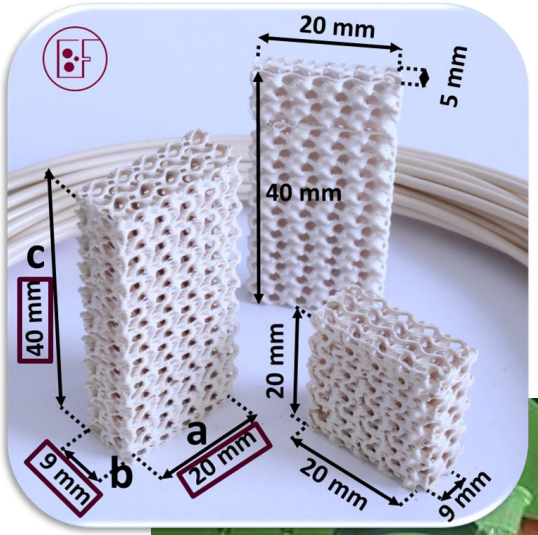


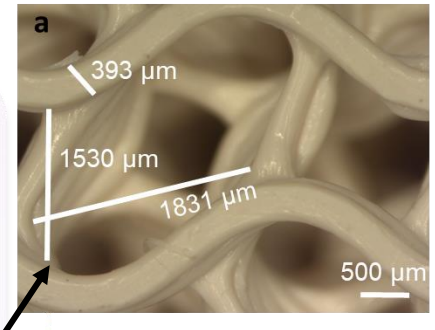
Material Extrusion: **FFF of Photoactive composites**

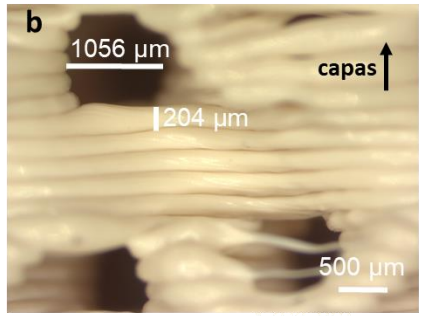


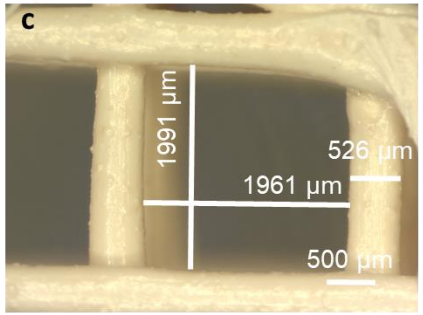


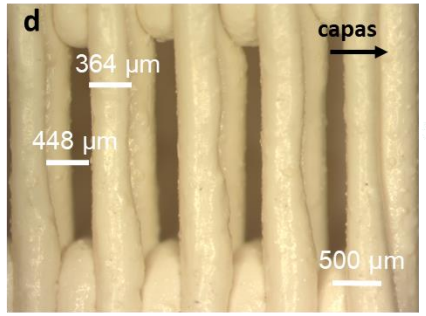


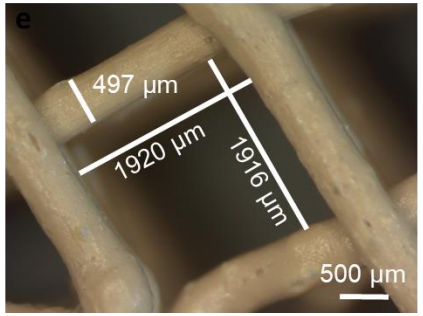


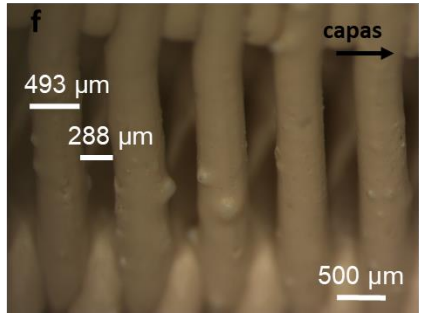




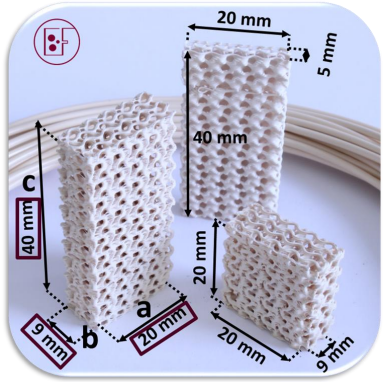




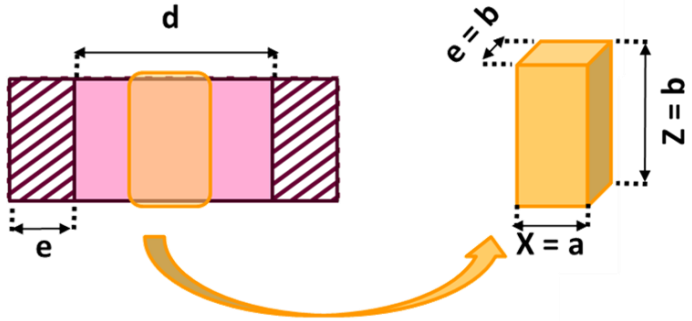


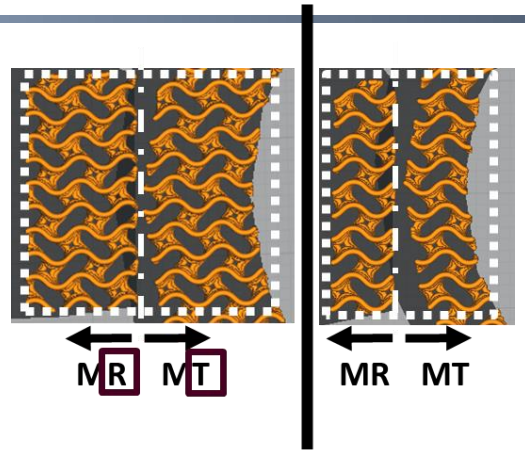


Design of porous structures with high specific surface area and photocatalytic activity



MR A







MT A → 60x50x10 mm

PLA

Sample	Dimensions (mm)	$t_{100\%}$ (h)	$t_{50\%}$ (h)	k (h^{-1})	Catalyst (g)	k ($h^{-1} \cdot g^{-1}$)
A-01	20x9x20	-	-	$4,05\ 10^{-2}$	0,16	$2,46\ 10^{-1}$
A-02	20x**5**x40	12	3	$6,35\ 10^{-2}$	0,19	$3,23\ 10^{-1}$
A-03	20x**9**x40	2	1	$1,01\ 10^{0}$	0,38	$2,62\ 10^{0}$
A-04	20x9x40	2	1	$0,95\ 10^{0}$	0,32	$2,96\ 10^{0}$

Kinetic limitation in the **thickness** of the membranes

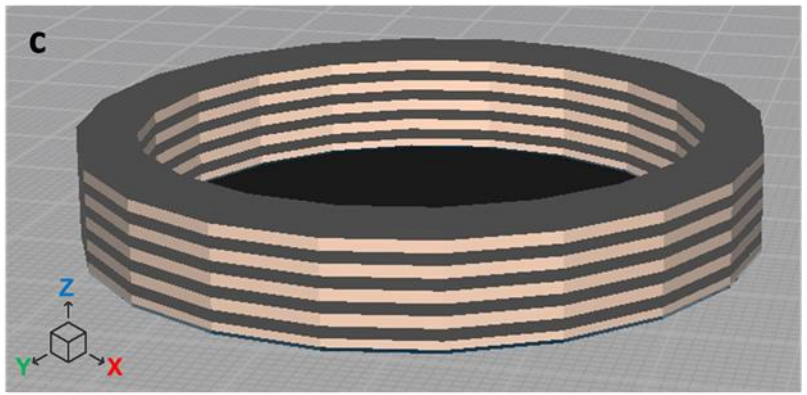
Design and printing of porous co-catalytic heterostructures

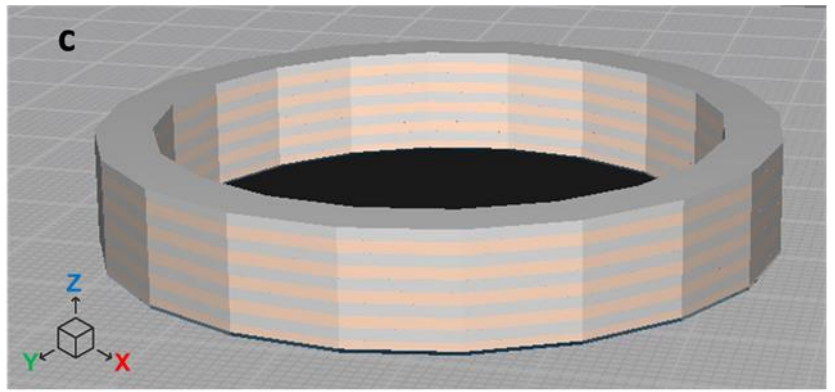


Photoactives composites filaments

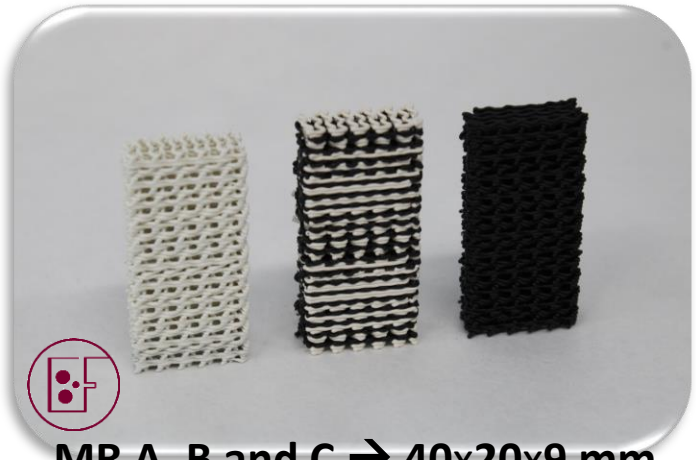


MT A, B and C → 60x50x10 mm





Catalytic Heterostructures Design

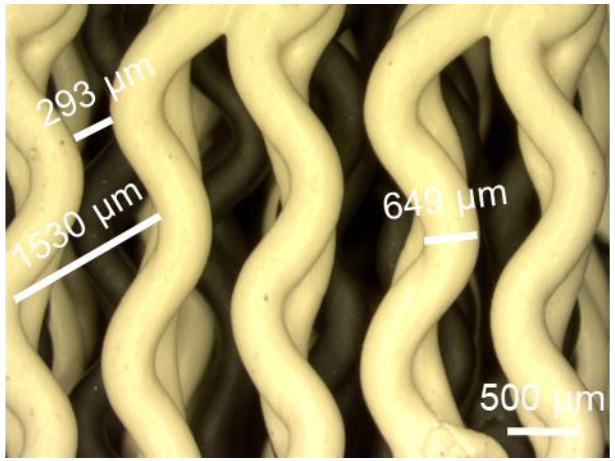


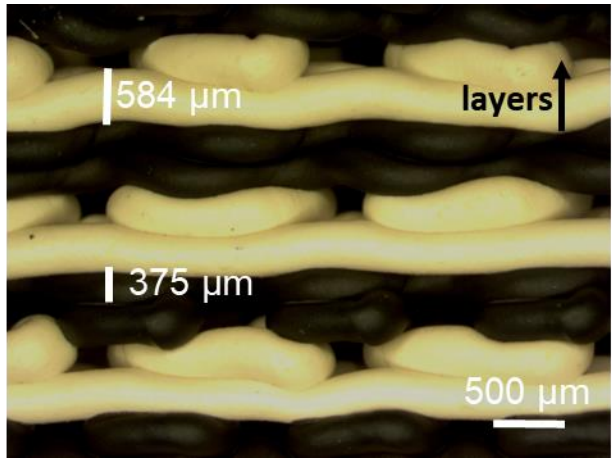
MR A, B and C → 40x20x9 mm

Design and printing of porous co-catalytic heterostructures

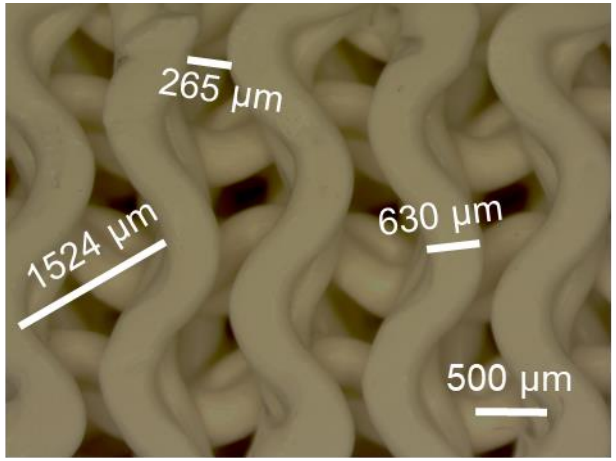
Porosity and microscopy of FFF printed membranes

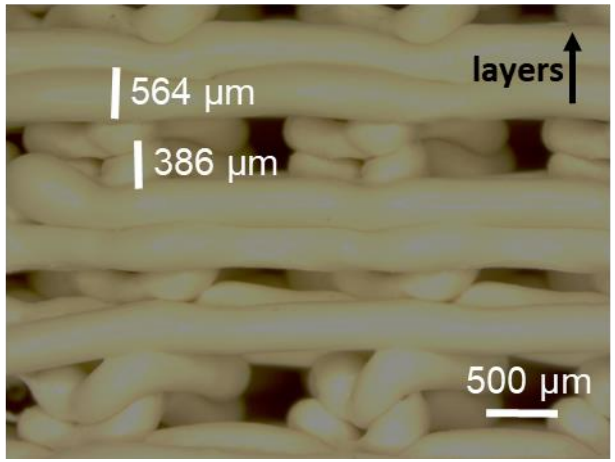
B **Co-catalytic structure**





C **Adsorbent Catalytic heterostructure**



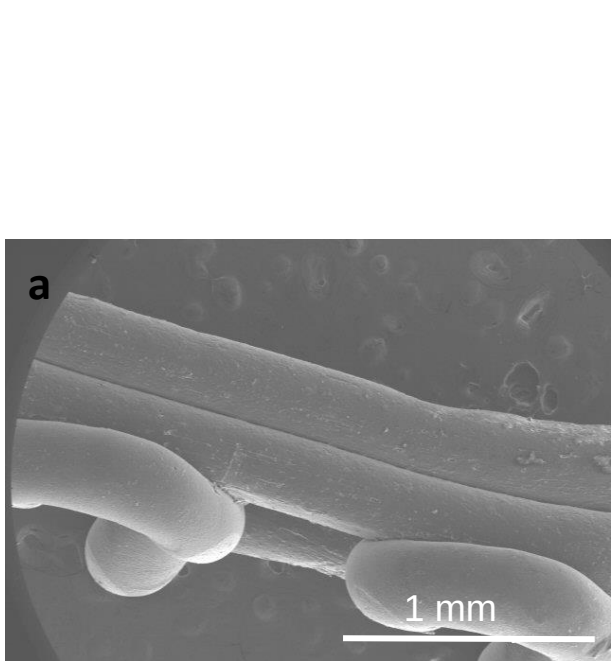


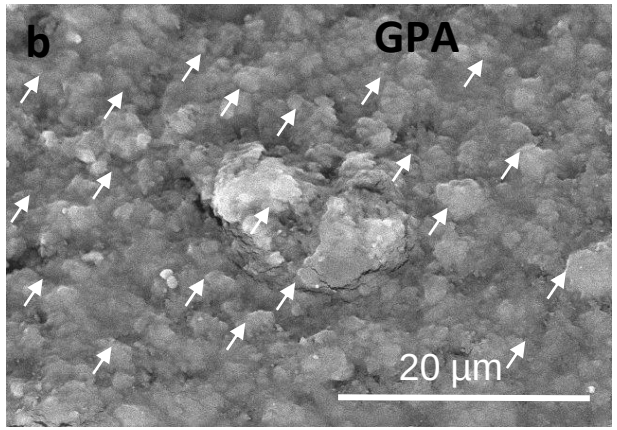
Design and printing of porous co-catalytic heterostructures

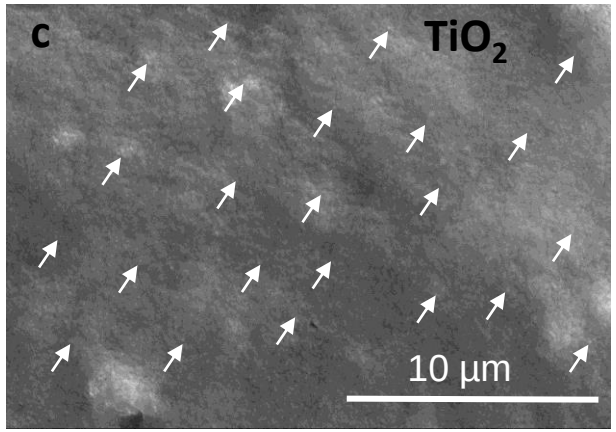
Porosity and microscopy of FFF printed membranes

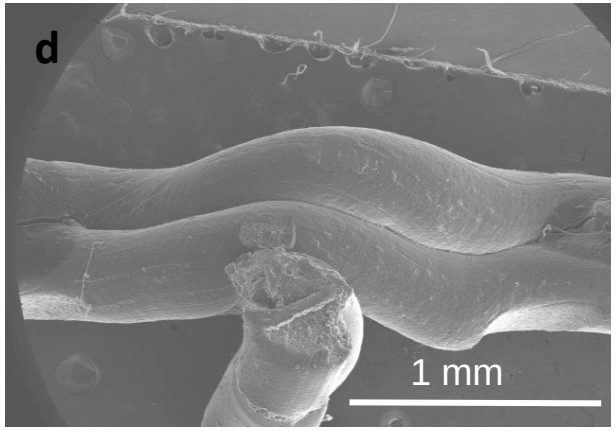
B **Co-catalytic structure**

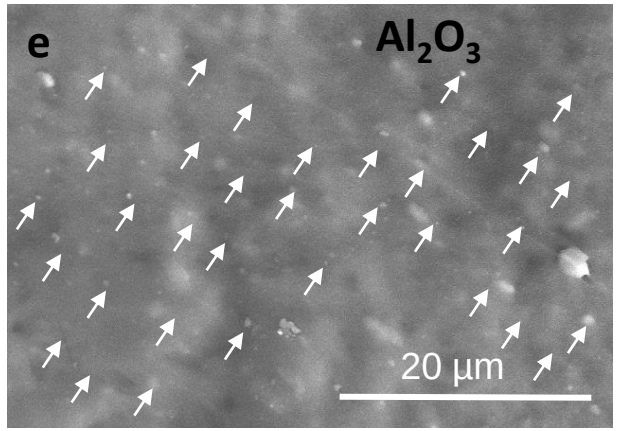
C **Adsorbent Catalytic heterostructure**

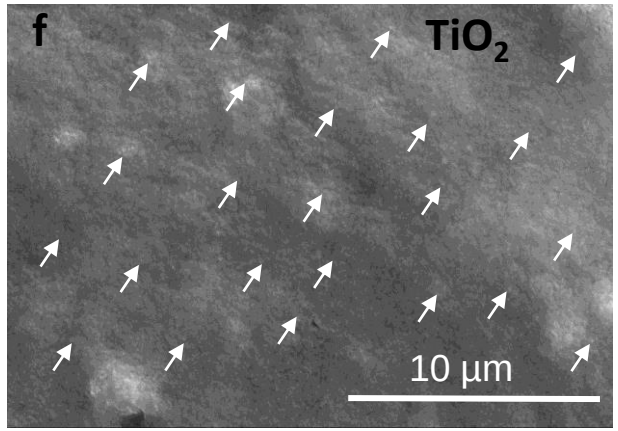






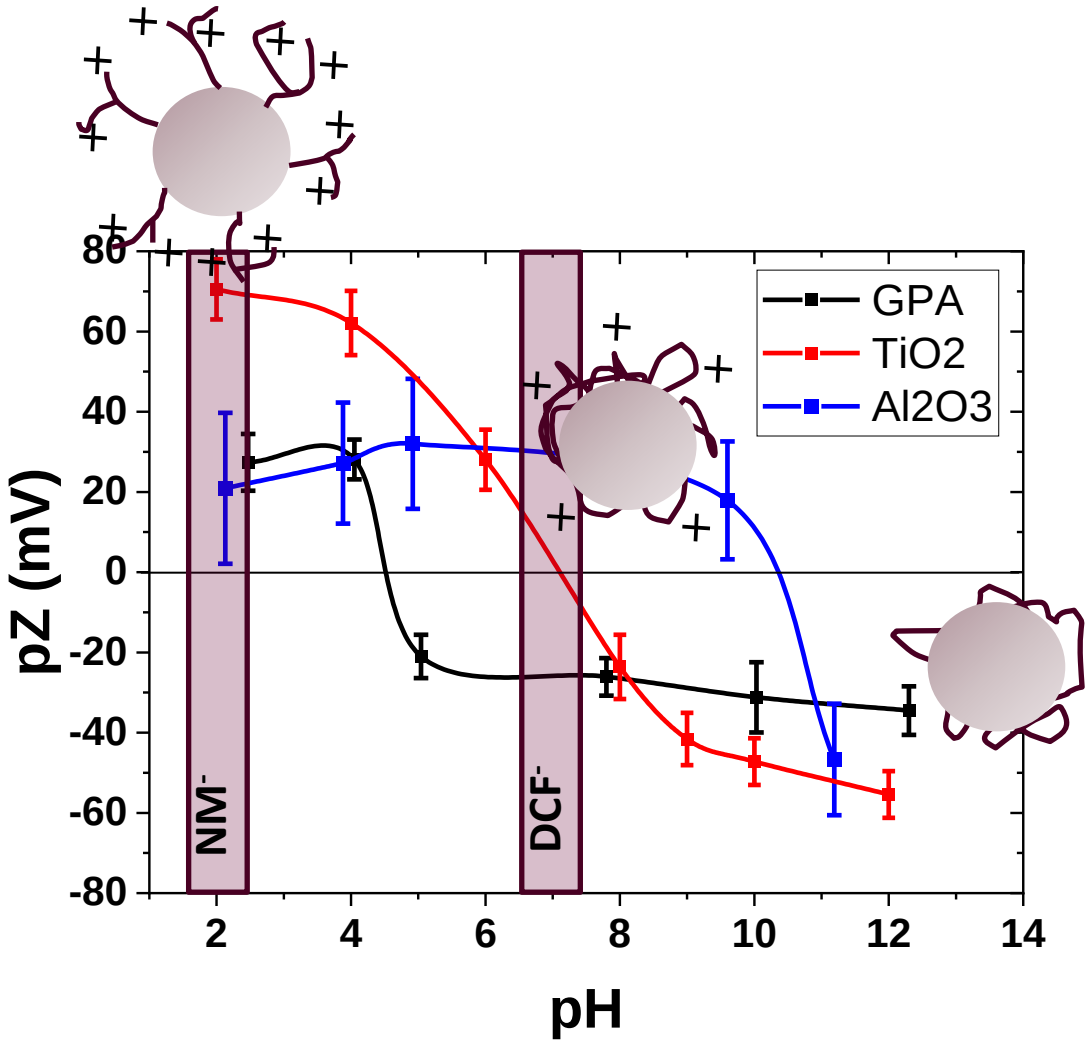


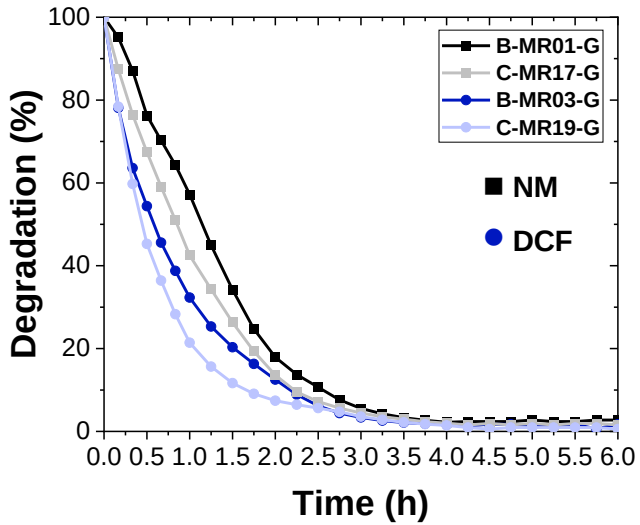


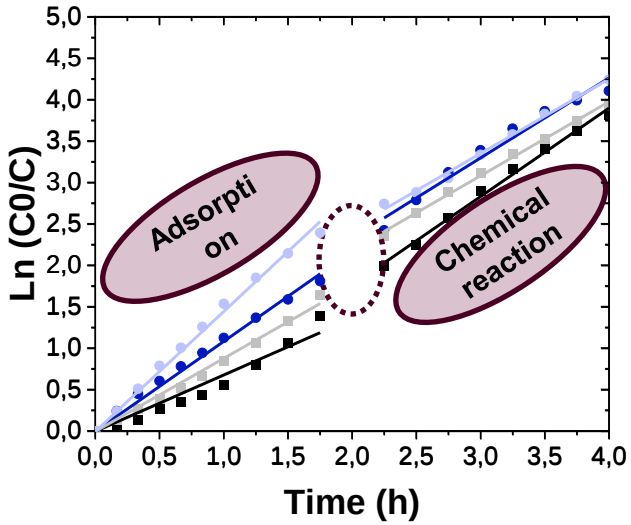


Reaction mechanism, photocatalytic activity and kinetics

Surface charge study (zeta potential)







K'' ($h^{-1} \cdot g^{-1}$)

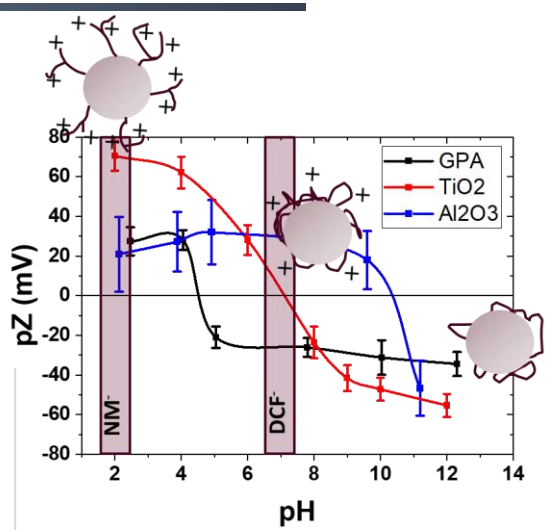
k_{ads} ($h^{-1} \cdot g^{-1}$)

k_{rq} ($h^{-1} \cdot g^{-1}$)

k_{media} ($h^{-1} \cdot g^{-1}$)

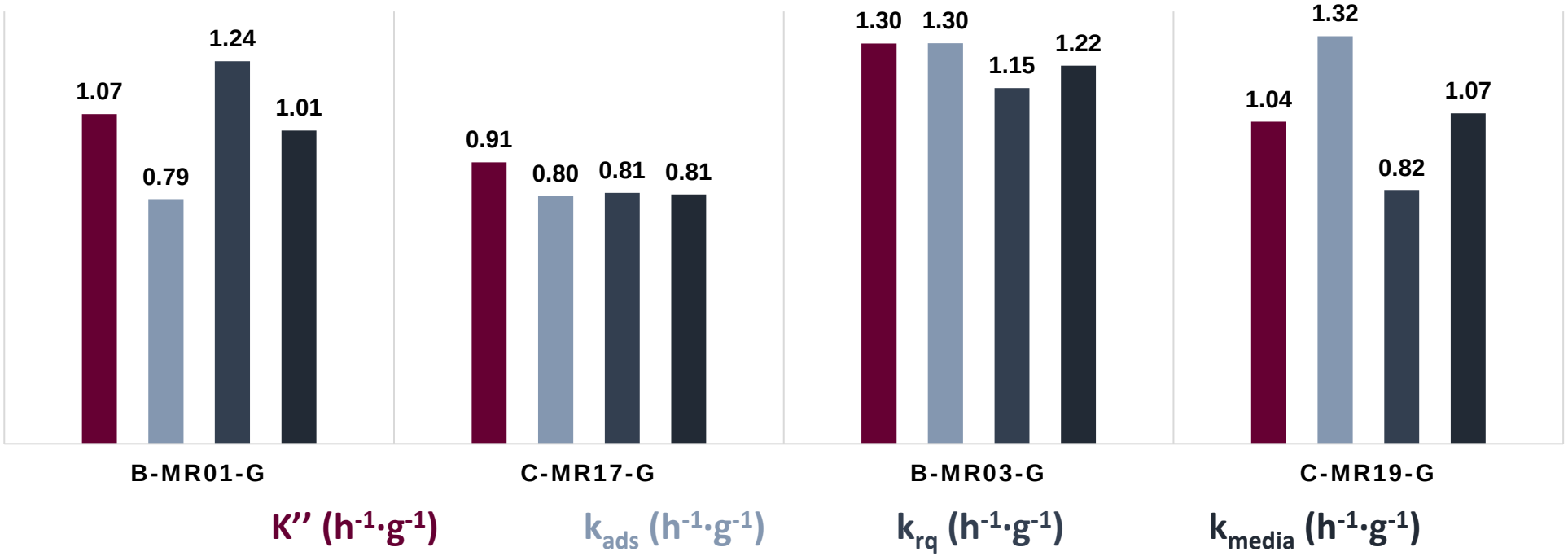
Reaction mechanism, photocatalytic activity and kinetics

Kinetic constant's different reaction mechanisms



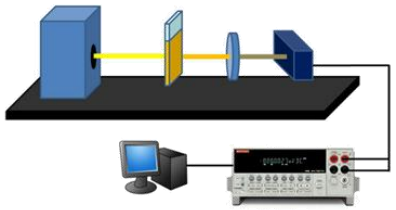
NM (pH=2)

DCF (pH=7)



Degradations achieved according to time and reactor type

Reactor / Sample composition	A	k ($h^{-1}\cdot g^{-1}$)	B	k ($h^{-1}\cdot g^{-1}$)	C	k ($h^{-1}\cdot g^{-1}$)
Flow Reactor (2h)	10%	$7{,}4\cdot10^{-1}$	40%	$4.4\cdot10^{-1}$	20%	$2.4\cdot10^{-1}$
Batch Reactor (2h)	10%	$1.1\cdot10^{-0}$	80%	$1.3\cdot10^{-0}$	90%	$1.04\cdot10^{-0}$
Flow Reactor (6h)	25%	$3.2\cdot10^{-1}$	-	-	-	-
Batch Reactor (6h)	25%	$7.6\cdot10^{-2}$	100%	$1.3\cdot10^{-0}$	100%	$1.0\cdot10^{-0}$
Flow Reactor (100h + refill)	85%	$1.5\cdot10^{-2}$	-	-	-	-
Batch Reactor (72h)	-	-	100% (72h)	$9.3\cdot10^{-1}$	100% (72h)	$8.1\cdot10^{-1}$



Batch Reactor

$$\text{Irradiance} = \frac{\text{Incident power (W)}}{\text{Exposed area (m}^2\text{)}}$$

	Flow rate (m^3/h)	HRT (s)	Irradiance (mJ/cm^2)	Exposed area (cm^2)	Power (W)
Batch reactor	0,00E+00	600	2,81E+07	3,6	150
Flow reactor	1,08E+00	5	2,50E+01	100	0,5
	9,00E-03	**600**	**3,00E+03**	100	0,5
	1,00E-06	5400000	**2,70E+07**	100	0,5
	8,00E-04	6750	1,01E+07	100	**150**



Flow Reactor

Flow reactor → irradiating with 0.5 W vs. 150W → 100 cm^2 vs. 3.6 cm^2 → lower irradiances

Highlights

- **COLFEED's high-tech feedstock** for MTE 3D printing of photocatalytically active membranes **has been validated in the scalability and printing of custom geometries tested** in a flow reactor at AQUALIA's pilot plant.

- **From the design** of the geometries and their optimization we **can improve the catalytic activity without compromising** too much the **fluid dynamic problems** that the tested membranes may cause.

- The prepared **co-catalytic structures** show **better degradation rates** in the degradation of the studied pollutants **than the catalytic heterostructures**.

- Therefore, **we have achieved a geometry that gives good catalytic yields** for the AQUALIA flow reactor **and good stability results** in the different media and tests.

Our Team



Dr. Juan A Escribano
CEO, Chemist, MBA
BD | Finance | Sales



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Material Sci. & Tech.
Printing Service | Junior Researcher



Esther Miguélez
Lab. Analysis & Quality Control
Production | Quality Control



Dr. Hossein Besharatloo
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R&D NEOTEC



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colloidal processing



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colloidal processing



Dr. Zoilo González
Chemistry Sci. & Eng.
PM | Functional Mat.



Dr. Joaquín Yus
Material Sci. & Tech.
PM | Sea Materials

50% of the founding partners are members of the research group, with an additional 10% from our CEO and the remaining 40% from external investors.

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Technological Spin-off from CSIC

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ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

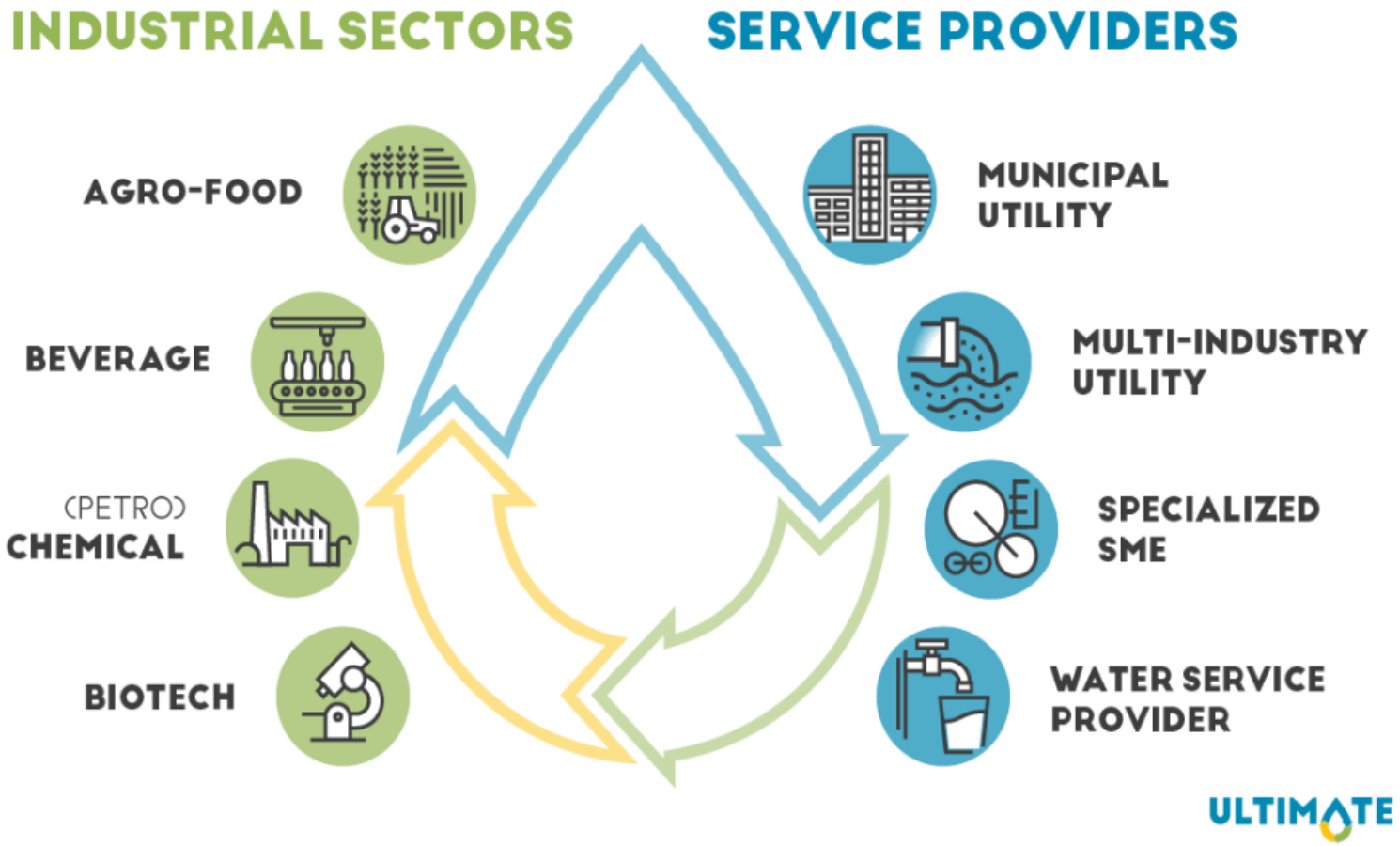
Industry water utility symbiosis for a smarter water society: webinar on biogas technologies

A. Kleyböcker, C. Bruni and A. Naves Arnaldos



May 31st 2023

WATER SMART INDUSTRIAL 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

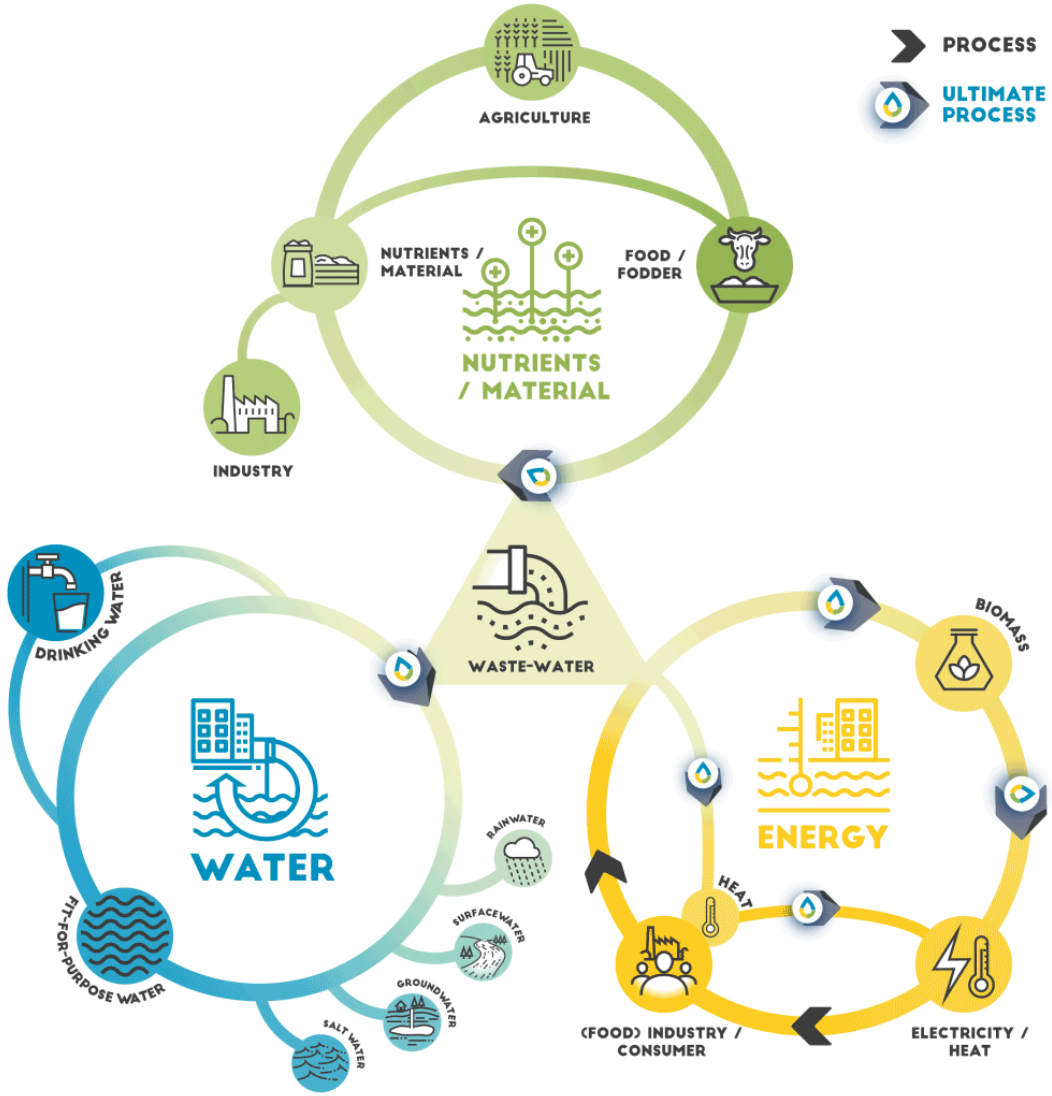
Coordinator: KWR

9 Case Studies



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



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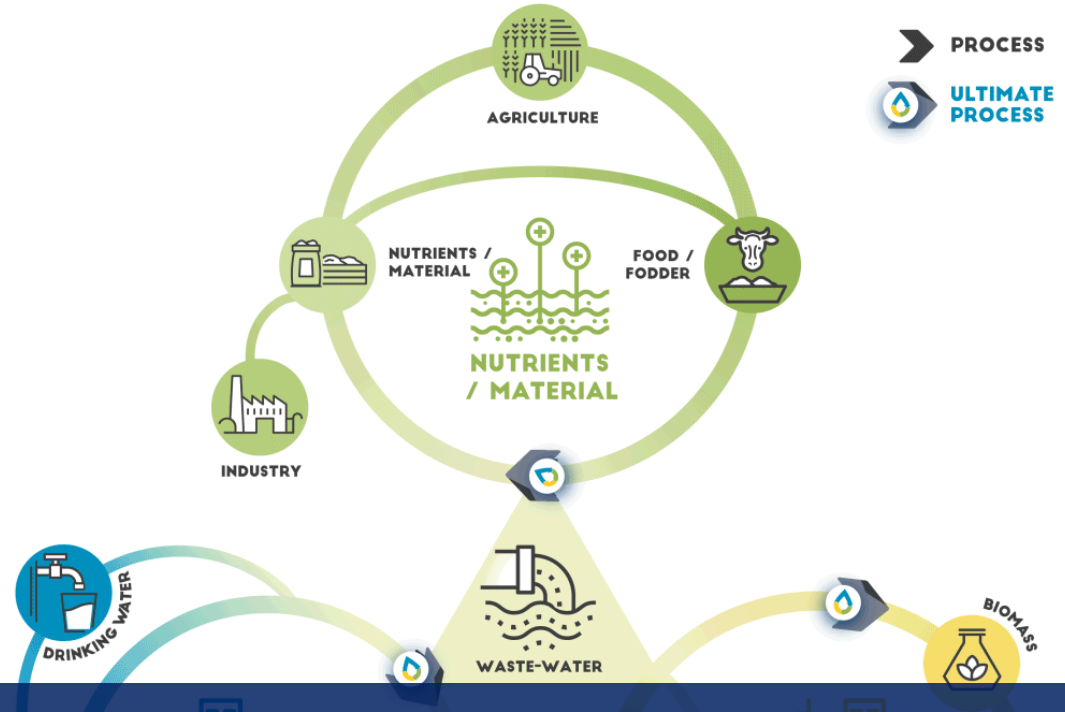
Ultimate solutions involve circular economy technologies



- Membrane technologies
- Adsorption technologies
- Electrostimulated systems

- 22 pilot plants
- 3 control and/or early warning systems
- 6 concept studies

- Biogas technologies
- Heat recovery
- Digitalization

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Water recovery:
8 of 8 pilot plants are operational

Membrane technologies

- Reverse osmosis + membrane distillation
- Novel ultrafiltration membrane (UF) + RO
- Nanofiltration (NF) + RO
- Small bioreactor platform (SBP)

Adsorption technologies

- Zeolite column for NH_4 removal
- Recovery of polyphenols/antioxidants

Monitoring and matchmaking system

- to avoid high chloride concentrations in reclaimed water

Other systems

- Electrodialysis for removal of salts
- Advanced oxidation processes

UF & RO

Zeolite column

Electro-dialysis

Monitoring & matchmaking system

SBP

AOP

RO











Material recovery:
6 of 7 pilot plants are operational

Nutrients:
- Ammonium and phosphate rich water
- Ammonium sulphate
- Struvite

High added-value products:
- Antioxidants
- Polyphenols

Adsorption material
- Production via thermal carbonisation: not feasible
- Reuse of byproducts as adsorption material

Electrodialysis



Adsorption system using byproducts



Adsorption of antioxidants



Adsorption of polyphenols



$(NH_4)_2SO_4$ production



Struvite production



Energy recovery:
6 of 7 pilot plants are operational

Biogas production technologies

- Anaerobic membrane bioreactor (AnMBR)
- Electrostimulated anaerobic reactor (ELSAR)
- Immobilised high rate anaerobic reactor (AAT)
- AAT combined with AnMBR and PAC

Biogas valorization

- Solid oxide fuel cell

Heat recovery system

- from AnMBR effluent

AAT



AnMBR



ELSAR



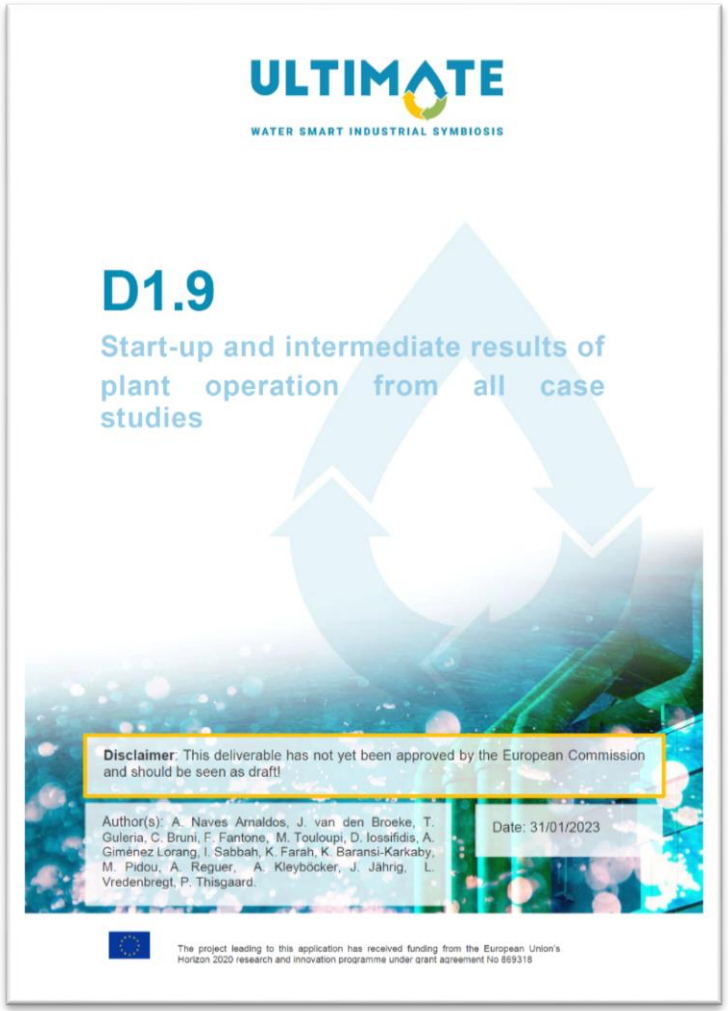
SOFC



AAT + AnMBR



Report about pilot plants (Jan. 2023)



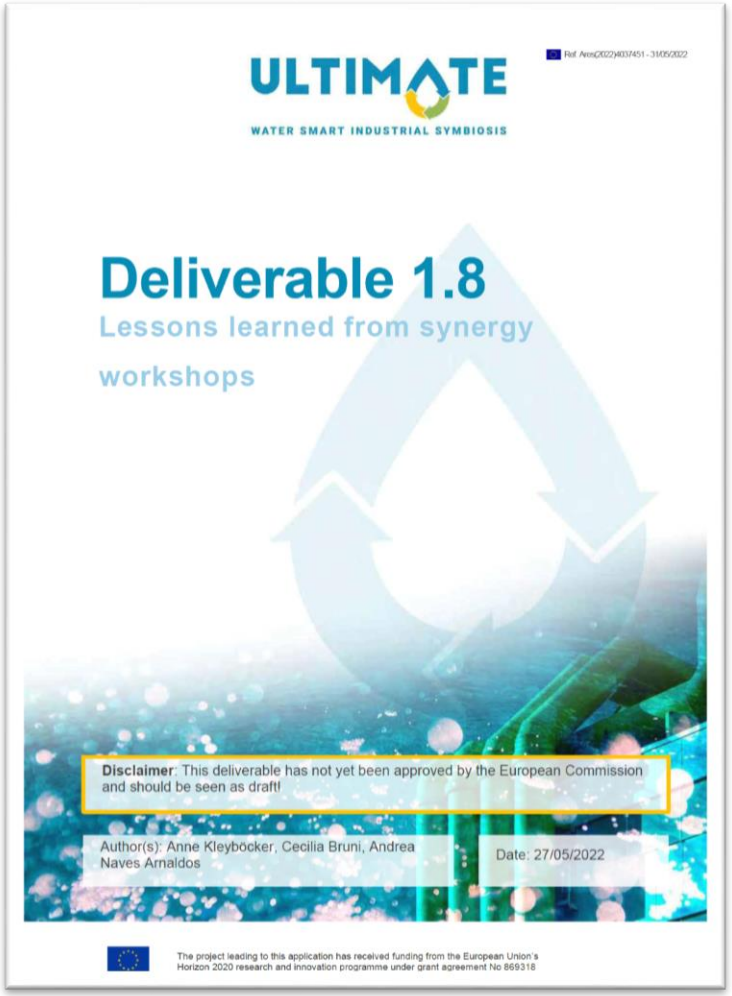
- **Start-up of pilot plants**
- **Intermediate results**

→ Accessible at:

https://ultimatewater.eu/results/

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

Report about synergy workshops (May 2022)



- Membrane & adsorption technologies
- Biogas& heat recovery systems
- Material & nutrient recovery systems
- Digitalisation
- Secret of sucessful symbioses

→ Accessible at:

https://ultimatewater.eu/results/

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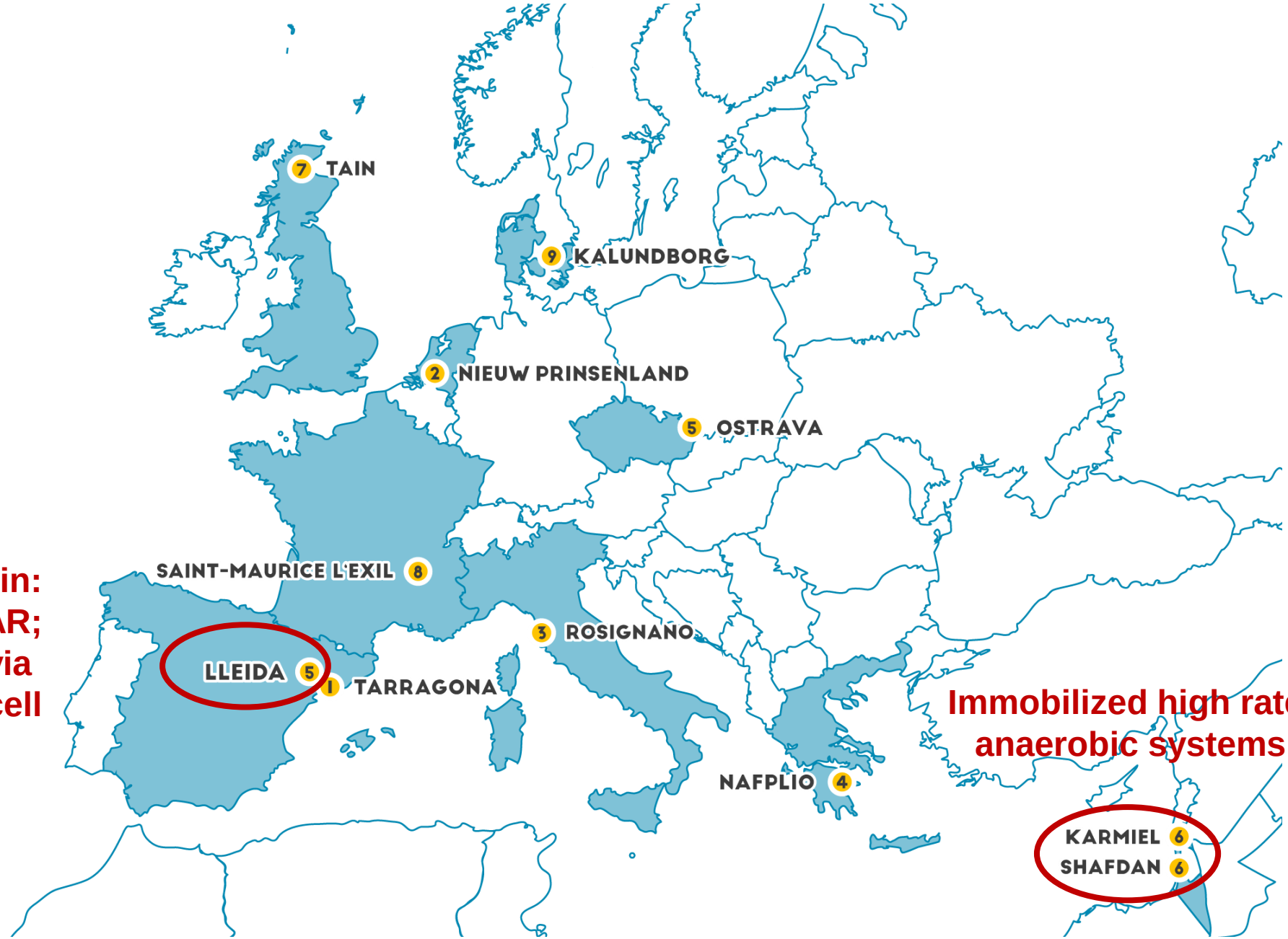
Today

Biogas production in: AnMBR & ELSAR; Biogas utilization via solid oxide fuel cell

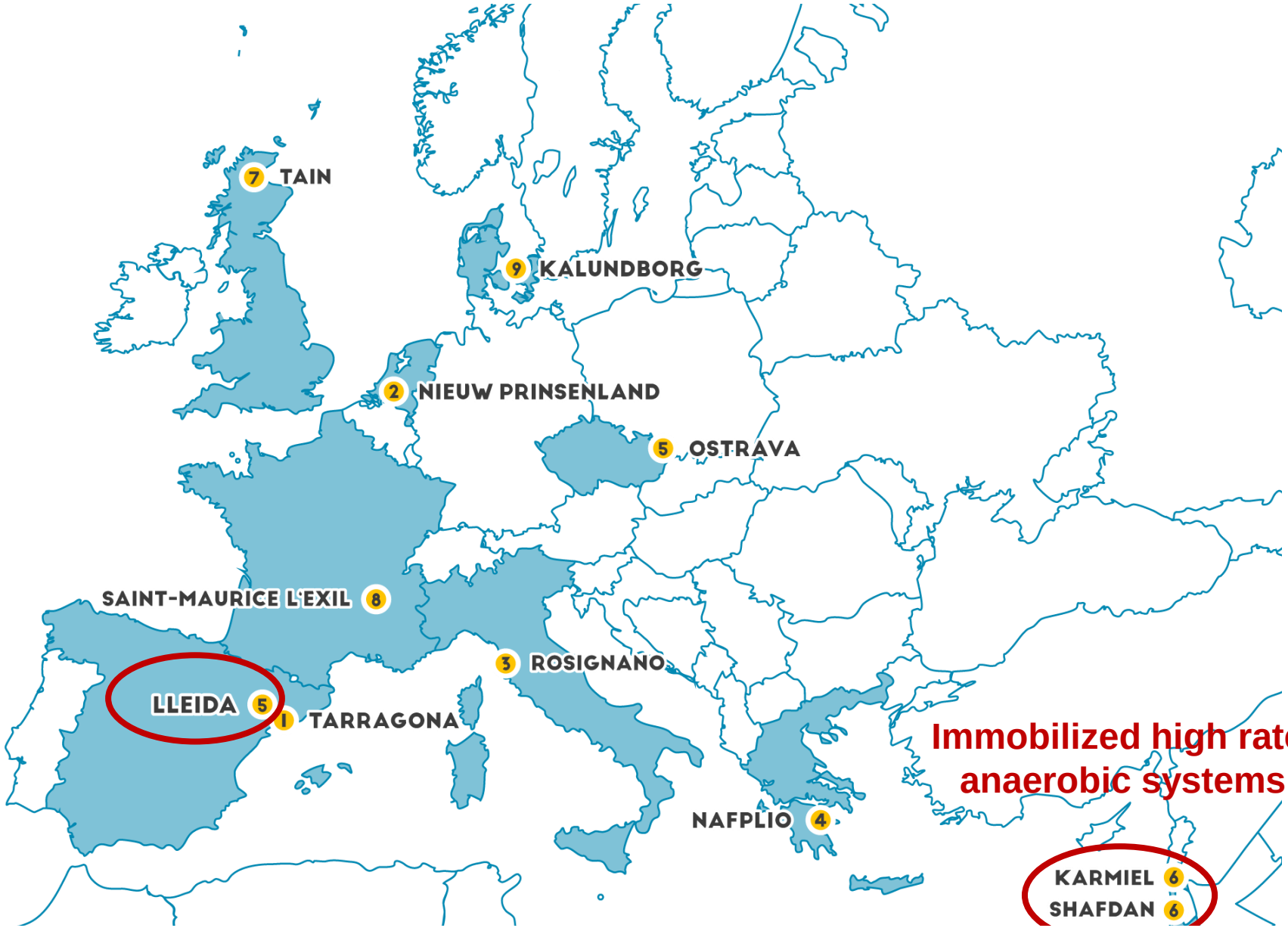


Immobilized high rate anaerobic systems

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

Today

Biogas production in:
AnMBR & ELSAR;
Biogas utilization via solid oxide fuel cell



Immobilized high rate anaerobic systems

Special guest:

wider uptake

Utilizing biogas in a natural gas grid

Agenda

13:00	**Welcoming & relevant news for all CS** *Anne Kleyböcker (KWB)*
13:10	**Biogas production and valorization in CS5 Lleida**: Anaerobic membrane bioreactor (AnMBR) versus electrostimulated anaerobic reactor (ELSAR) & solid oxide fuel cell (SOFC) using biogas to produce electricity and heat *Antonio Giménez Lorang (FCC Aqualia)*
13:30	**Biogas production in CS6 Shafdan & Karmiel**: Immobilized high rate anaerobic system (AAT) & biogas process stabilizing measures (PAC) *Isam Sabbah (The Galilee Society)*
13:50	**Break**
14:00	**Wider-Uptake:** Utilizing biogas from sludge digestion in a natural gas energy grid in Norway *Lene Anita Opsal Beadle (IVAR)*
14:20	**Discussion**
15:00	**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. Based in the recording, we will prepare detailed minutes of the meeting including all the questions of the participants and our answers.

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ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

Biogas production and valorization in CS5 Lleida:

AnMBR vs. ELSAR® & SOFC, using biogas to produce electricity and heat

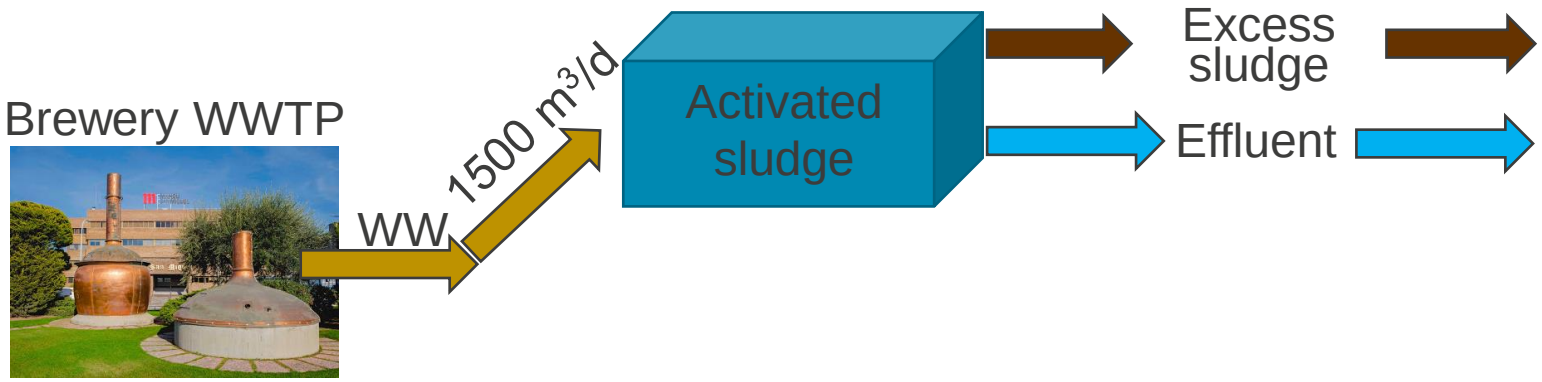
A. Giménez-Lorang

aqualia



31.05.2023

Case study nr. 5: baseline conditions



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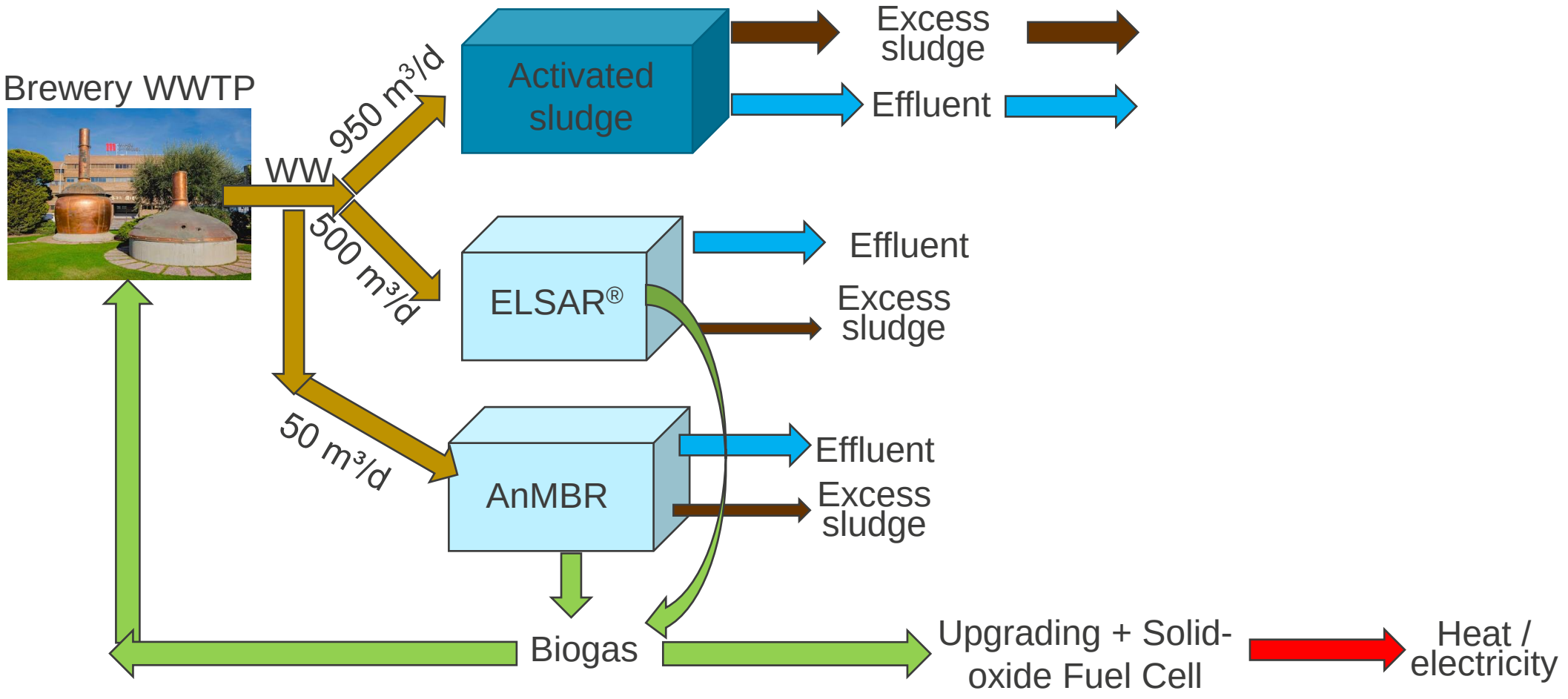
Case study nr. 5: ULTIMATE water-smart solution



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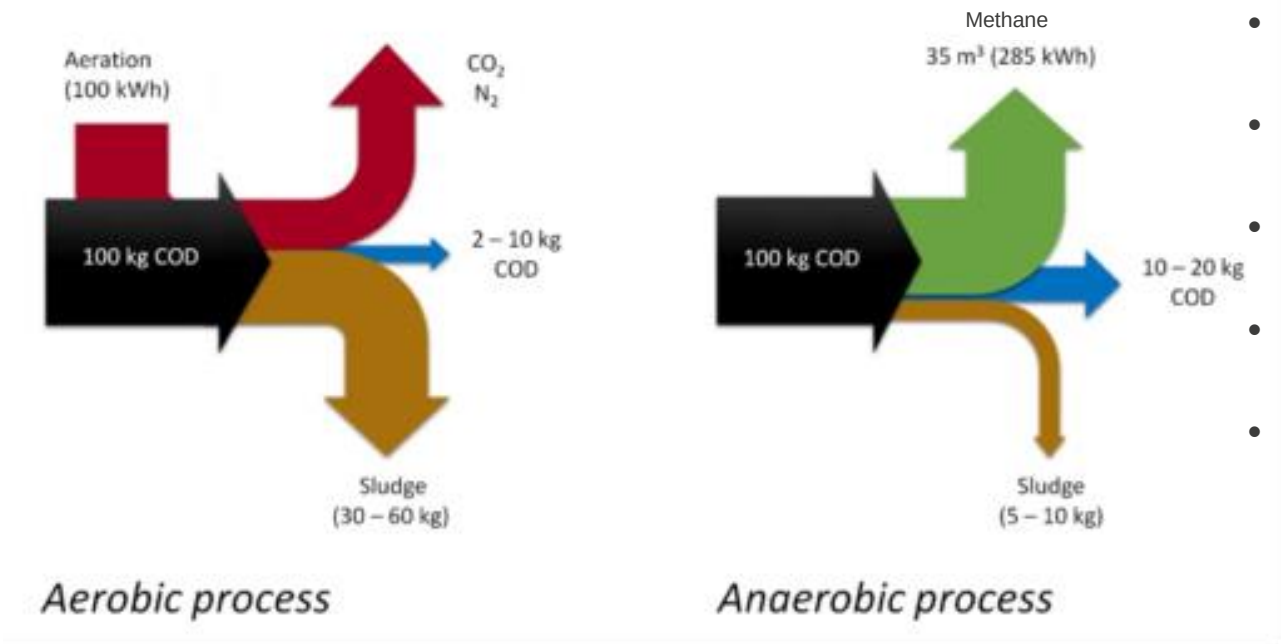
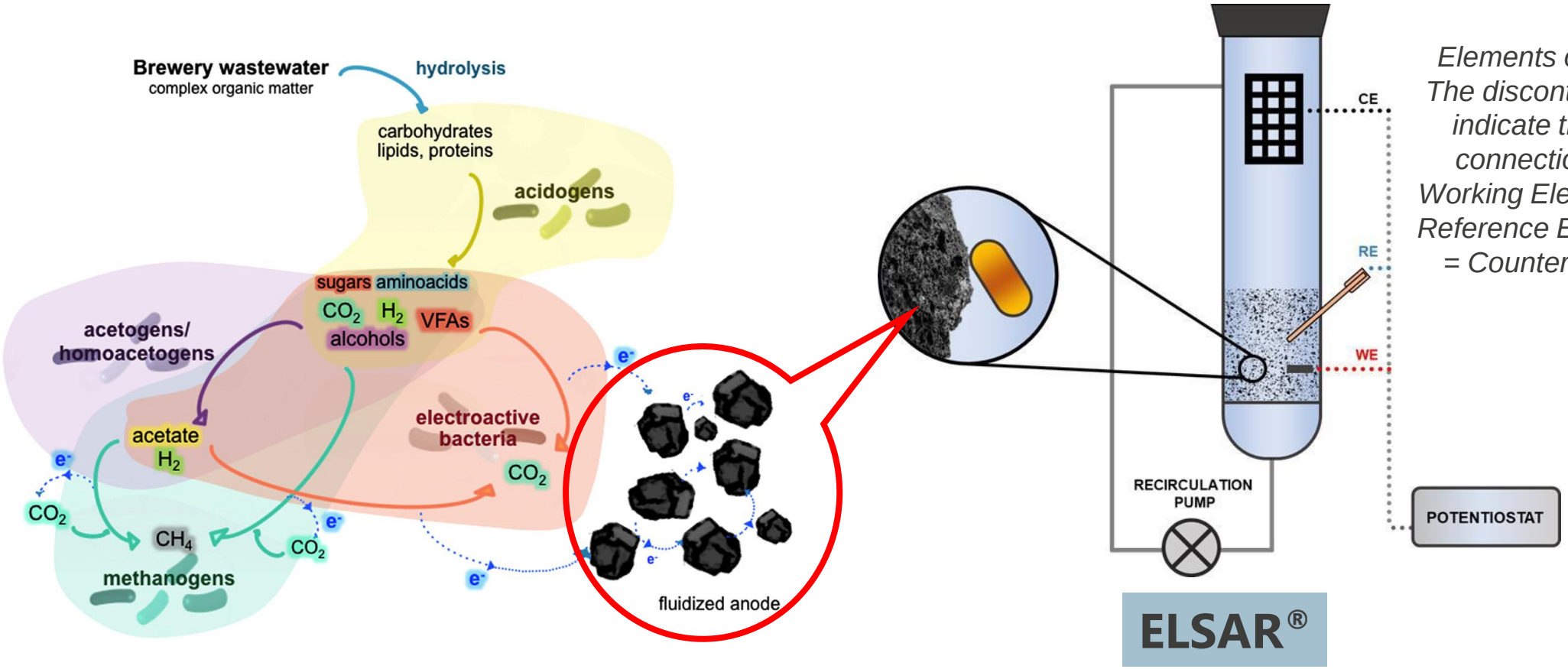
Why anaerobic?



- Less sludge production
- Biogas generation
- Low nutrient requirements
- Compact (in iWW context), HRT<6h
- No aeration needed

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

Definition of ELSAR®



Elements of ELSAR®. The discontinuous lines indicate the electric connections. WE = Working Electrode. RE = Reference Electrode. CE = Counter Electrode.

Schematic of the different anaerobic communities that might coexist within the ELSAR® and the possible competitive reactions among them for the electron donors. Adapted from Tejedor-Sanz *et al.*, 2018

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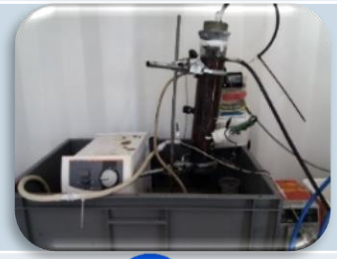
The path to market of ELSAR®*

**Method for treating wastewater in a fluidized bed bioreactor* (Ref. EP 2927196 A1).

	Lab-scale FBBR	Pre-pilot	Prototype	Demo	Pre-industrial
Technical features	• **TVR 1,2L** • Brewery WW • CC: graphite plate + SS mesh / SS sponge	• **TVR 5,4L** • Brewery WW • CC: graphite plate + SS sponge	• **TVR 450L** • Brewery WW	• **TVR 1m^3** • Urban WW • CC: carbon fiber structure + SS sponge	• **TVR 140m^3** • Brewery WW • CC: carbon fiber structure + SS structure • Q 20 $m^3 \cdot h^{-1}$; • OLR 2.000 $kgCOD \cdot L^{-1}$
Running years	2013-2014	2018	2019	2020-2021	2023
Picture					
Financing Project	ITACA	ANSWER	ANSWER	ADVISOR	ULTIMATE
Main goal	Optimization of operational para-meters and design	ELSAR® vs. AFBR. Competitive advantages	Long-term operation (20 months)	Operational environment and low-strength WW.	Operational environment and high-strength WW.

*TVR = **T**otal **V**olume **R**eactor; ELSAR = **EL**ectro-**S**timulated **A**naerobic **R**eactor; WW = wastewater; FBBR = **F**luidized **B**ed **B**io-**R**eactor ; AFBR = **A**naerobic **F**luidized **B**ed **R**eactor; CC = current collector*

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Evaluation of bioelectrochemical parameters of ELSAR®: high OLR need high anode potential

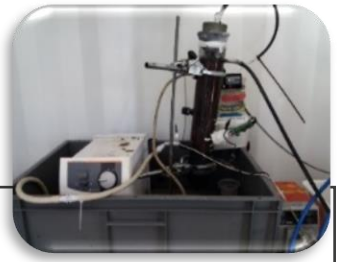
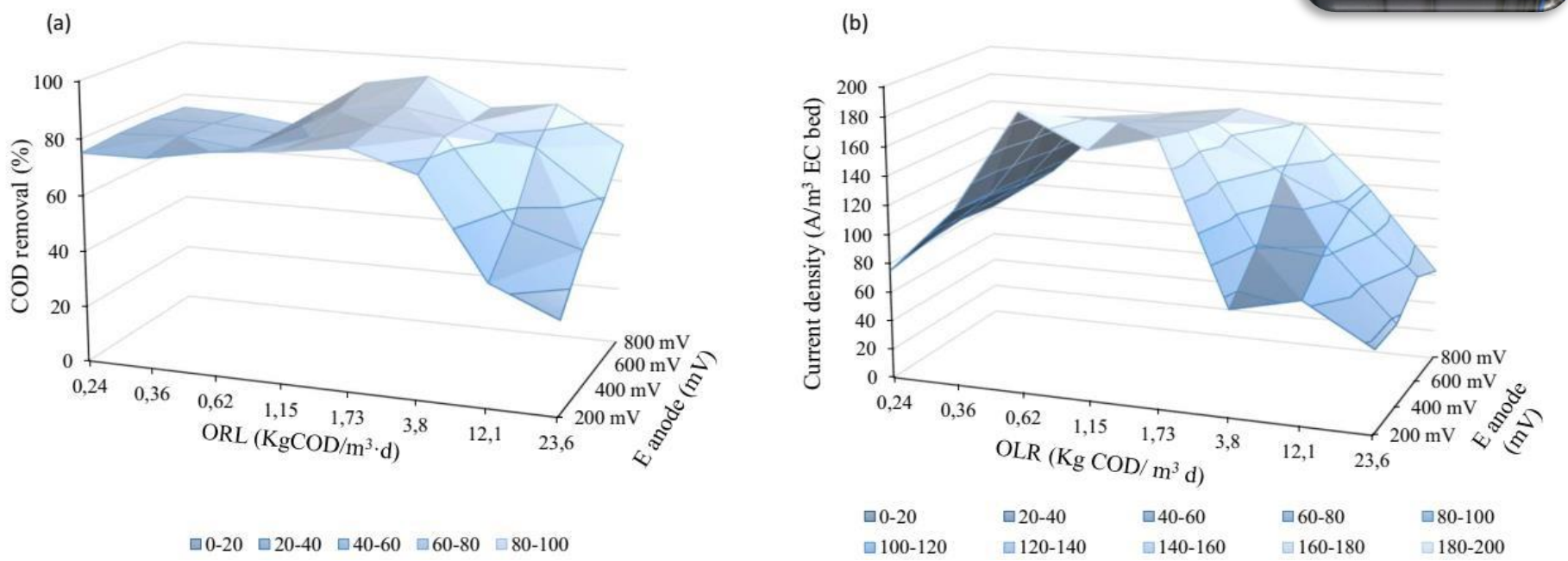


Table. Inlet stream composition.

PARAMETER	BREWERY WW
Conductivity [mS·cm^{-2}]	2.7 ± 0.2
COD [mg·L^{-1}]	2947 ± 139
Total nitrogen [mg·L^{-1}]	58.2 ± 11.2
Total phosphorous [mg·L^{-1}]	17.2 ± 2.1



(a) COD removal output as a function of the organic matter loading rate (OLR) and fluidized anode potential
(b) Current density.

OLR = Organic Loading Rate

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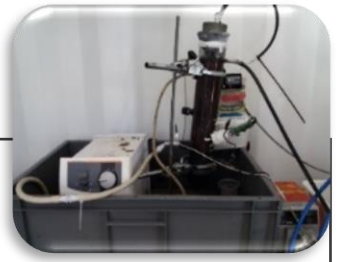
Evaluation of bioelectrochemical parameters of ELSAR®: low energy consumption



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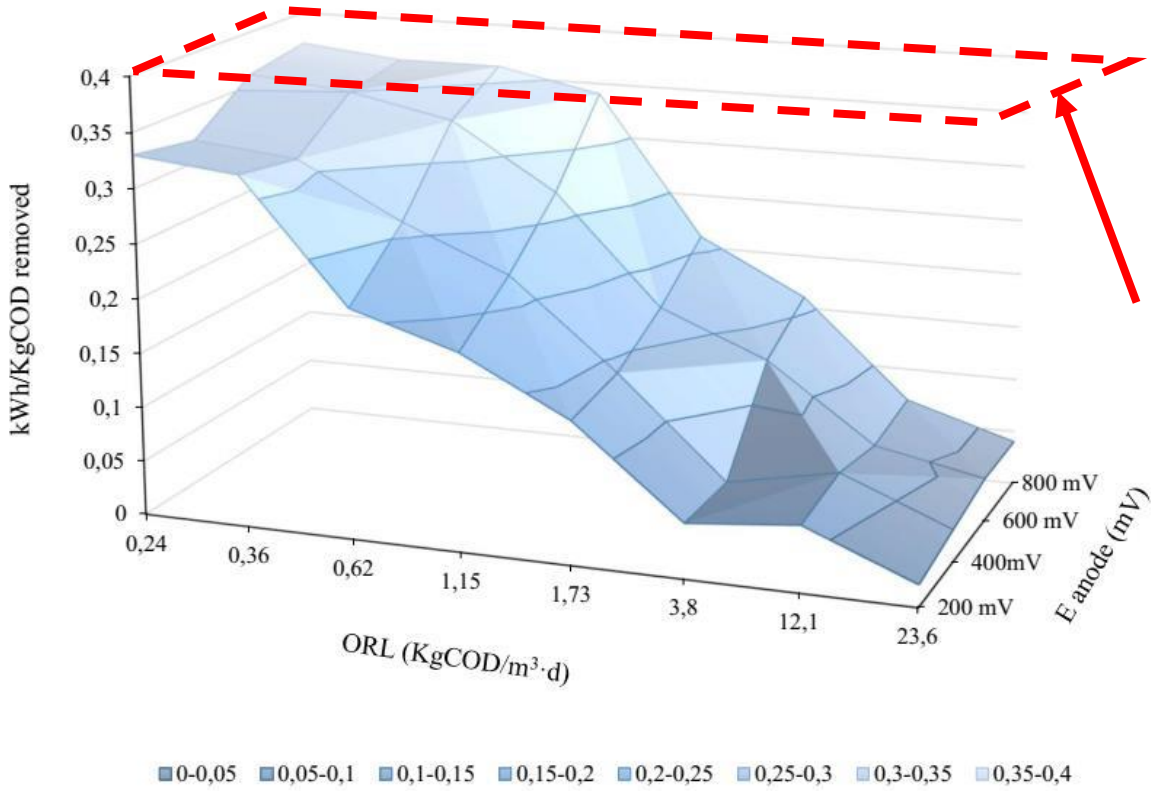

Usual value for conventional activated sludge systems = 0,4 kWh/ kg COD removed

Energy consumption per organic matter removed for the OLR and anode potentials tested. OLR = Organic Loading Rate

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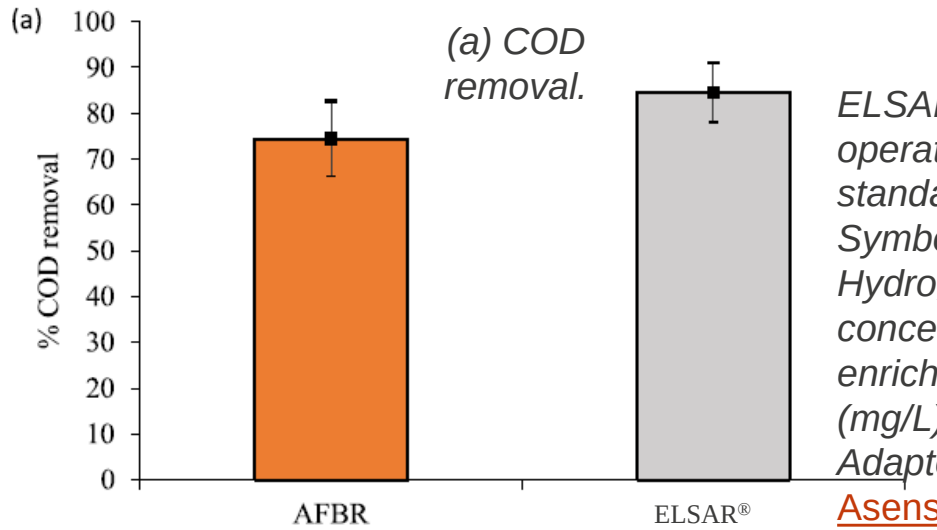
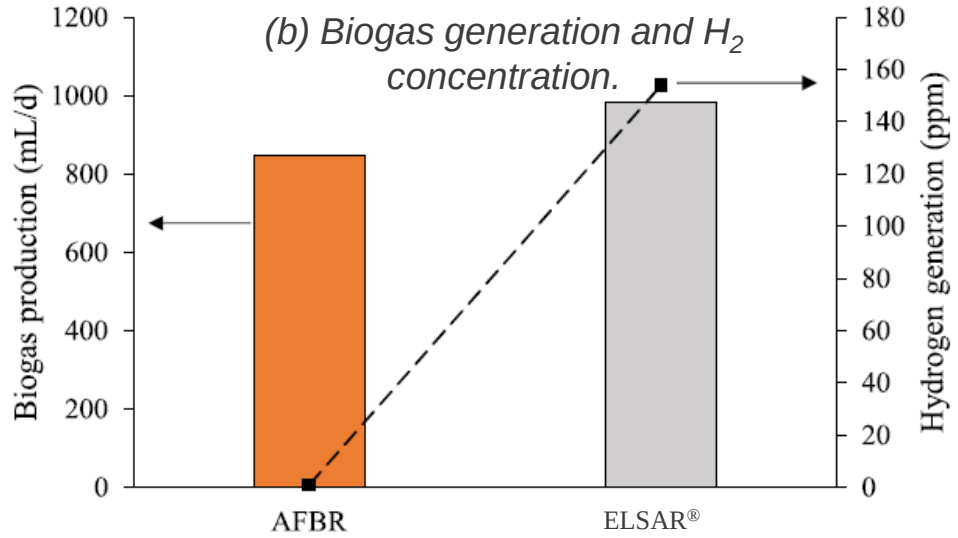
Competitive advantages of ELSAR® vs. conventional anaerobic fluidized bed reactor (AFBR)





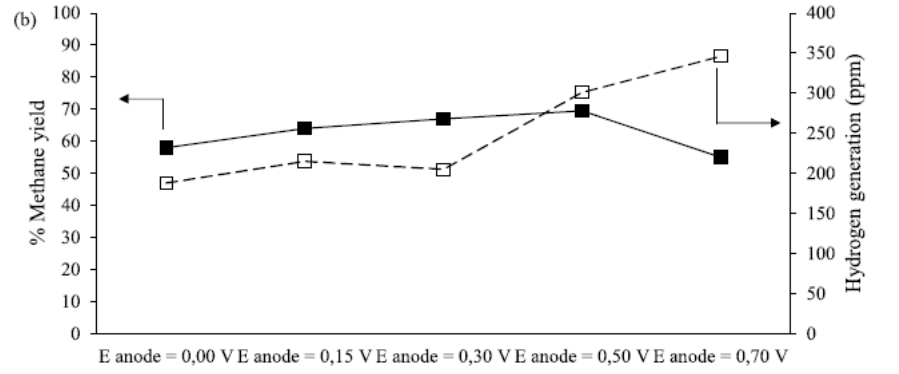
(a) COD removal.



(b) Biogas generation and H_2 concentration.

ELSAR® and AFBR operation during standard operation. Symbols: (■) Hydrogen concentration on the enriched biogas (mg/L).
Adapted from: Asensio *et al.*, 2021

Methane and hydrogen production in an ELSAR® reactor.
Adapted from: Asensio *et al.*, 2021



Highlights

- ELSAR® improves the wastewater treatment capacity of conventional AFBR.

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

Competitive advantages of ELSAR® vs. conventional anaerobic fluidized bed reactor (AFBR)

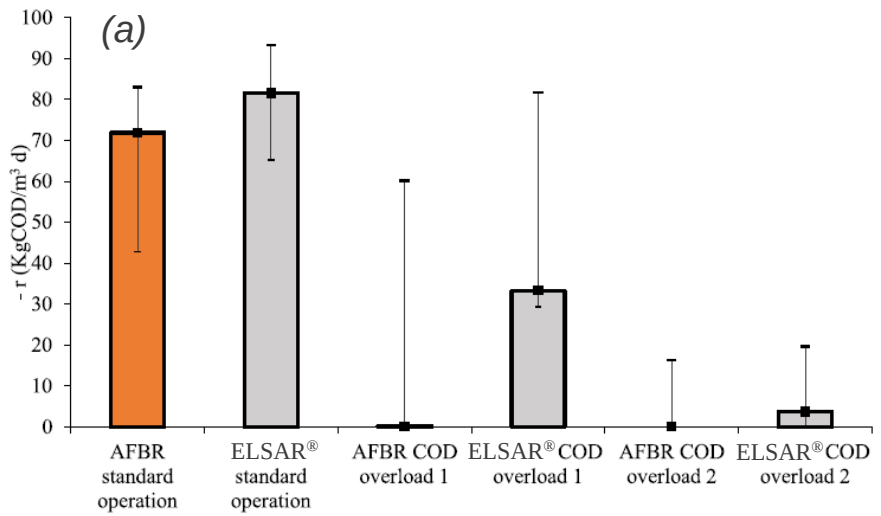


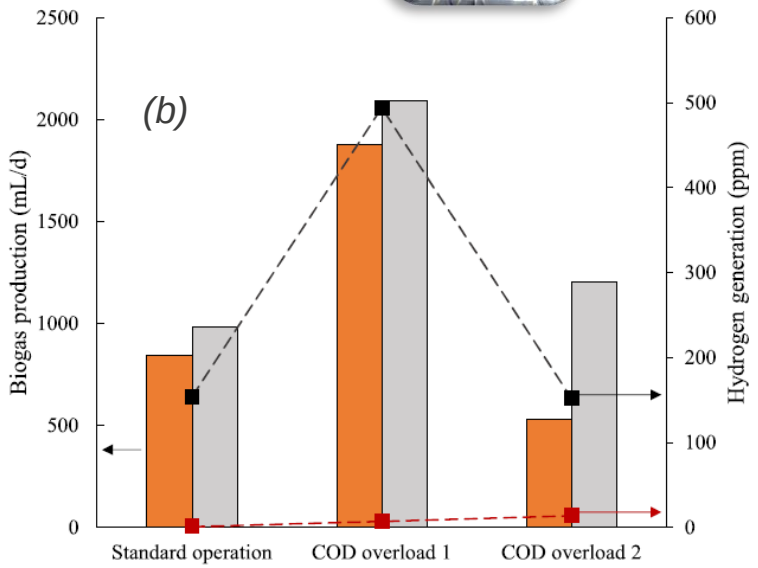
1. COD overload

2. Presence of biocides

3. Starving periods

4. Low Temperature





(a) COD removal rate under COD overloads of AFBR and ELSAR® reactors
(b) Biogas generation and hydrogen production.
(■) Hydrogen production during ELSAR® operation (mg/L)
(■) Hydrogen production during AFBR operation (mg/L).
Adapted from: Asensio *et al.*, 2021

Conditions	t [d]	OLR [kgCOD·m^{-3}·d^{-1}]	HRT [(h]
Standard operation	1- 31	7.10	9.0
COD overload 1	32- 38	27.2	
Standard operation	39- 52	6.0	
COD overload 2	53-59	51.2	

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Competitive advantages of ELSAR® vs. conventional anaerobic fluidized bed reactor (AFBR)



1. COD overload

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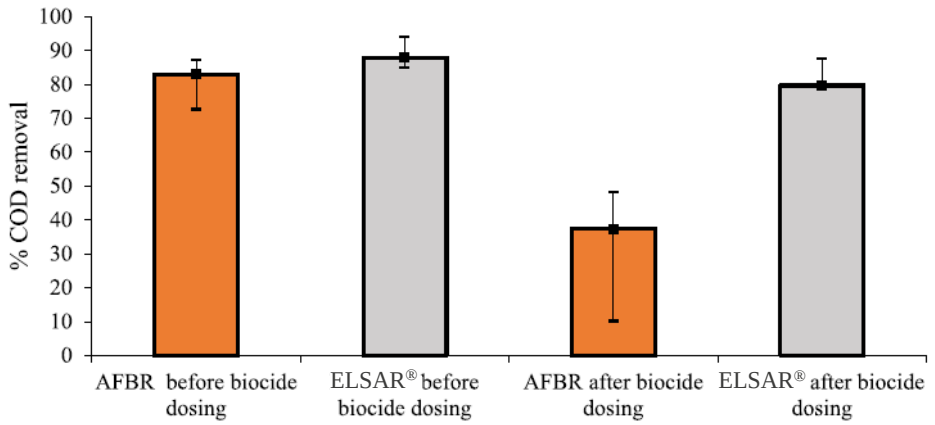

Conditions	t (d)
Standard operation	60- 72
Quaternary amines normally used as cleaning agent (DDAC, 5% $V_{biocide}$ / $V_{reactor}$)	73- 79

COD removal of AFBR and ELSAR® reactors before and after the biocide dosing. Adapted from: Asensio *et al.*, 2021

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Competitive advantages of ELSAR® vs. conventional anaerobic fluidized bed reactor (AFBR)



1. COD overload

2. Presence of biocides

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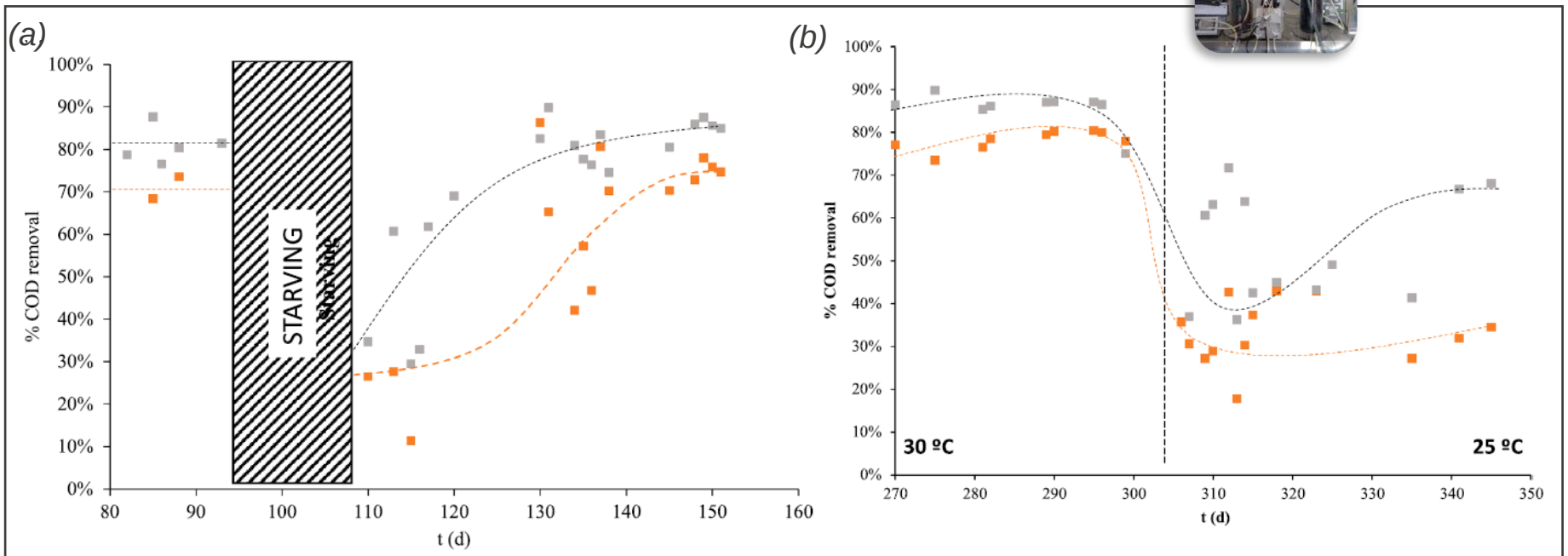
4. Low Temperature



(a) % COD removal of AFBR and ELSAR® reactors before, during and after a starving step.
(b) % COD removal of AFBR and ELSAR® reactors before and after low operational temperatures (25 ºC).
Adapted from: Asensio et al., 2021. Symbols: (■) AFBR, (■) ELSAR®.

Conditions	t (d)
Starving period	88–110
Low temperature (30ºC → 25ºC)	306-340

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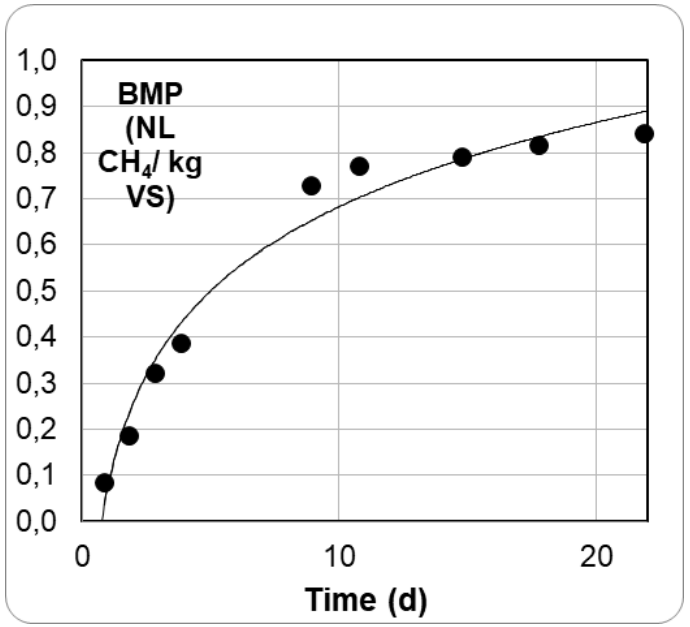
The next step: pre-industrial ELSAR®. Firts preliminary results.

- Exhaustive brewery wastewater characterization (1 month long)
- Biochemical methane potential (BMP) tests showing adequate anaerobic biodegradability. A potential of 0,31 Nm^3 CH_4/ removed kg COD was found. This result is consistent with other sources.
- Preliminary geotechnical study & basic design projects shows no technical limitations for proposed solutions (but certain need for foundation & civil works)



PARAMETER	AVERAGE ± STANDARD DEVIATION	UNITS
COD (stirred sample)	5586±1732	mg/L
COD (settled sample)	4674±1765	mg/L
NH4	3±3	mg/L
NO3	2±1	mg/L
Total N	64±23	mg/L
Total P	17±4	mg/L
Sulphates	158±32	mg/L
Sulphur	<1	mg/L
Conductivity	2551±627	µS/cm
Total alkalinity	19,3±6,6	meq/L
Partial alkalinity	8,8±4,4	meq/L
Intermediate alkalinity	12,9±3	meq/L
Volatile fatty acids	15±3,6	mg Ac/L
pH	6,67±0,96	-log[H^+]
Total suspended solids	199±99	mg/L
Volatile suspended solids	124±51	mg/L
% SSV	0,67±0,16	%
Settled solids	40±30	mg/L

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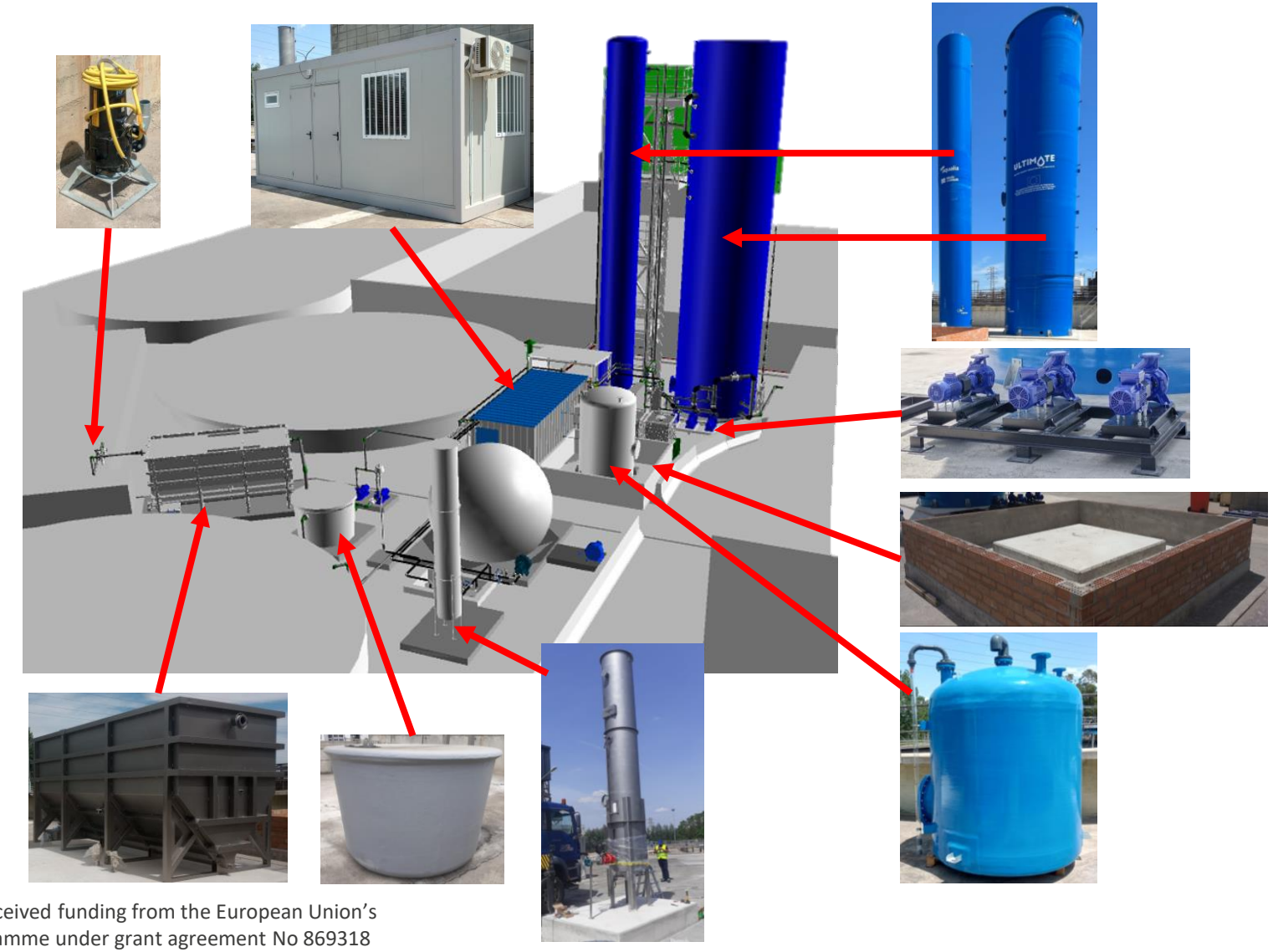
The next step: pre-industrial ELSAR®

- *Capacity*
  - *Brewery Wastewater*
  - *Flow 20 m^3/h*
  - *OLR 2.000 kg COD/d*
- *Reactor dimensions*
  - *Total Volume Reactor 140m^3*
  - *Ø 3,5m*
  - *Water height =15m*
  - *Mesophilic range (30 - 37ºC)*
- *Materials:*
  - *Tank: Glass-Fiber Reinforced Plastic*
  - *Anodic collector: carbon fiber*
  - *Cahtodic collector: stainless steel*
- *Expected results:*
  - *90% COD removal*
  - *30 Nm^3 of biogas/h*



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Previous results in pilot ELSAR®

ELSAR® pilot scale (1 m^3).

· Fed with brewery WW since Feb-2022



High OLR and pH fluctuation may have brought instability to the process

PARAMETER	UNITS	I	II
Electrostimulated?	Y / N	N	N
Temperature	ºC	36,3±0,3	35,6±2,2
pH	-log[H^+]	8,4±1,6	7,3±2,1
ORP	mV	-58,4±7,4	-55,9±26,8
OLR	kg tCOD/m^3/d	3,3±1,7	10±2,4
OLR	kg sCOD/m^3/d	3±1,5	8,6±2,1
tCOD removal	% tCOD	90,1±2,8	75,5±6,3
sCOD removal	% sCOD	93,9±1,2	81,9±6,8
VFA / Total Alkalinity	-	0,26±0	0,31±0,06
CH4 biogas content	%CH_4 v:v	82,1±2,2	78,9±6,2
CH4 productivity	Nm^3 CH_4/removed kg COD	0,35±0,21	0,26±0,06

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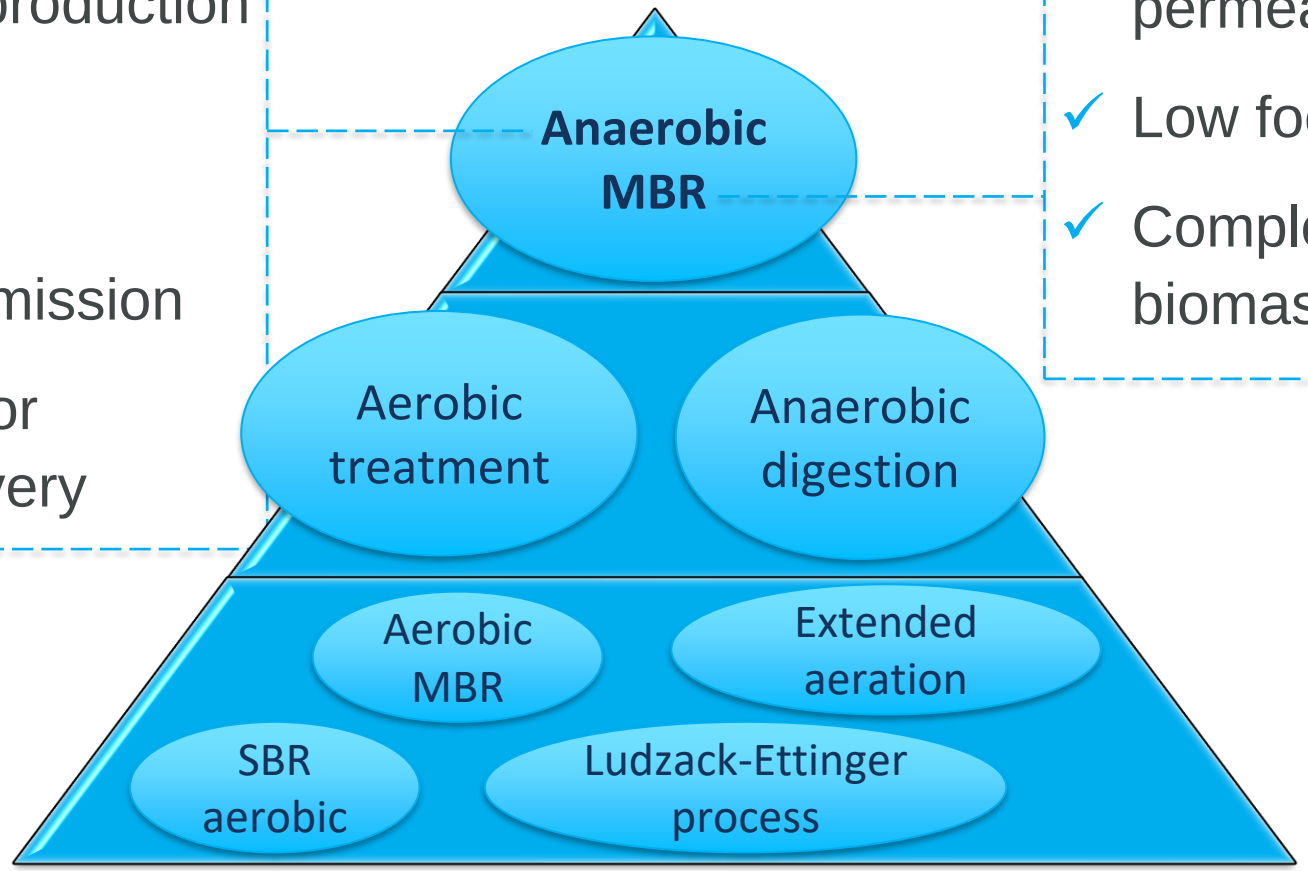
Why AnMBR? Potential benefits

- ✓ 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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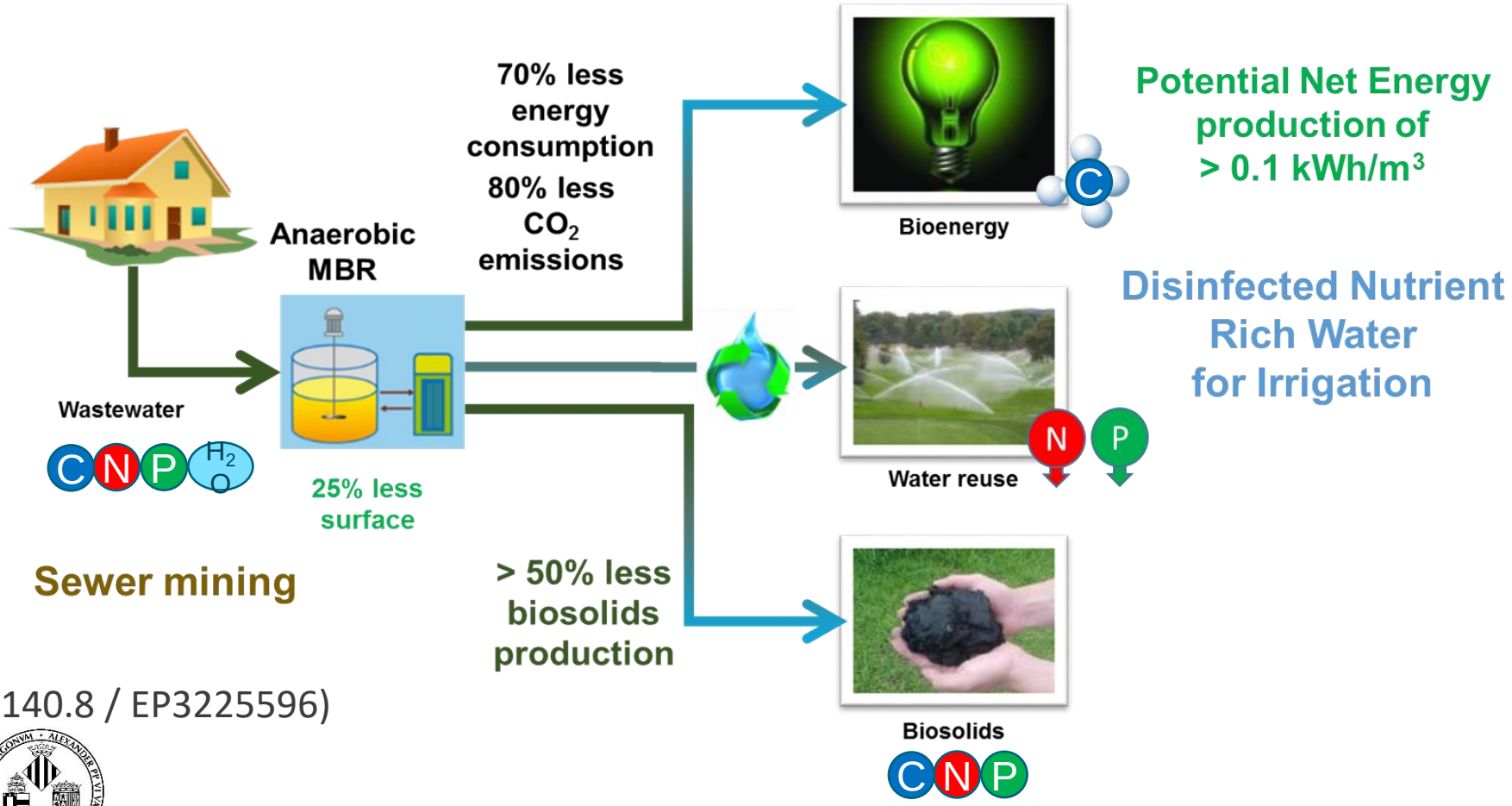
Why AnMBR? Potential benefits



Joint patent (EP16382140.8 / EP3225596)

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VNIVERSITAT DE VALÈNCIA

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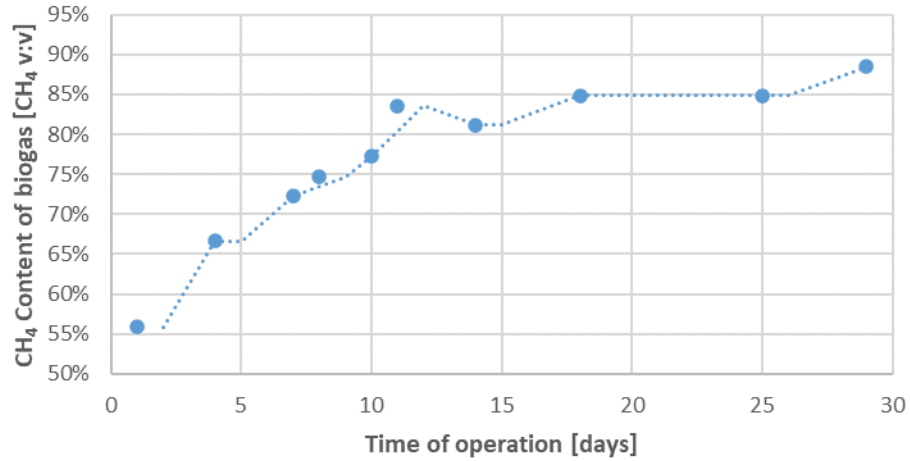
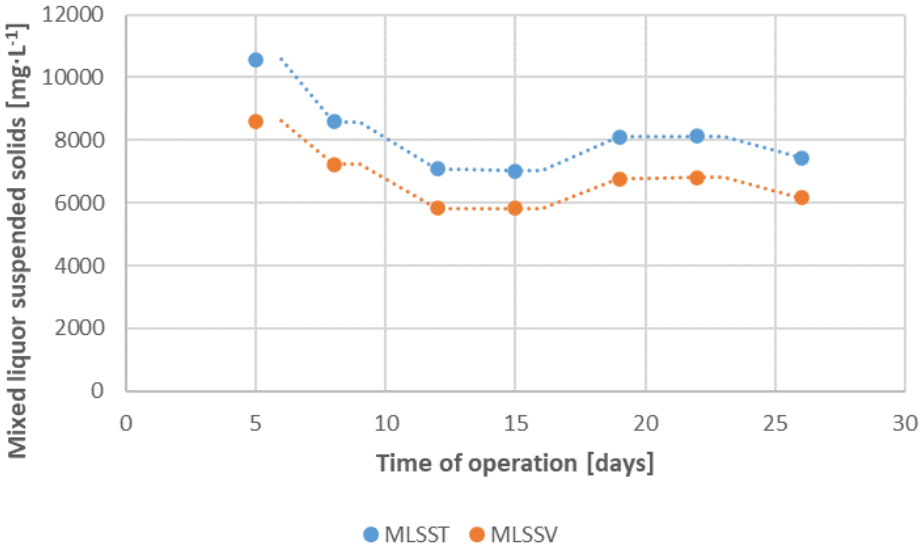
Some results of the AnMBR of CS5 fed with municipal WW, so far

PARAMETER	UNITS	Result
Flux 20ºC	L/m2/h	7,60±0,46
Temperature	ºC	20,9±1,3
pH	-log[H^+]	6,70±0,17
ORP	mV	-394±32
OLR	kg tCOD/m^3/d	0,55±0,21
tCOD removal (w/o CH_4 removal)	% tCOD	69,6±7,8
TMP	mbar	-256±73
CH_4 biogas content	%CH_4 v:v	82,1±2,2





→ Hot start-up successful

→ Starting to get stability

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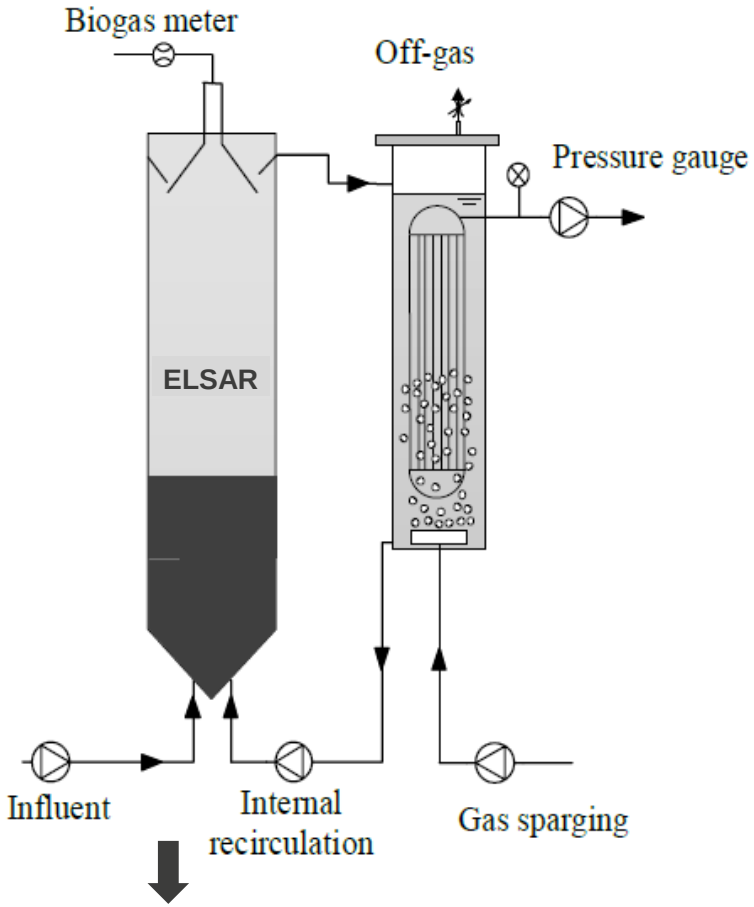
Approach of AnMBR in CS5: joining ELSAR® with MBR



Proposed granular AnMBR scheme for CS5 (adapted from Wang, 2018)

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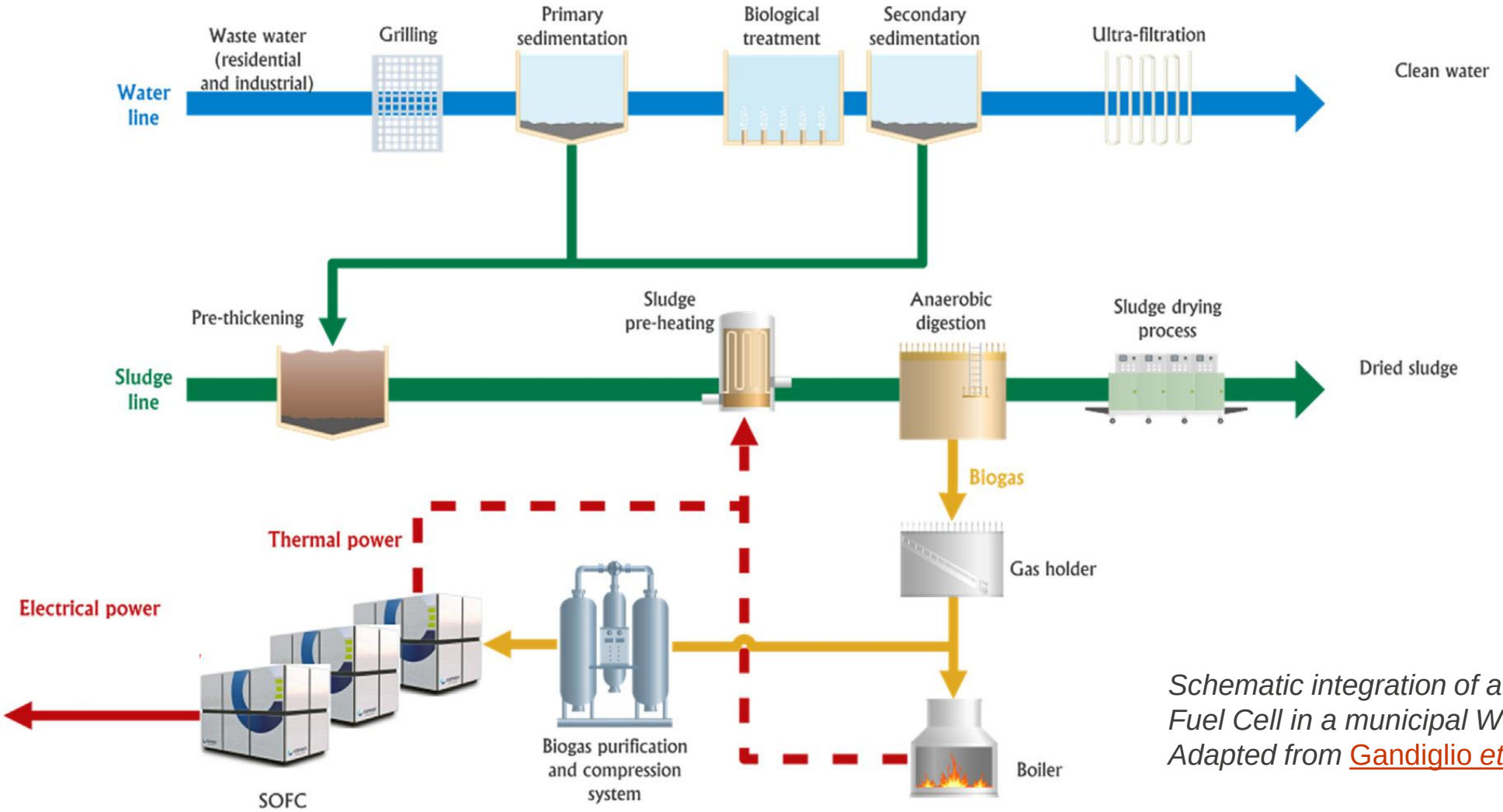
Solid Oxide Fuel Cells: an efficient way to obtain energy from biogas



Schematic integration of a Solid Oxide Fuel Cell in a municipal WWTP. Adapted from Gandiglio et al., 2020

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Solid Oxide Fuel Cells: fundamentals & potential

- Steam reforming

$$CH_4 + H_2O \rightleftharpoons 3H_2 + CO, \quad \Delta H^0_{298} = 206.3\,{}^{kJ}/_{mol}$$

$$CO + H_2O \rightleftharpoons H_2 + CO_2\,, \quad \Delta H^0_{298} = -41.1\,{}^{kJ}/_{mol}$$

- Partial oxidation → requires oxygen
- Dry reforming → requires high operating temperature (800–1000 °C) & higher proportion of CO_2

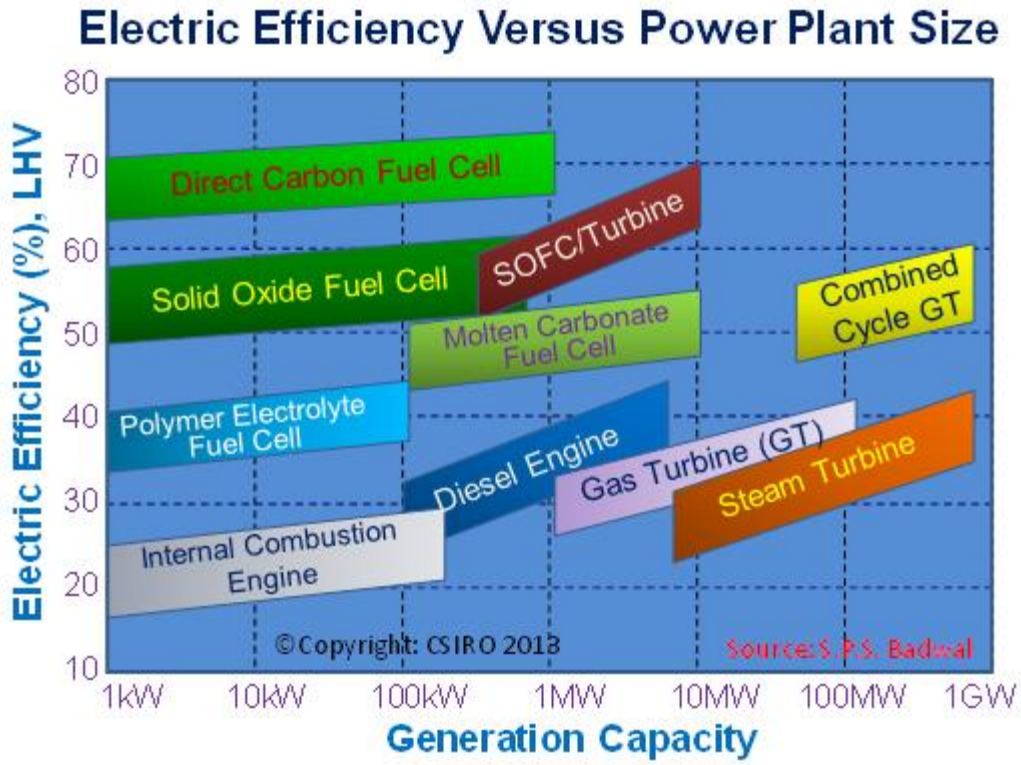

Figure. The electric efficiency versus power plant size for different power generation technologies. Source: https://csiropedia.csiro.au/ceramic-fuel-cells/

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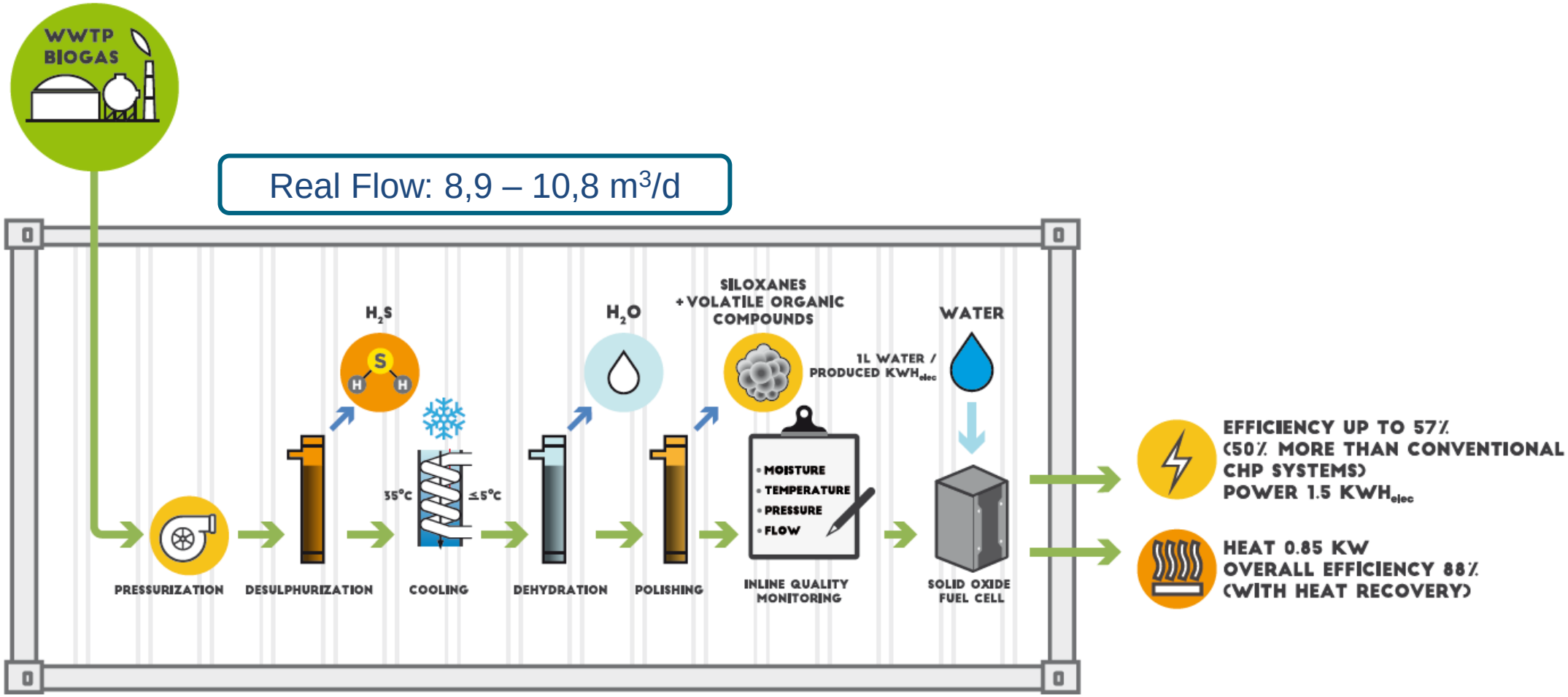
Solid Oxide Fuel Cells: experience in CS5



→ **Pre-treatment of biogas before entering the SOFC has been validated.**

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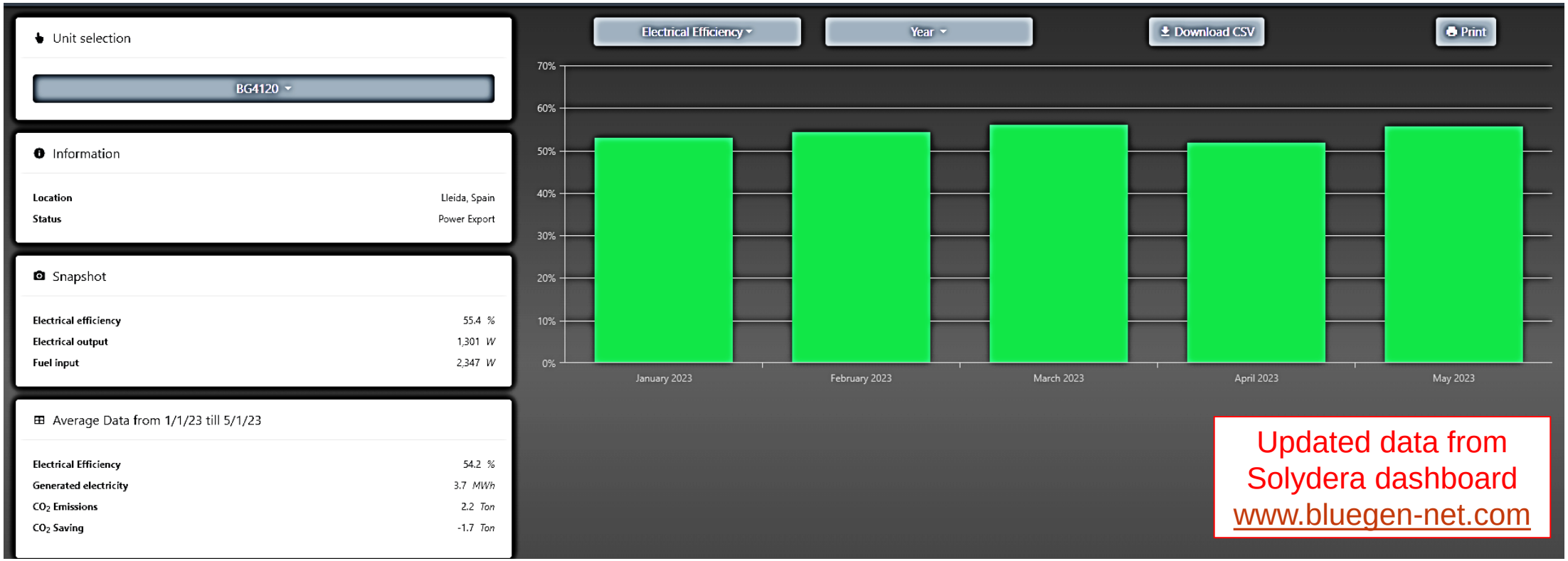

→ First 5 months of operation show a constant and expected output's behavior:

→ Constant electrical efficiency between 55.0 and 58.5%, confirming ca. +50% vs. conventional CHP

→ Produced power 1,3 kW (>3.7 MWh produced @ 15.05.2023)

→ Slight adjustments for optimization are still to be done: automatization, measuring, etc.

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ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

Biogas production and valorization in CS5 Lleida:

AnMBR vs. ELSAR® & SOFC, using biogas to produce electricity and heat

A. Giménez-Lorang

aqualia



31.05.2023

ULTIMATE

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, M. Hasanin, A. Aharoni, H. Raanan Kiperwas, D. Iossifidis, E. Bizani, C. Christophoridis, M. Touloupi



CS meeting on “Biogas Technologies”: May 31st, 2023

Symbiosis in Karmiel and Shafdan:



Current situation

Karmiel

30 K m³/d → Karmiel WWTP

Municipal / Agro-industrial WW and (demo scale AAT)

- Pre-treatment
- Primary clarifier
- Activated sludge
- Sand filtration

Shafdan

400 K m³/d → Shafdan WWTP

Municipal / Agro-industrial WW

- Pre-treatment
- Primary clarfier
- Activated sludge
- Tertiary treatment via SAT

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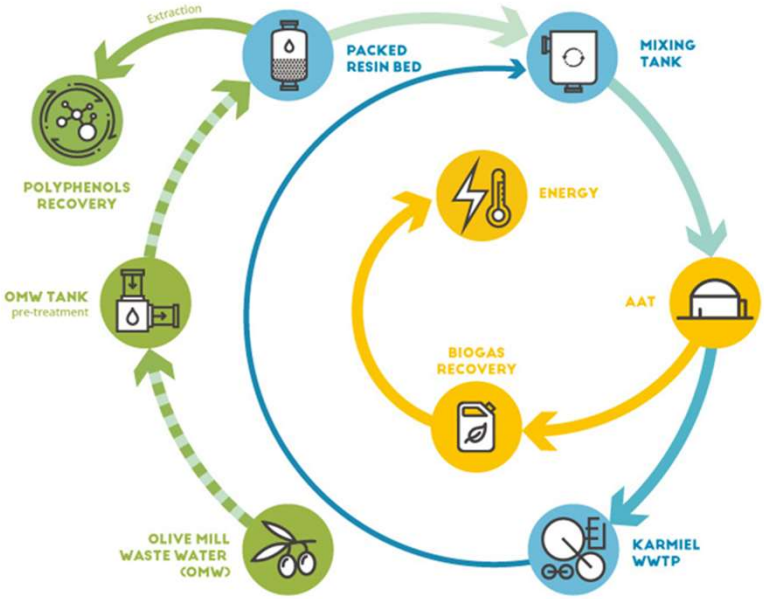
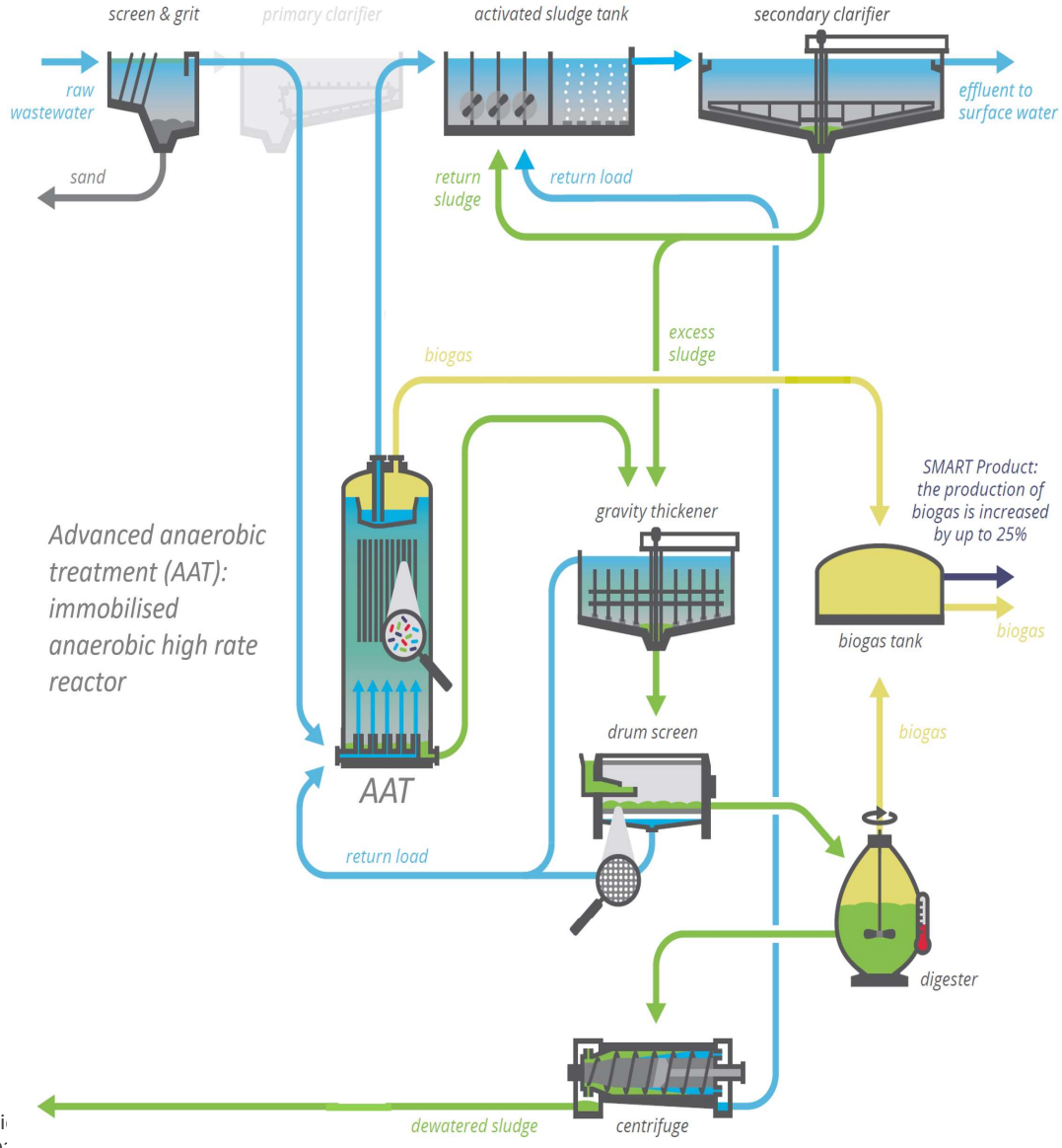
ENERGY - Task 1.3.3

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

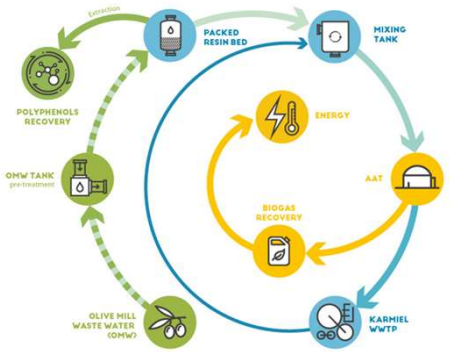




The project leading to this application has received funding from the European Uni
Horizon 2020 research and innovation programme under grant agreement No 869

ENERGY - Task 1.3.3

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

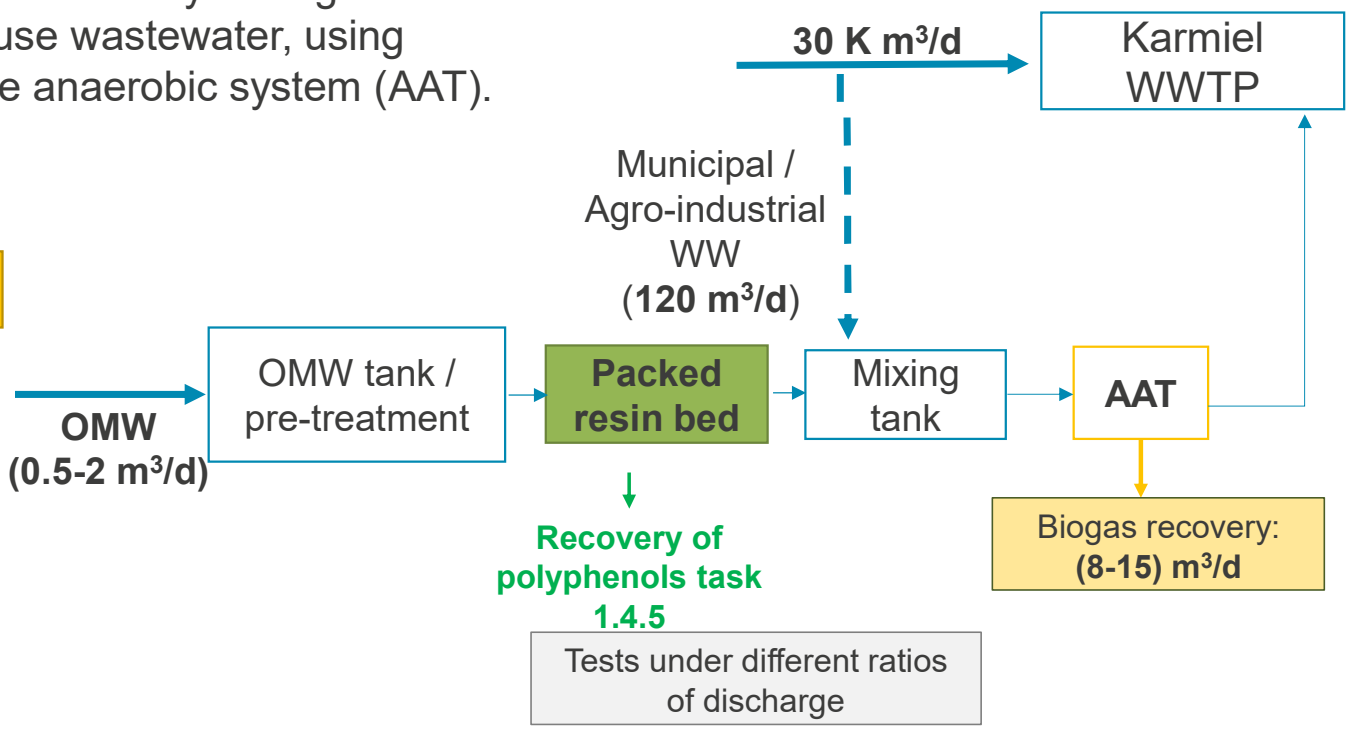


OBJECTIVE:

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).



Scenario 2



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 m³ CH_4/kg oDM

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





Polyfoam filling



Aim

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

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

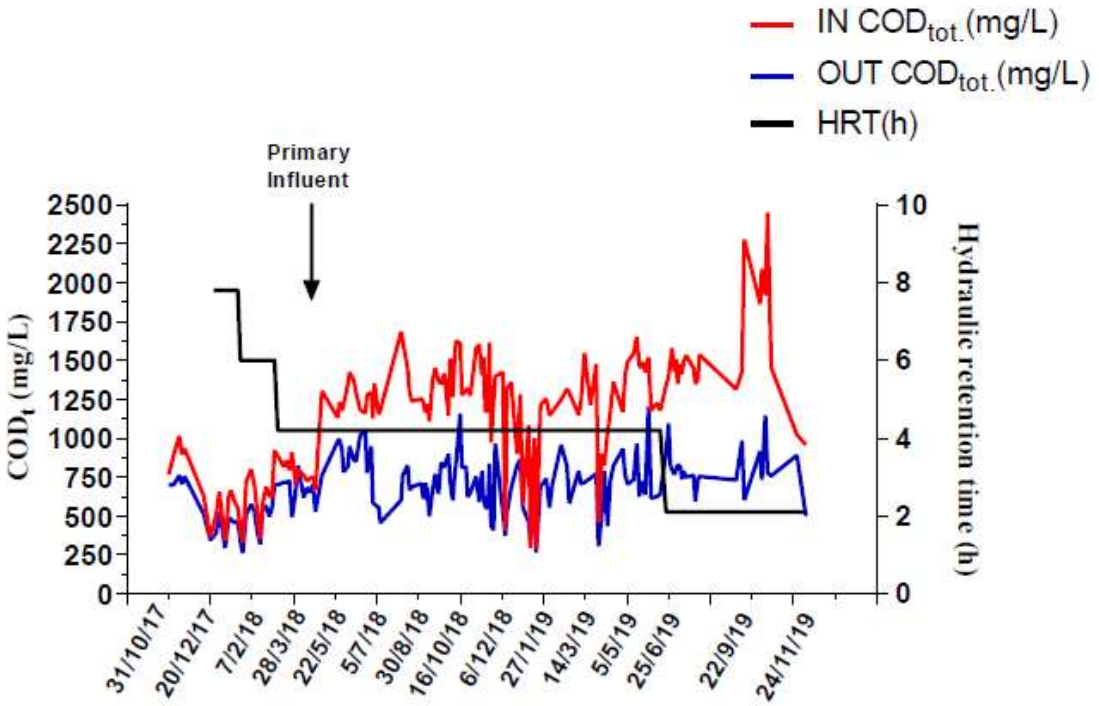
European Commission | Horizon 2020 European Union funding for Research & Innovation

Operation

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

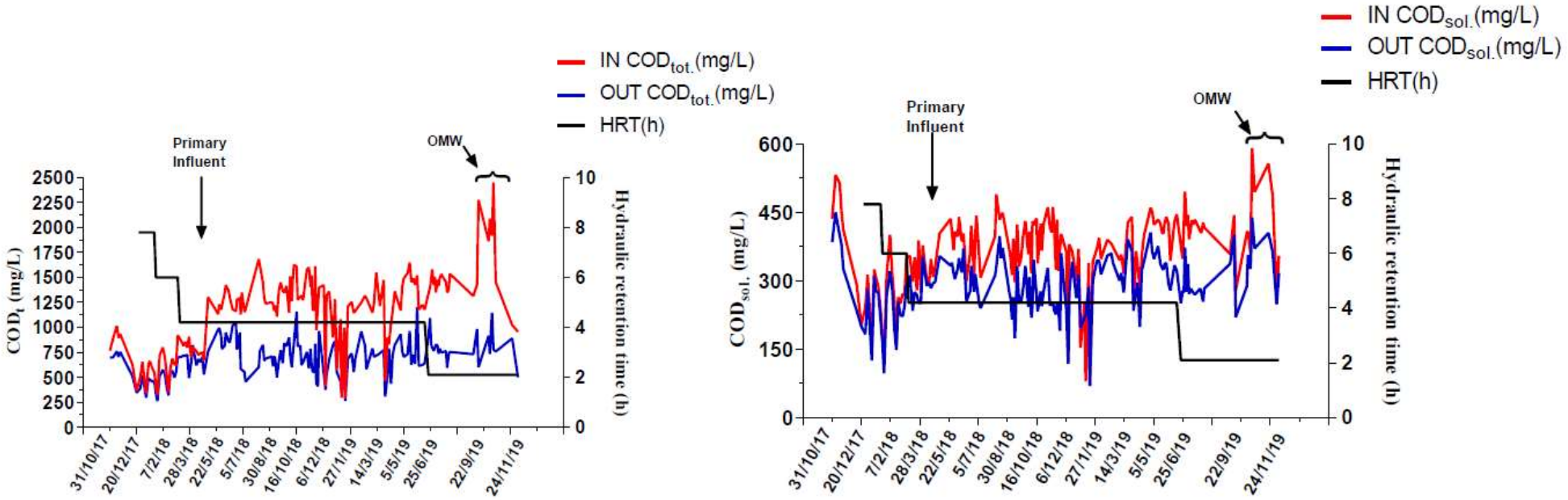
Recovery Efficiency

- 5-10 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

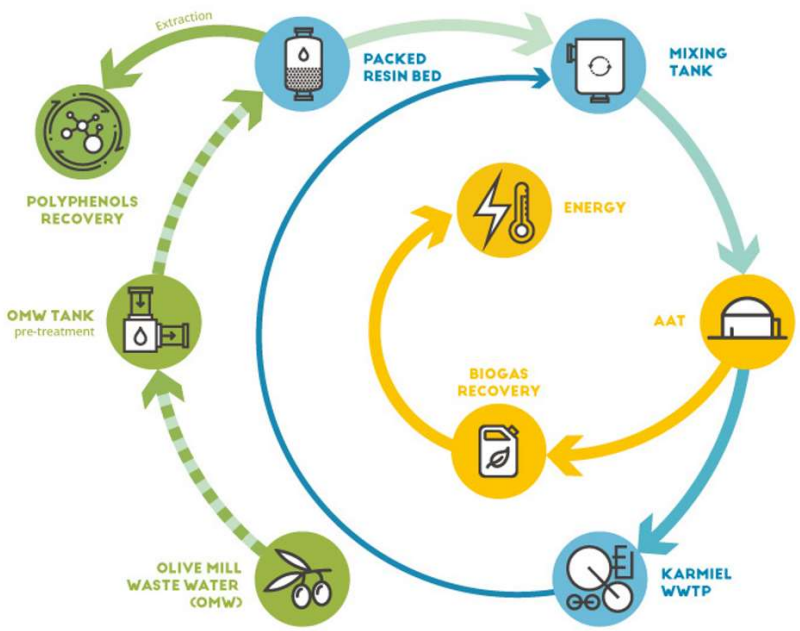
Shaving the peaks



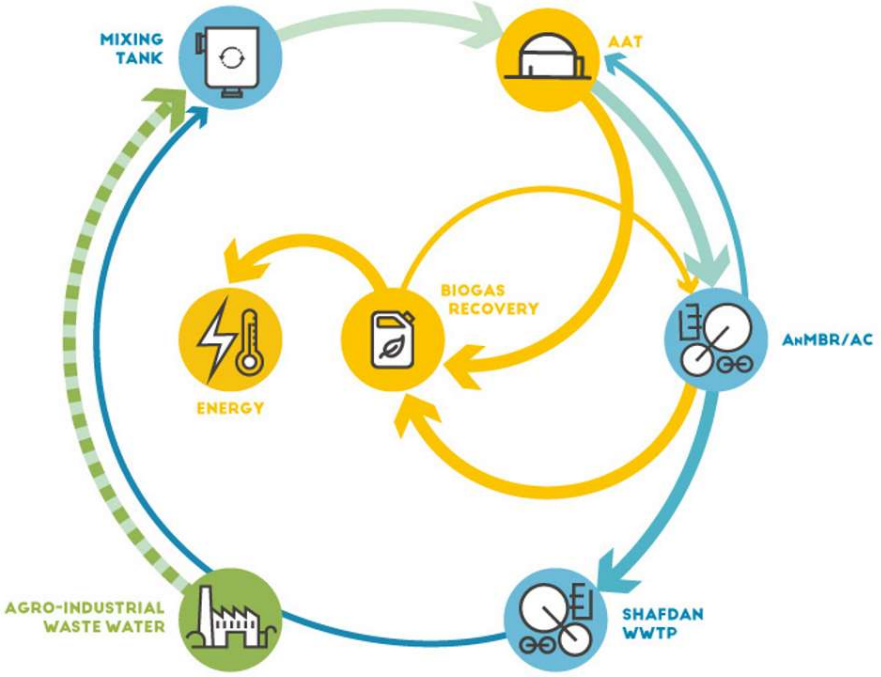
The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

Case study 6 - Karmiel and Shafdan

Karmiel



Shafdan



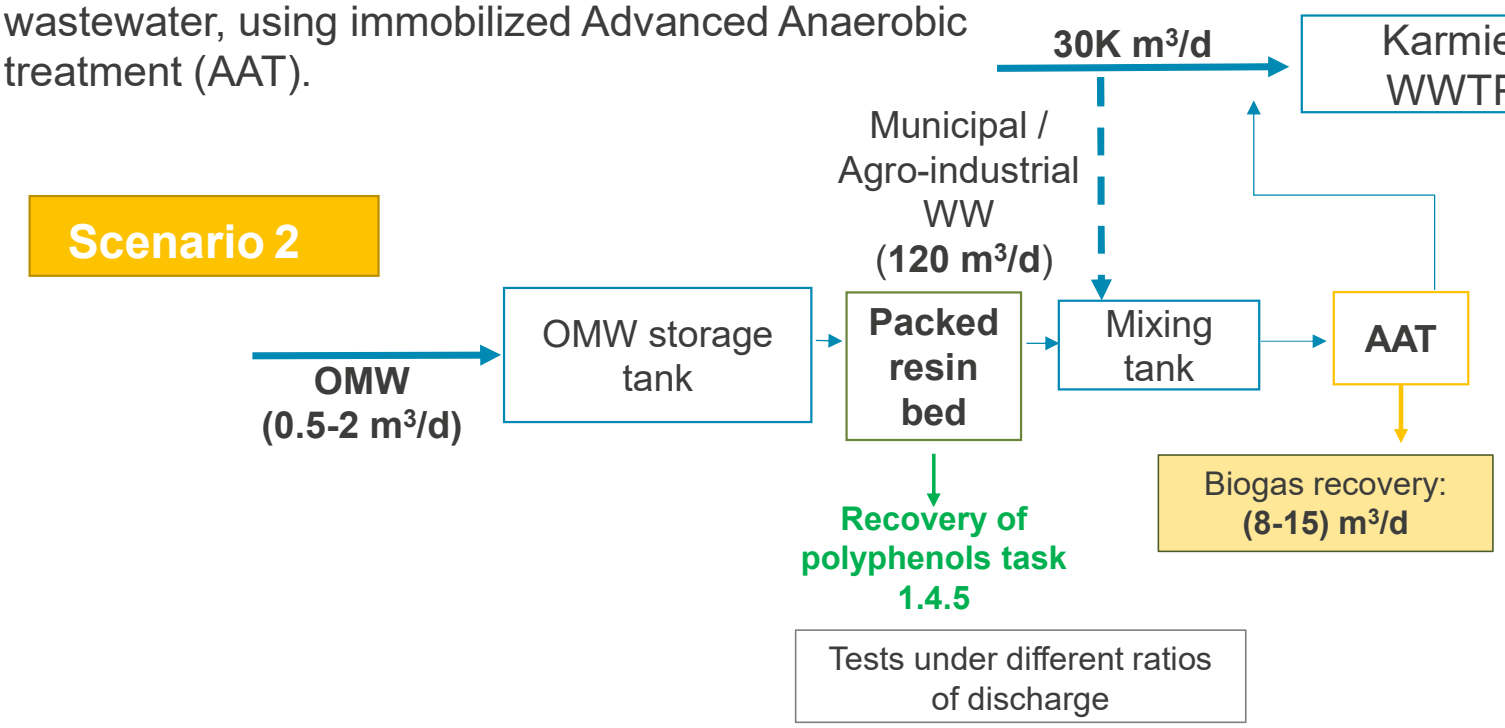
The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

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

Partners: MEKOROT Israel National Water Co., AgRobics, The Galilee Society, Greener than Green TECHNOLOGIES

OBJECTIVE:
Reducing the high organic load peaks in WWTP main stream, caused by mixing with olive mill wastewater, using immobilized Advanced Anaerobic treatment (AAT).



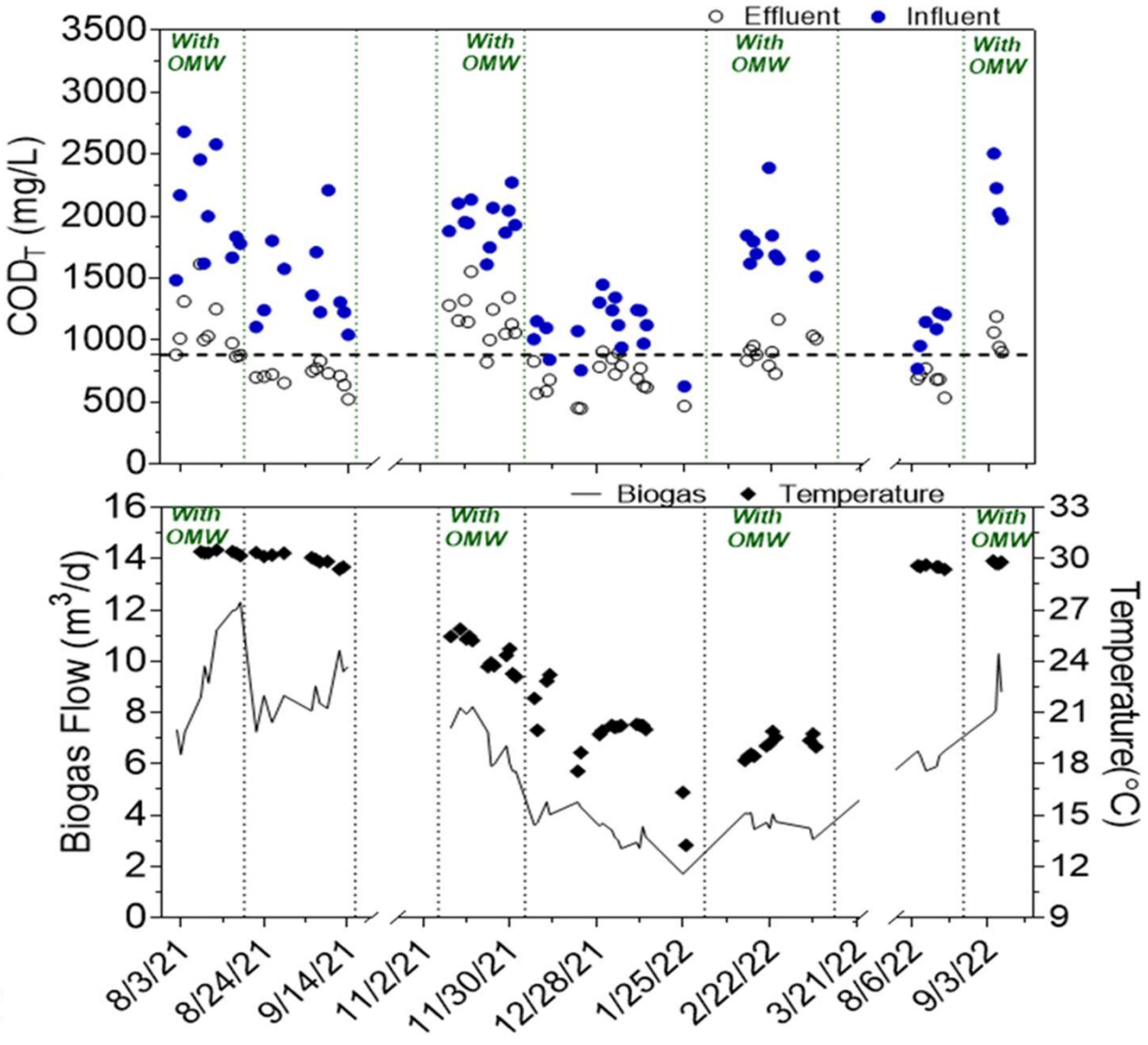




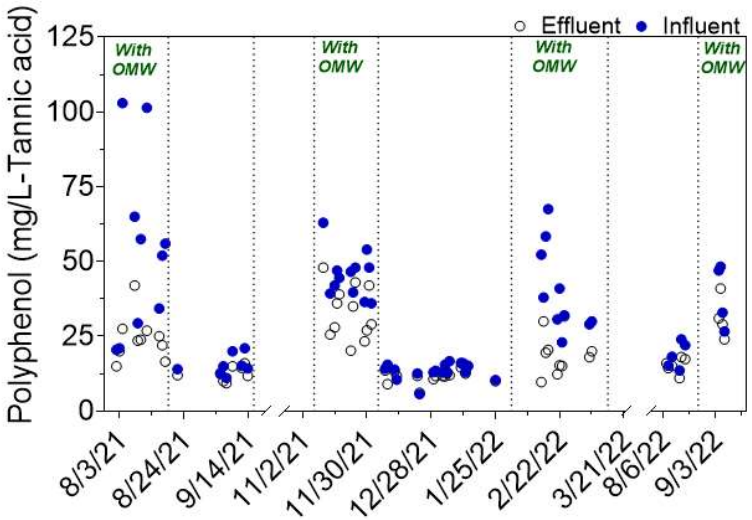
The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

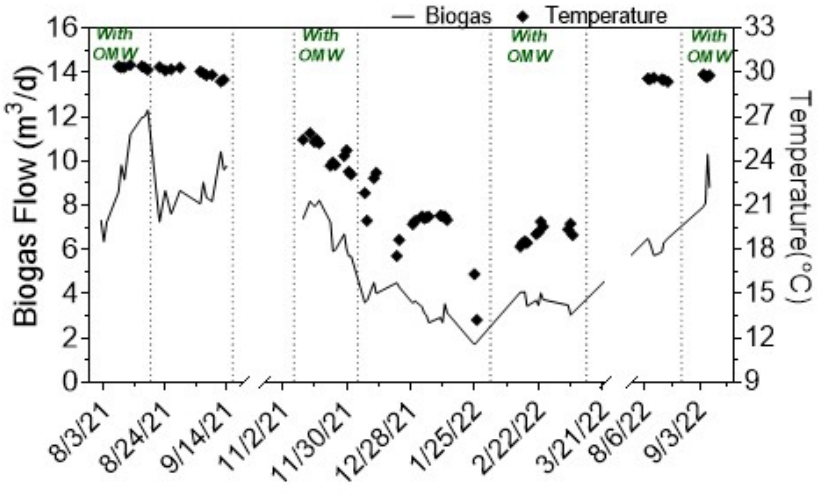
COD: Stable AAT effluent despite the fluctuations in the influent as a result of OMW discharge.

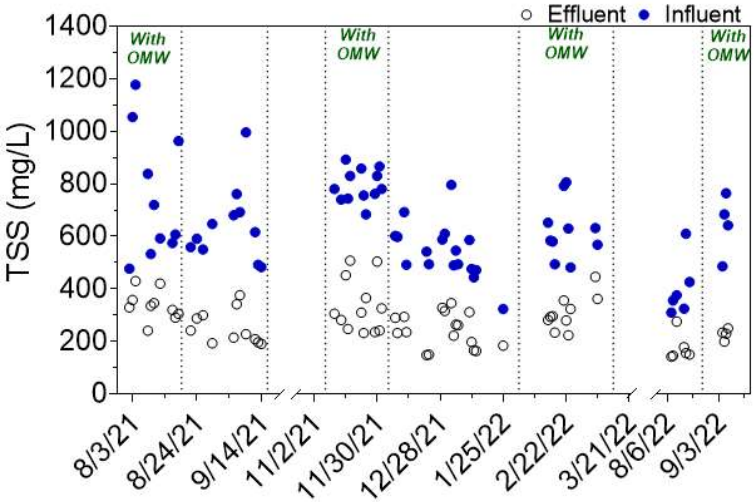
Biogas production: AAT produces biogas throughout its operation. In summer biogas production is its maximum rate and is highly dependent on the influent COD and high temperature.

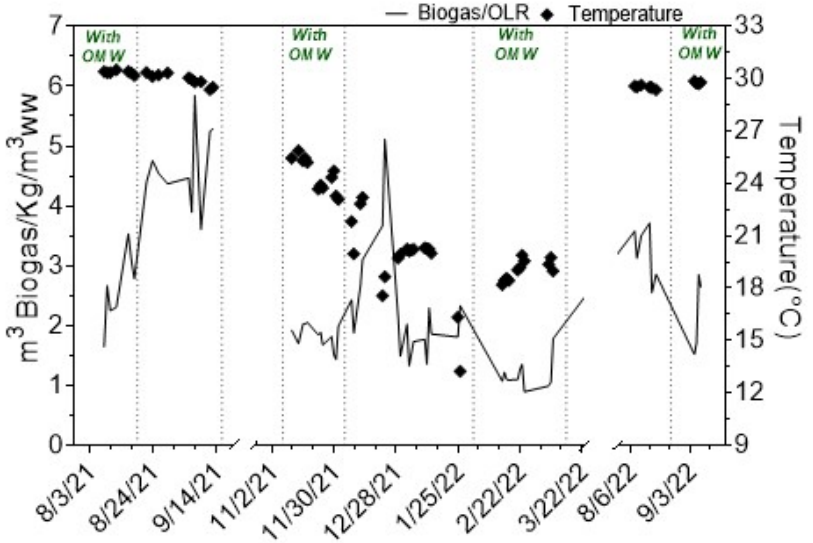


The project leading to this application has received fundi
Horizon 2020 research and innovation programme under









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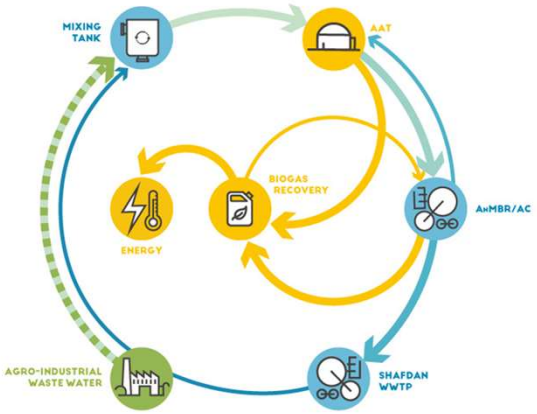
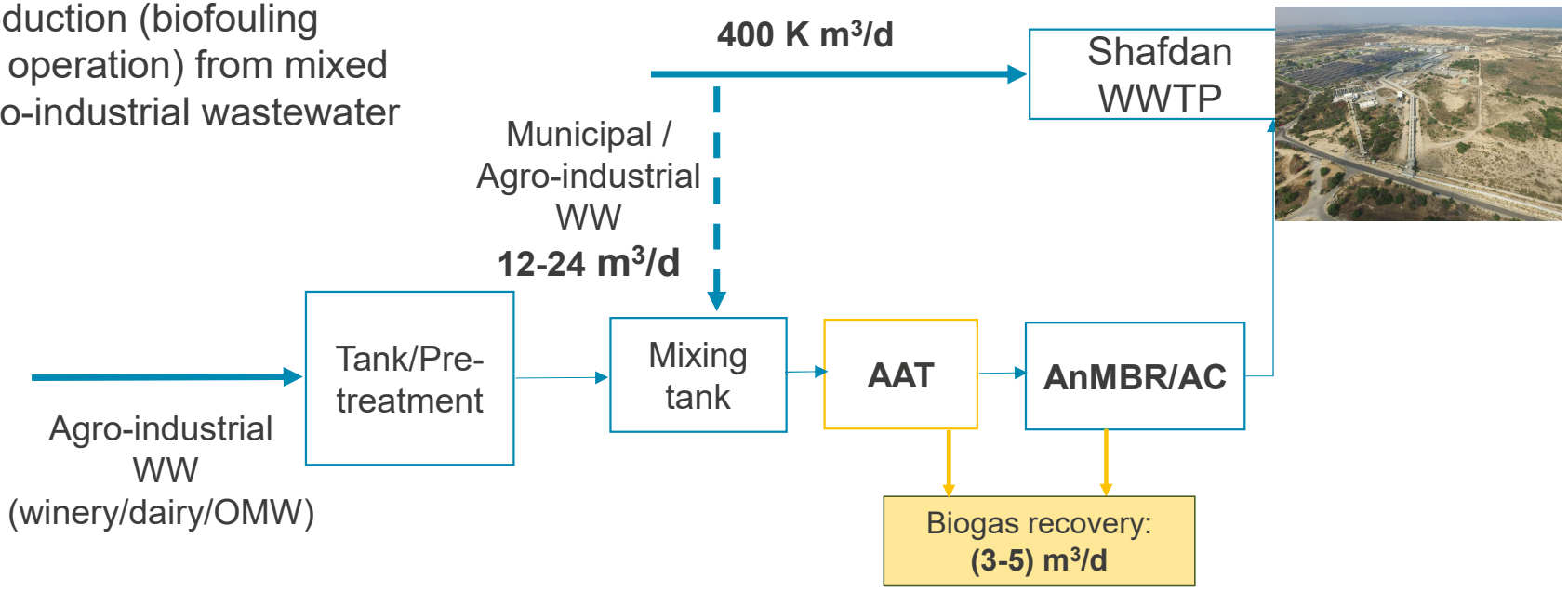
ENERGY - Task 1.3.4

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



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 m³ CH_4/kg oDM

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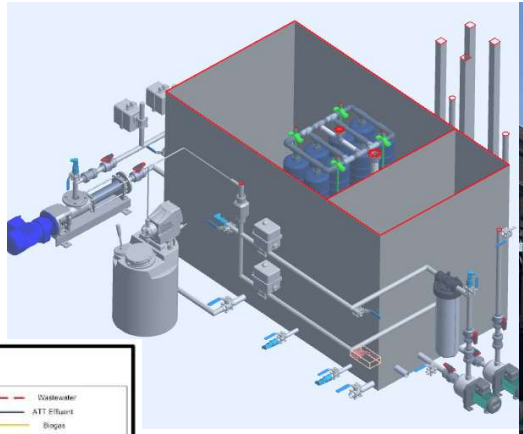
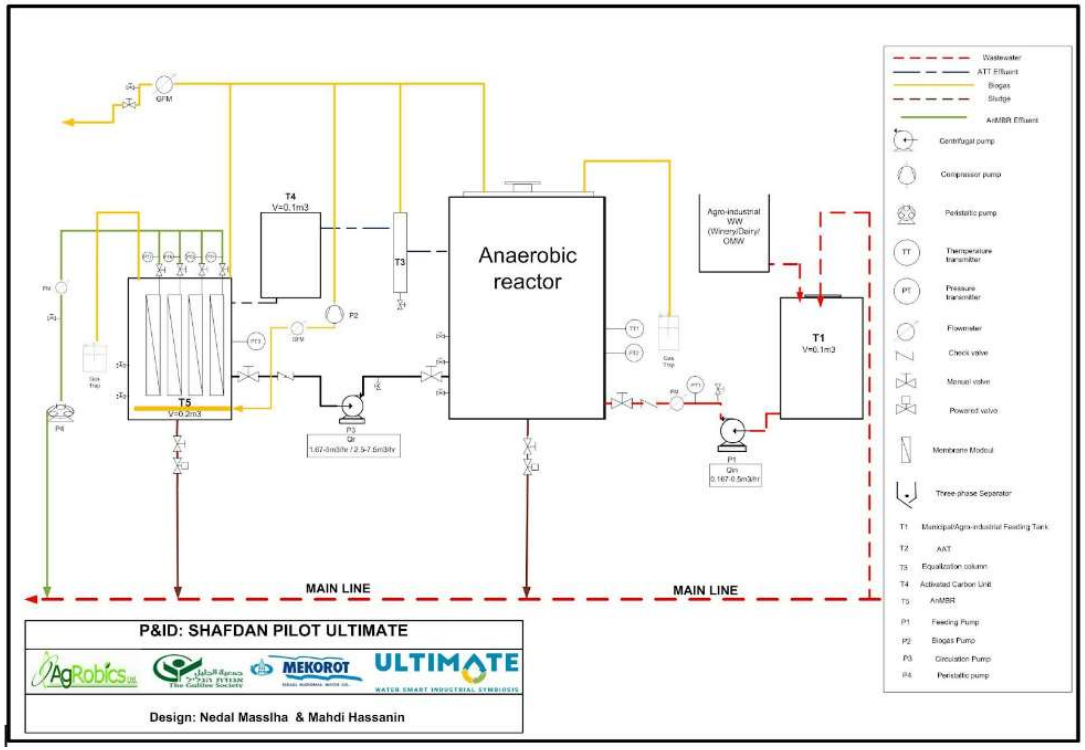
Case study 6 - Shafdan









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

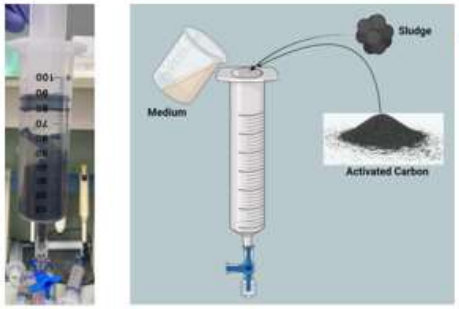
Innovation: The use of immobilized biomass in PAC fixed foam instead of granular biomass offers a promising approach for fouling reduction which is unexplored yet within AnMBR technologies.



IBF

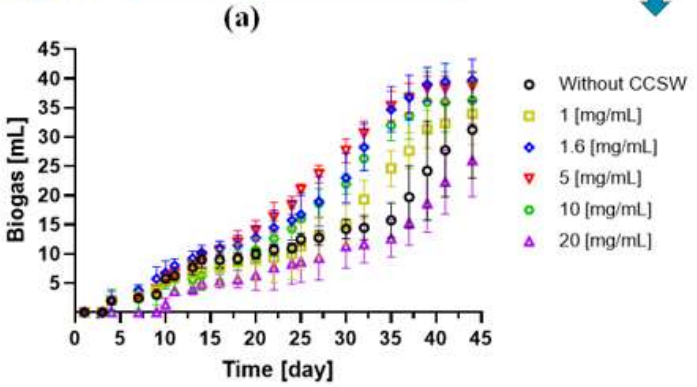
The project leading to this application has received fur
Horizon 2020 research and innovation programme under grant agreement No

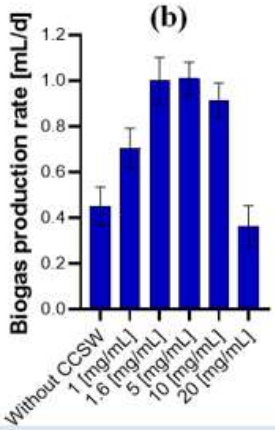
Lab scale results

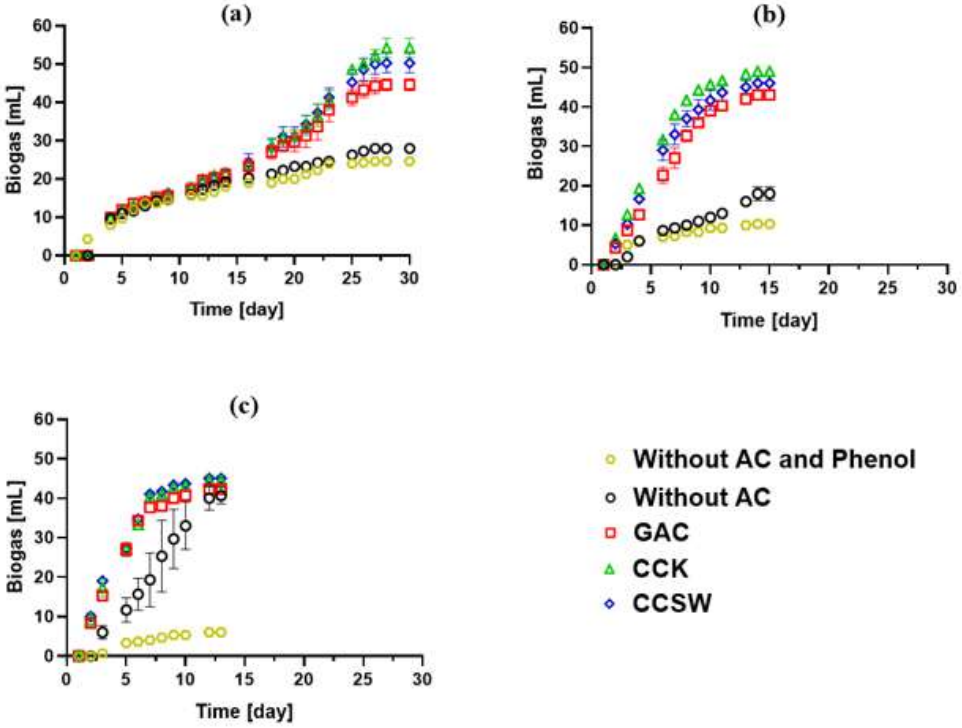


BMP reactor with activated carbon addition

Accumulated Biogas (a) and biogas production rate (b) for different CCSW concentrations with medium containing 500 mg/L phenol







Accumulated biogas for all different AC types at 500 mg/L phenol in the first (a), second (b), and third (c) batches.

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Thank you for your attention!



Isam Sabbah



Katie Baransi Karkaby



Sari Musa



Nedal Massalha
CTO



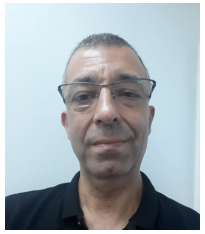
Mahdi Hassanin



Avi Aharoni



Hadas Raanan Kiperwas



Khalid Farah



Nuur Awwad
M.Sc. Student



Stav Shimshoni
M.Sc. Student



Saleh Zatme



Dimitri Iossifidis



Myrto Touloupi

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

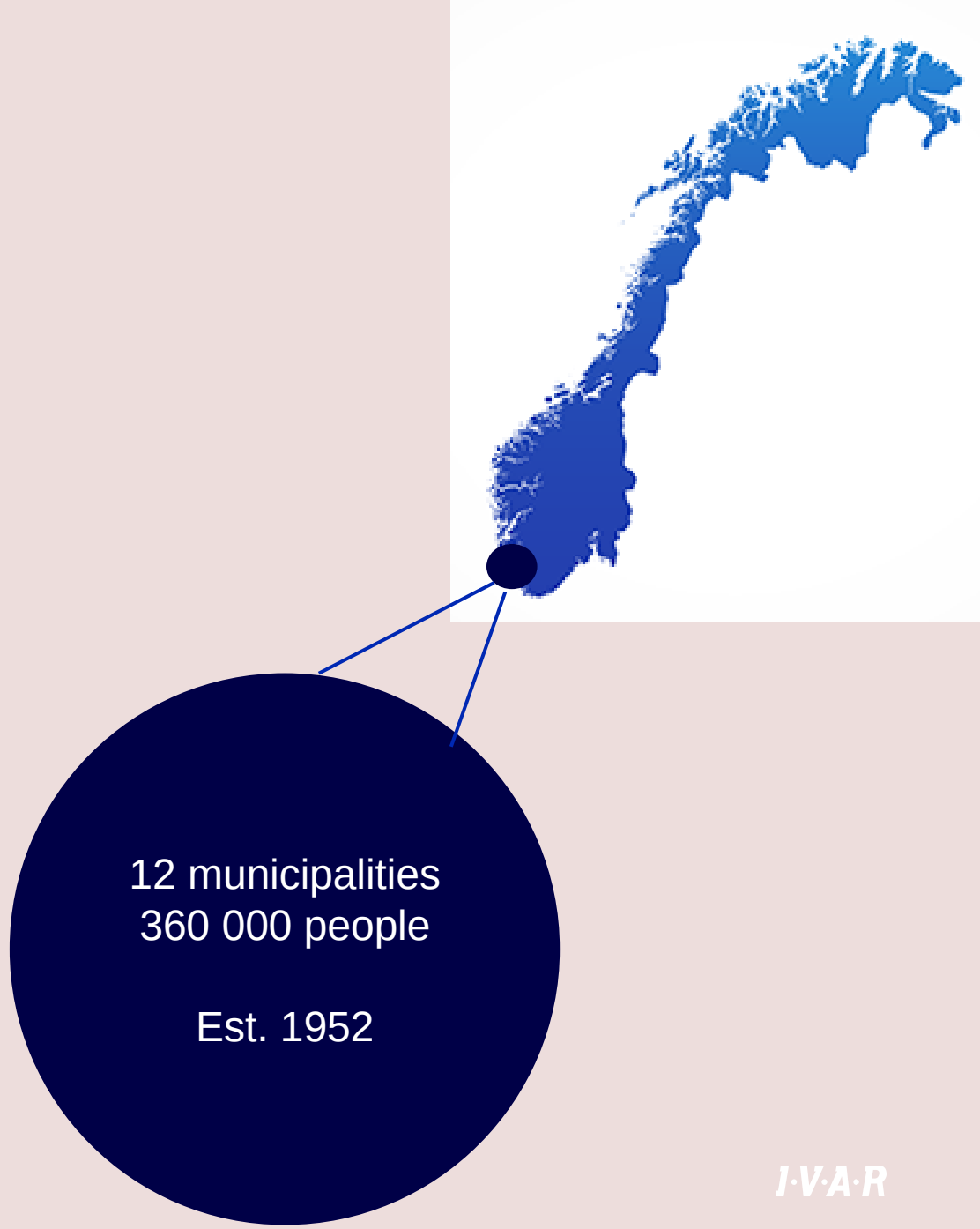
A society where nothing goes to waste…

Lene Beadle
Head of department
Business Development

Webinar May 30th 2023
Biogas Technologies

Who is IVAR?

- Municipality owned company in Norway
- Produced drinking water for the region since 1952
- Waste water treatment and waste mangement for the region since 1979
- Production of biogas from waste water sludge since 1992



I·V·A·R

Industrial plants

- 2022 – Produced 42,1 million m^3 drinking water
- 2022 – Treated 48,5 million m^3 waste water
- 2022 – Handled 131 194 tonn waste from households
- 2022 - Produced over 60 GWh energy (over 50 GWh from biogass plants)









BIOGASS – The adventured started in 1992.....

I·V·A·R

Two biogas plants

- 1992 – Waste water treatment & biogass production at Mekjarvik
- 1992 – 2011 Biogas for own use – not upgraded
- 2011 – Installed plant for upgrading biogas
- 2016 – Plant nr. 2 at Grødaland for utilizing food waste from households + waste water sludge



Plant 1 - Mekjarvik

- Mainly waste water sludge + some organic waste from local industry
- Continous anaerobic flow reactors
- Amine – for upgrading biogass + addition of propane
- Hygenize after digestion – heat dries sludge
- Production of organic fertilizer (4 200 tonn in 2022)





Plant 2 - Grødaland

- Mainly food waste + waste water sludge + some organic waste from local industry
- Continous anaerobic flow reactors
- Hygenize before digestion – Thermal hydrolosis (5 bar + 160 °C)
- Amine – for upgrading biogass + addition of propane
- Digested organic matter used as organic fertilizer on fields





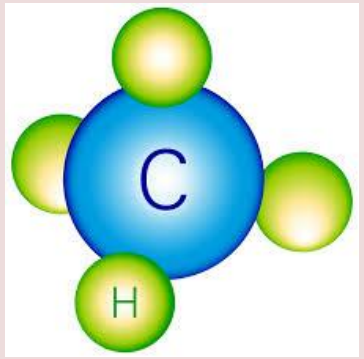
IVAR – focus on sircular economy

We make «gold» out of waste











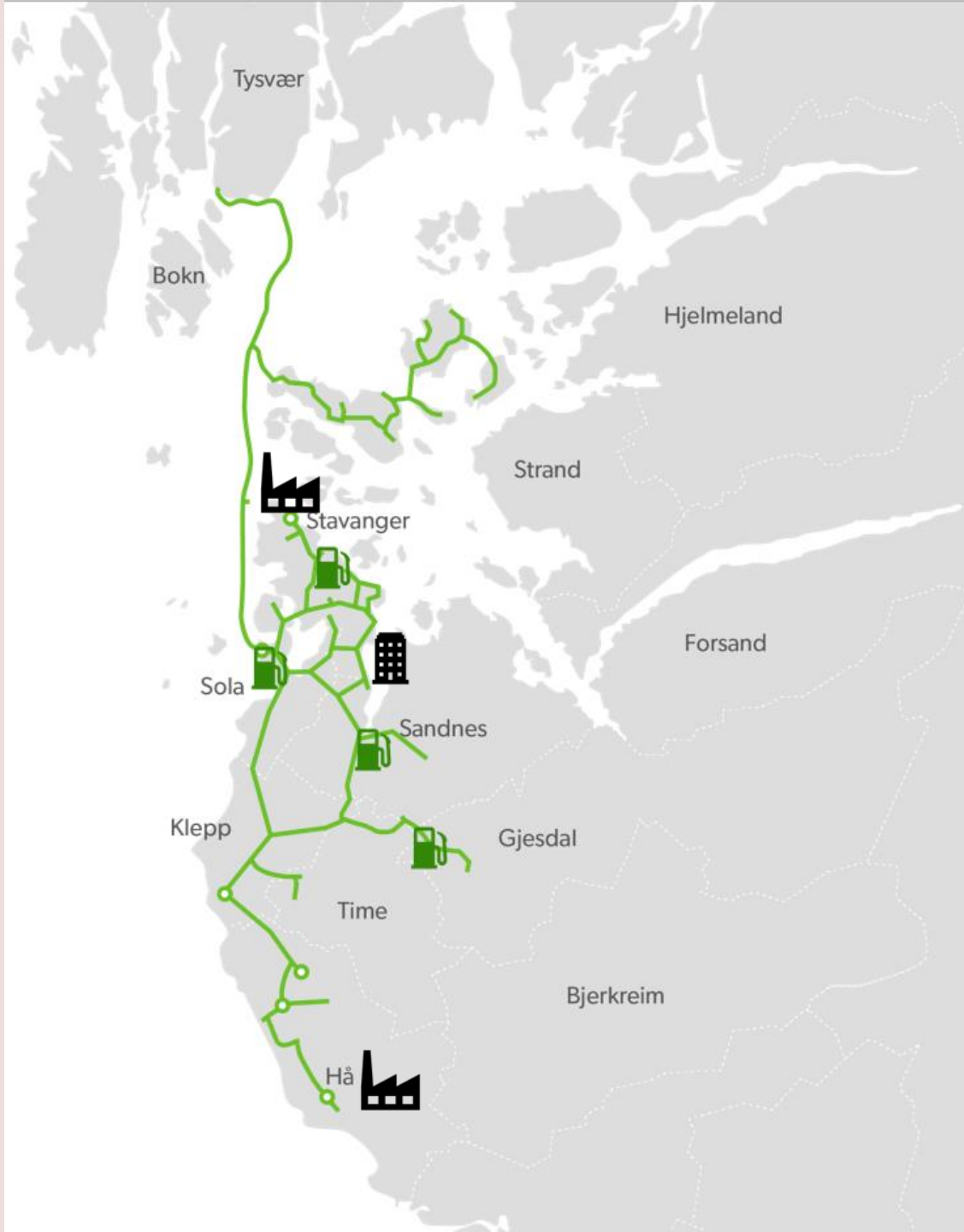


Green CH4 + organic fertilizers + green CO2

I·V·A·R

Distribution and sale

- 2003 – Lyse established gass distribution pipe infrastructure for natural gas
- 600 km
- 2011 – IVAR started selling CBG to Lyse
- Use: fuel for biogas vechicles, heating for businesses, district heating



I·V·A·R

ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

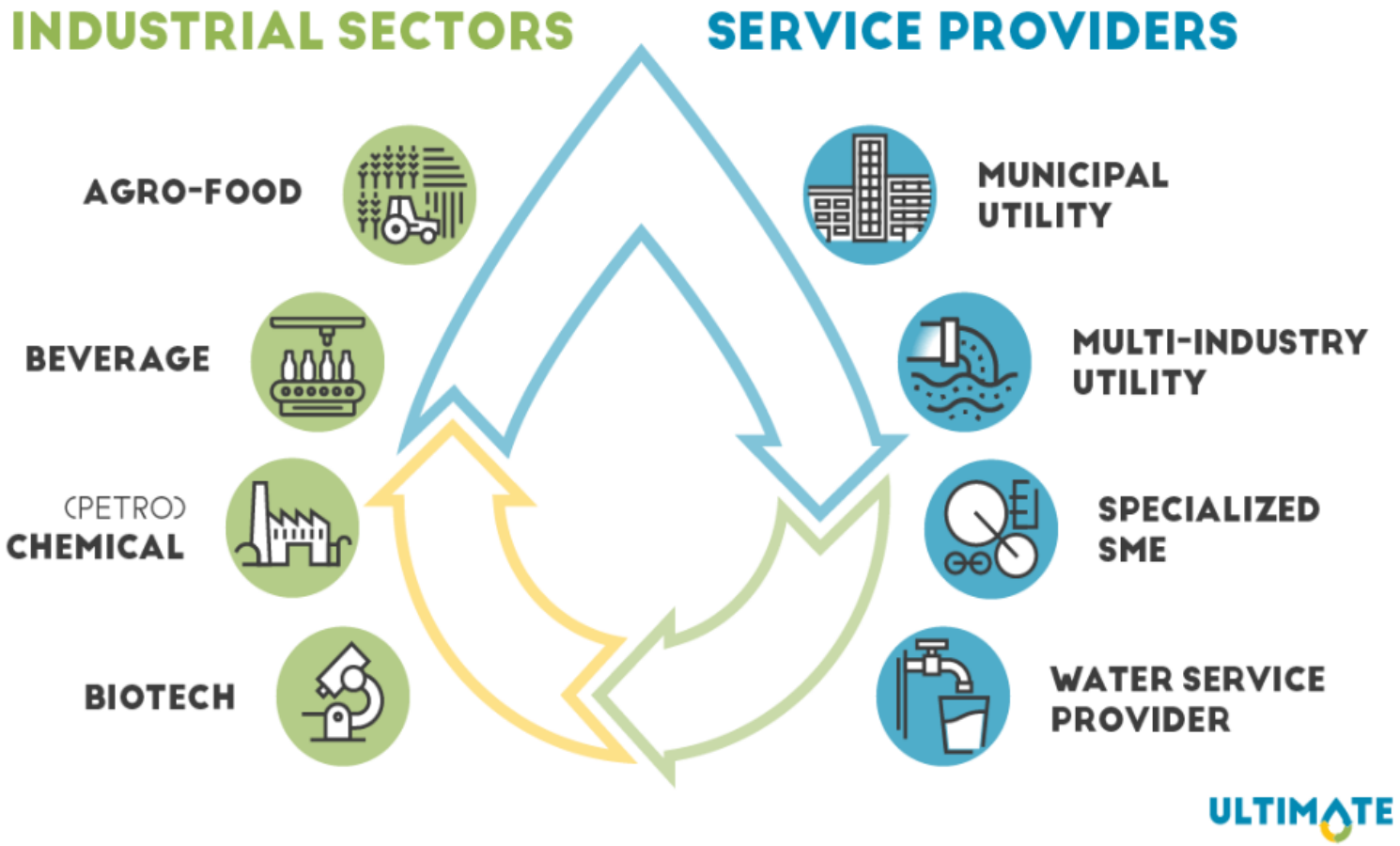
Industry water utility symbiosis for a smarter water society: webinar on heat recovery

A. Kleyböcker, C. Bruni and A. Naves Arnaldos



March 30th 2023

WATER SMART INDUSTRIAL SYMBIOSES BETWEEN:



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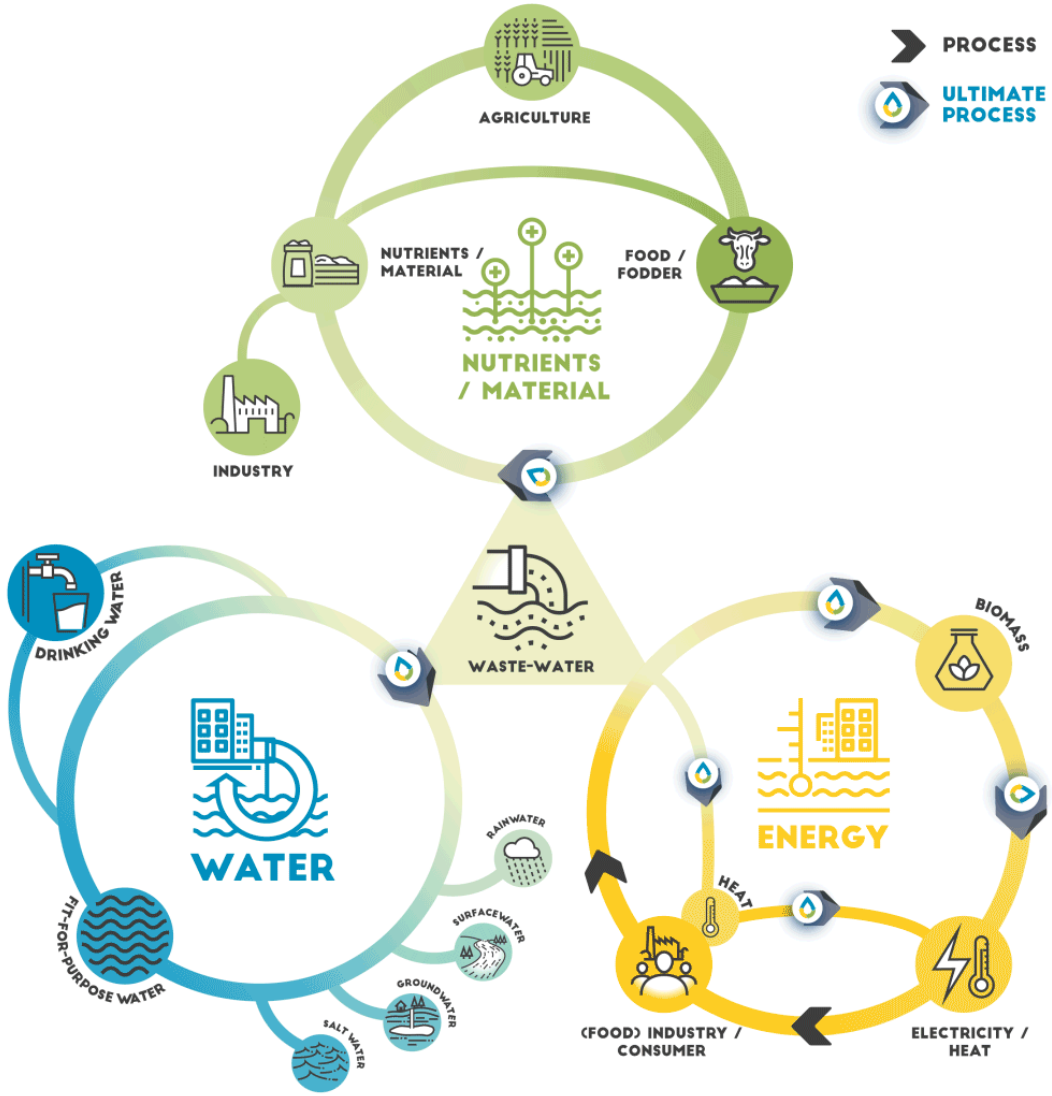
Coordinator: KWR

9 Case Studies



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



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Ultimate solutions involve circular economy technologies



- Membrane technologies
- Adsorption technologies
- Electrostimulated systems

- 22 pilot plants
- 3 control and/or early warning systems
- 6 concept studies

- Biogas technologies
- Heat recovery
- Digitalization

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Water recovery:
8 of 8 pilot plants are operational

Membrane technologies

- Reverse osmosis + membrane distillation
- Novel ultrafiltration membrane (UF) + RO
- Nanofiltration (NF) + RO
- Small bioreactor platform (SBP)

Adsorption technologies

- Zeolite column for NH_4 removal
- Recovery of polyphenols/antioxidants

Monitoring and matchmaking system

- to avoid high chloride concentrations in reclaimed water

Other systems

- Electrodialysis for removal of salts
- Advanced oxidation processes

UF & RO

Zeolite column

Electro-dialysis

Monitoring & matchmaking system

SBP

AOP

RO











Material recovery:
6 of 7 pilot plants are operational

Nutrients:
- Ammonium and phosphate rich water
- Ammonium sulphate
- Struvite

High added-value products:
- Antioxidants
- Polyphenols

Adsorption material
- Production via thermal carbonisation: not feasible
- Reuse of byproducts as adsorption material

Electrodialysis



Adsorption system using byproducts



Adsorption of antioxidants



Adsorption of polyphenols



$(NH_4)_2SO_4$ production



Struvite production



Energy recovery:
6 of 7 pilot plants are operational

Biogas production technologies

- Anaerobic membrane bioreactor (AnMBR)
- Electrostimulated anaerobic reactor (ELSAR)
- Immobilised high rate anaerobic reactor (AAT)
- AAT combined with AnMBR and PAC

Biogas valorization

- Solid oxide fuel cell

Heat recovery system

- from AnMBR effluent

AAT



AnMBR



ELSAR



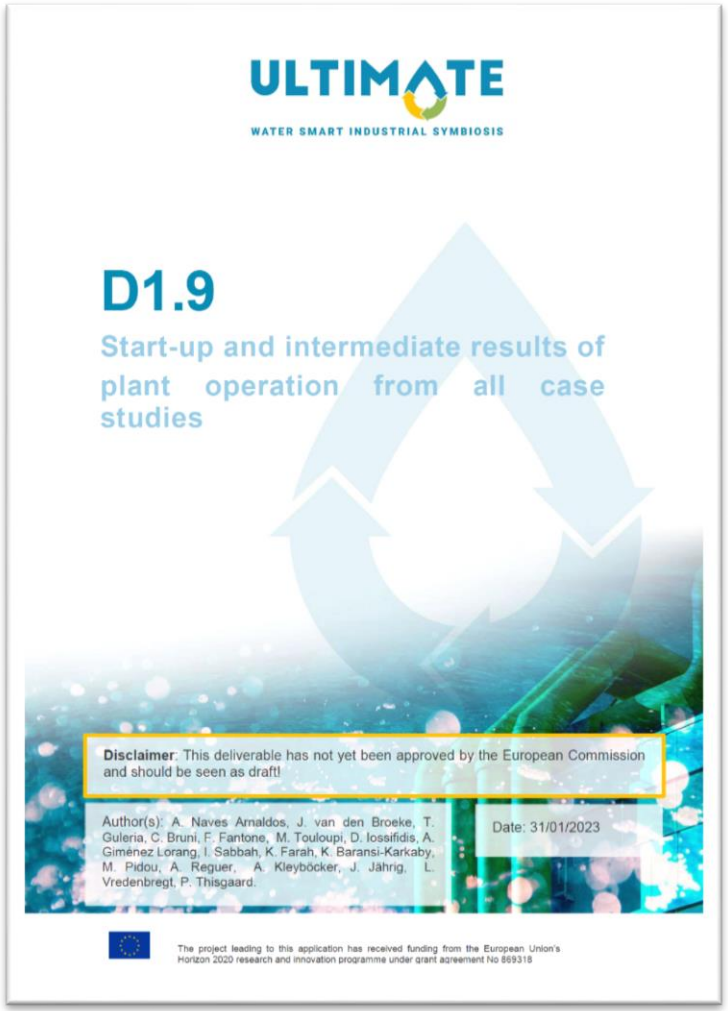
SOFC



AAT + AnMBR



Report about pilot plants (Jan. 2023)



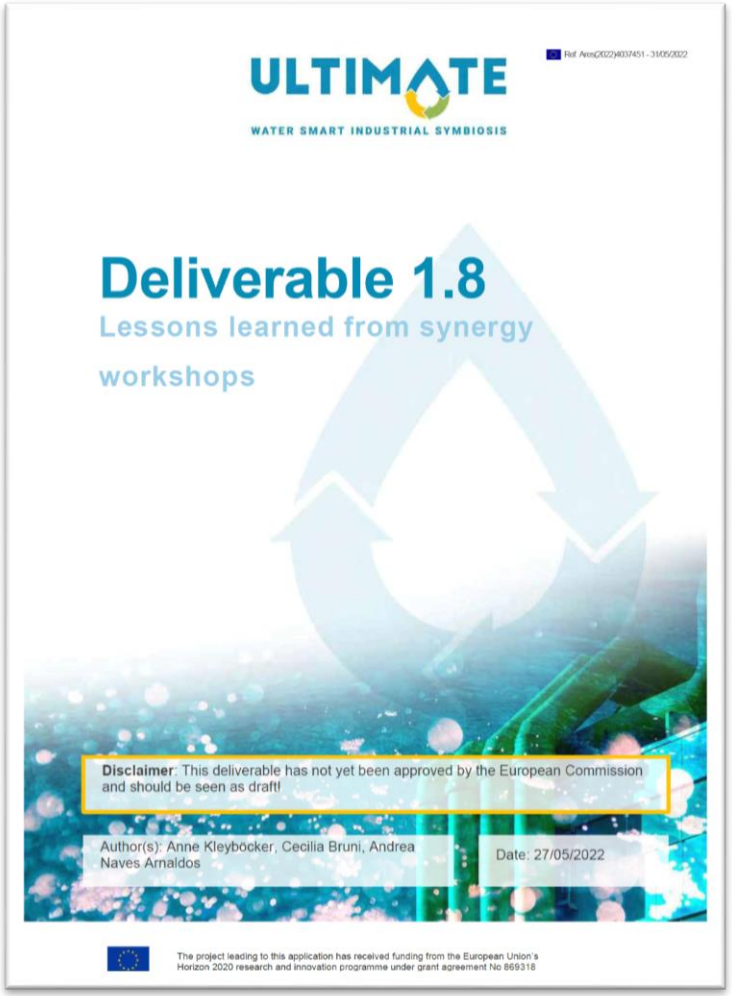
- **Start-up of pilot plants**
- **Intermediate results**

→ Accessible at:

https://ultimatewater.eu/results/

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

Report about synergy workshops (May 2022)



- **Membrane & adsorption technologies**
- **Biogas& heat recovery systems**
- **Material & nutrient recovery systems**
- **Digitalisation**
- **Secret of sucessful symbioses**

→ Accessible at:

https://ultimatewater.eu/results/

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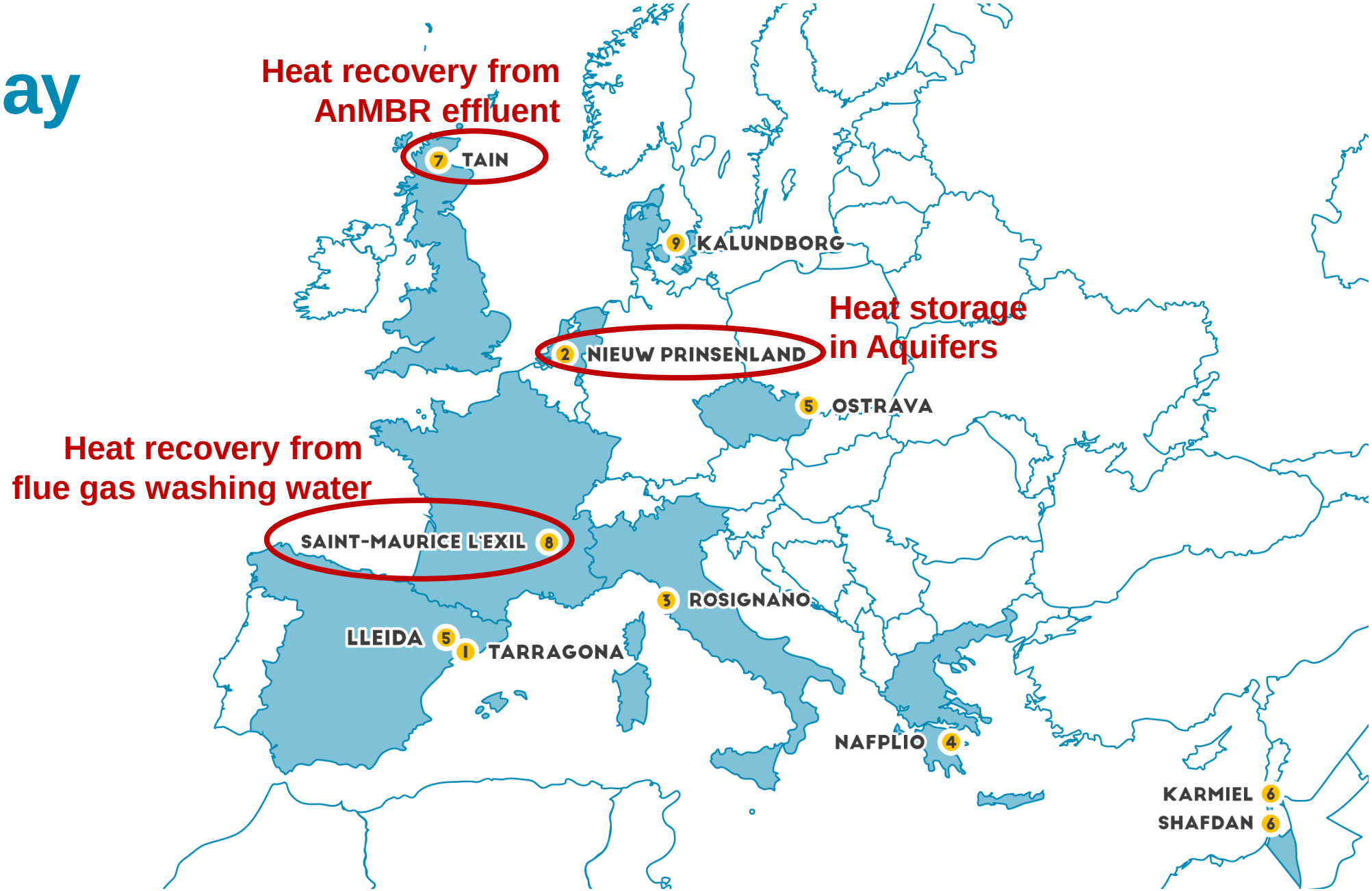
Today



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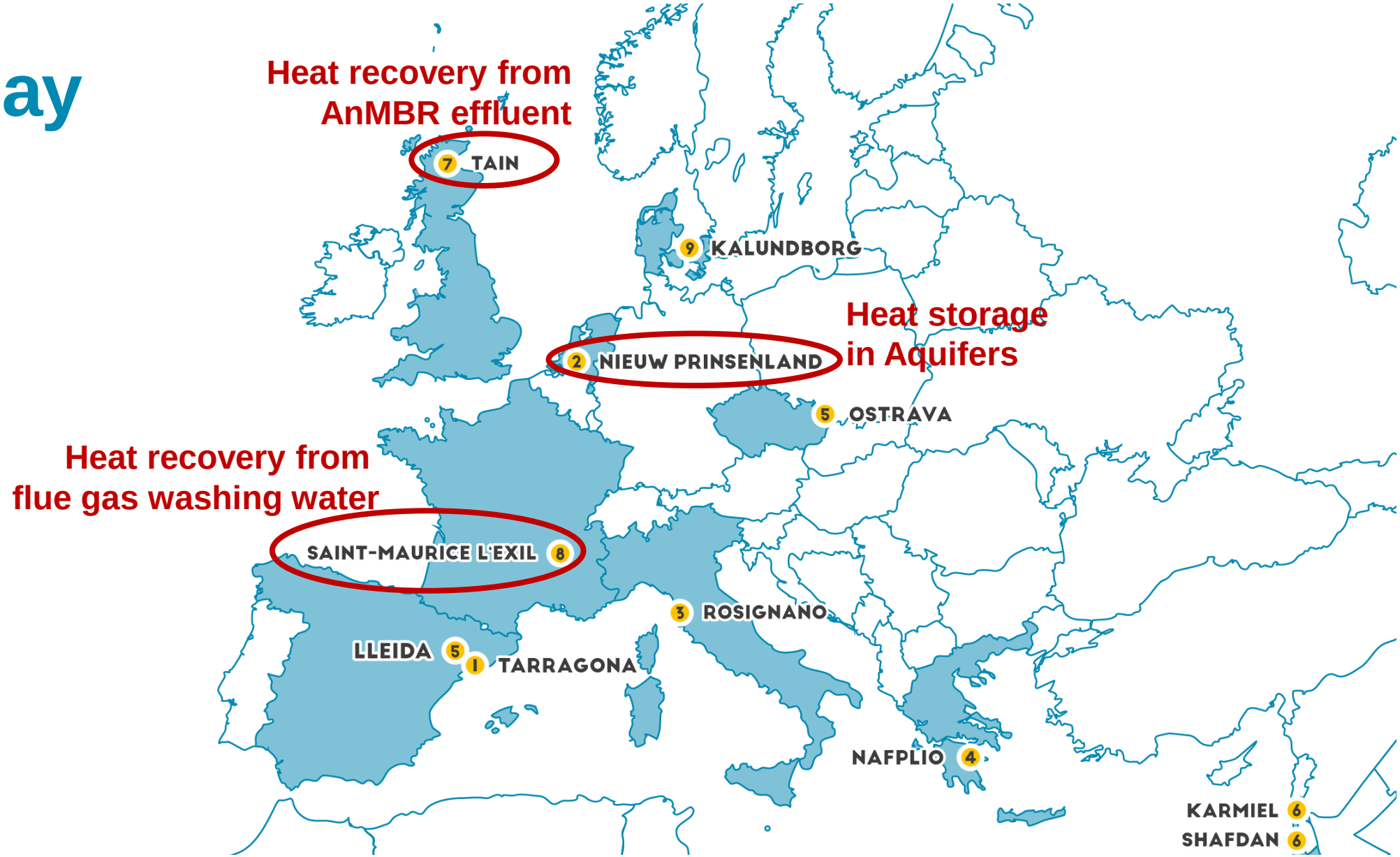
Today



Special guest:

water mining

Heat recovery for brine treatment

Agenda

10:10	**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)*
10:50	Short break
11:00	**CS2 Greenhouse areas in the Netherlands**: Heat storage in aquifers. Symbiosis between geothermal heat and heat storage for greenhouses *Martin Bloemendal (KWR)*
11:20	**WaterMining**: Heat recovery for brine treatment *Dimitris Xevgenos (TU Delft) & Alessandro Trezzi (SWS)*
11:40	**Discussion**
12:00	**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. Based in the recording, we will prepare detailed minutes of the meeting including all the questions of the participants and our answers.

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)

Heat utilisation

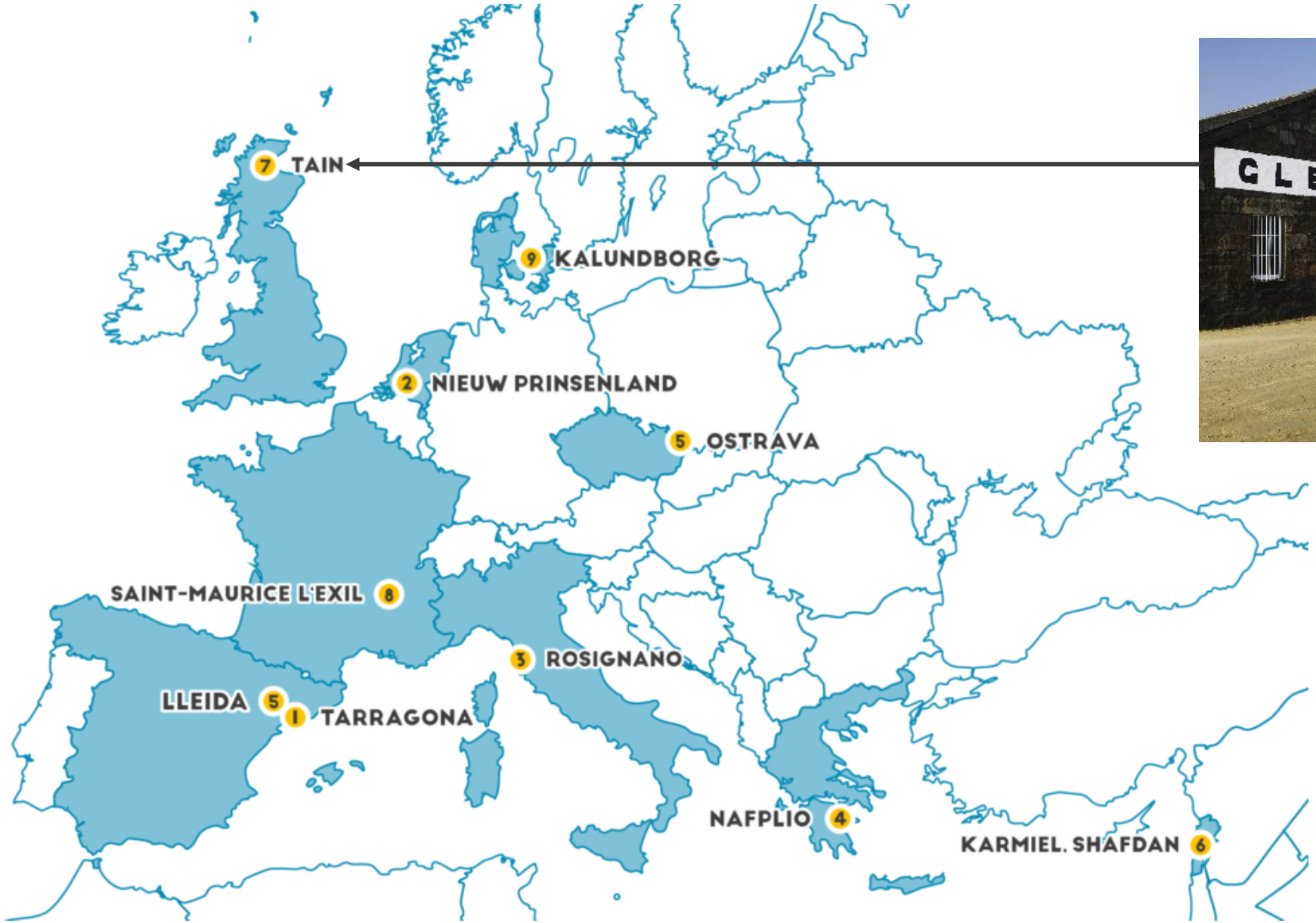
Cranfield University

Aquabio

Meeting: 30th March 2023



CS7 - Glenmorangie distillery







CS7 - Glenmorangie distillery

Partners:

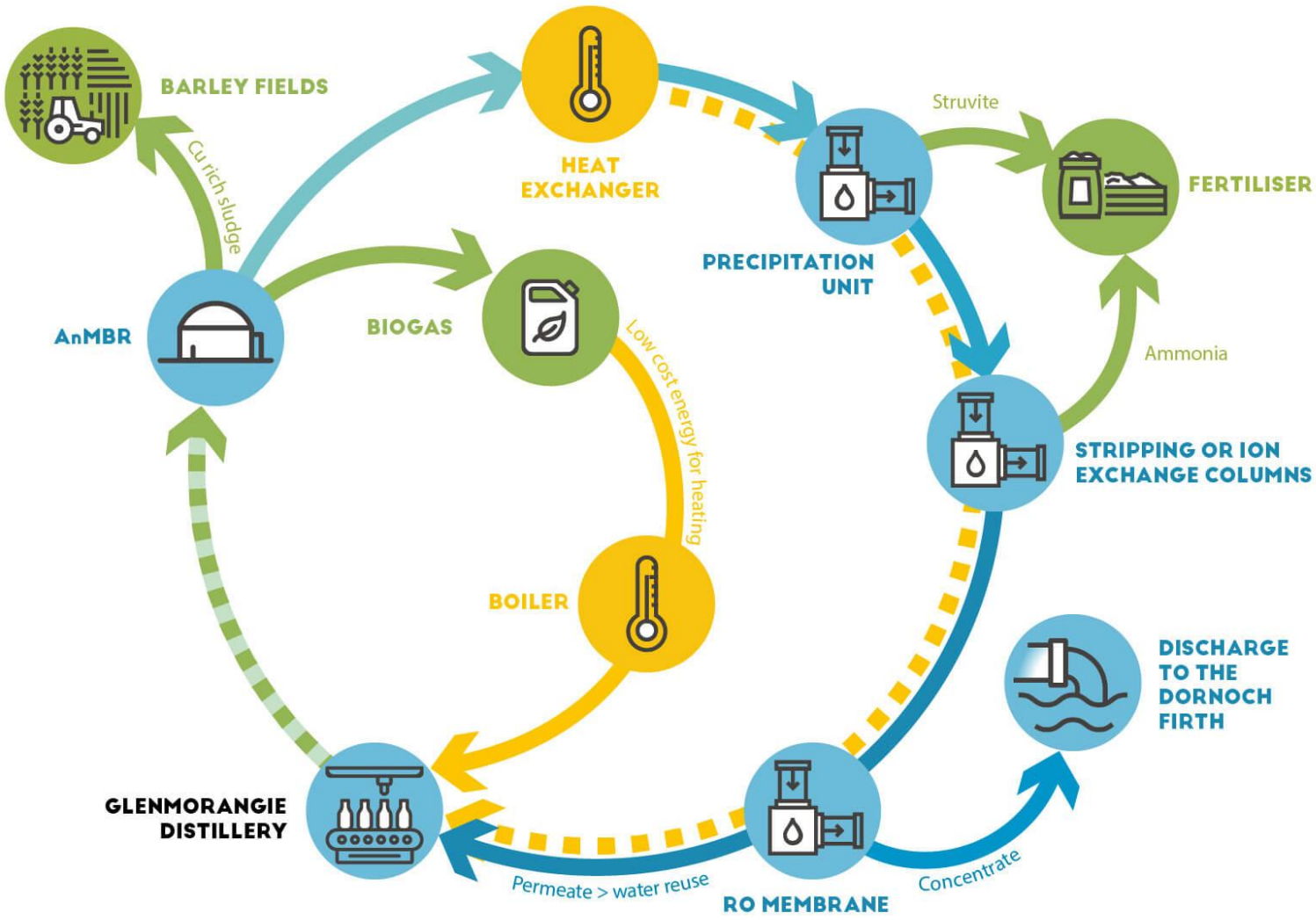
Aquabio

Cranfield University

With the support of:

The GLENMORANGIE COMPANY

Alpheus
part of the Anglian Water Group



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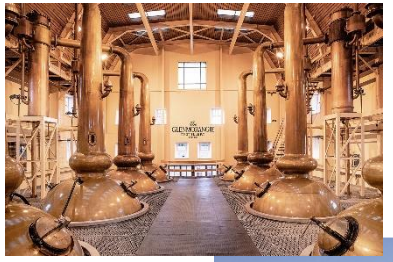
Current system

Reduces the dependence in fossil fuel

of the distillery by 15%











Low-cost energy for heating

Boiler

Biogas

Ww

Mesophilic

Effluent

Dornoch Firth

32-38°C

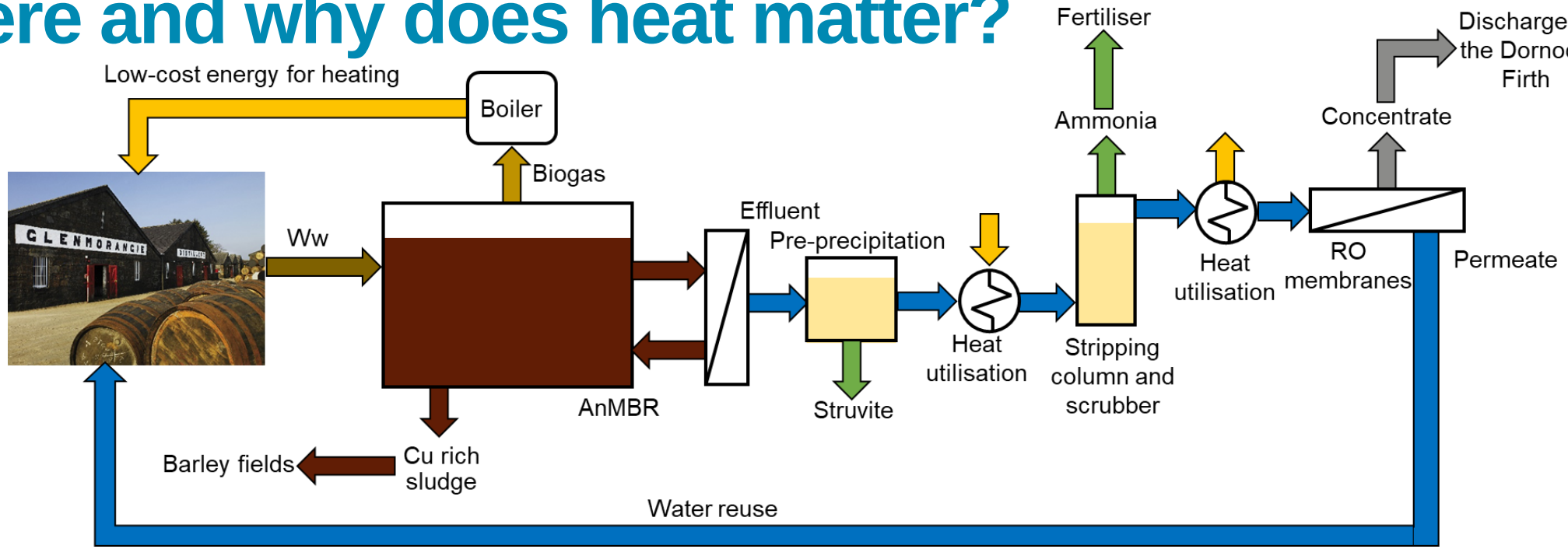
AnMBR

Barley fields

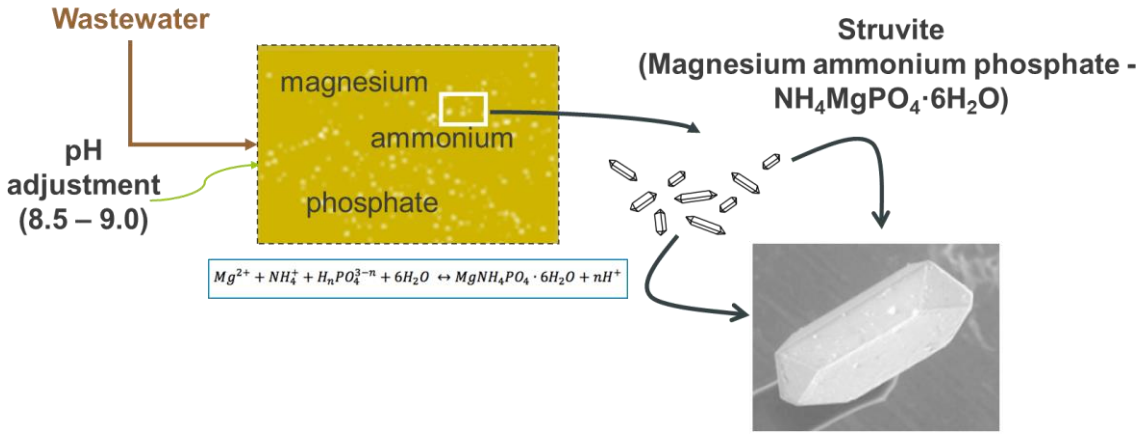
Cu rich sludge

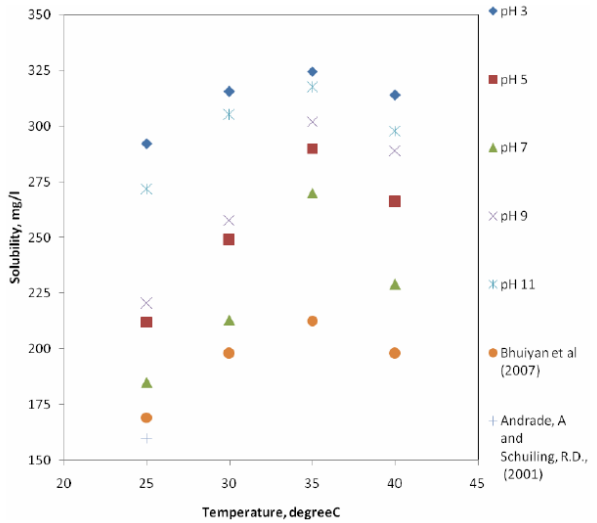
The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

Where and why does heat matter?



Precipitation

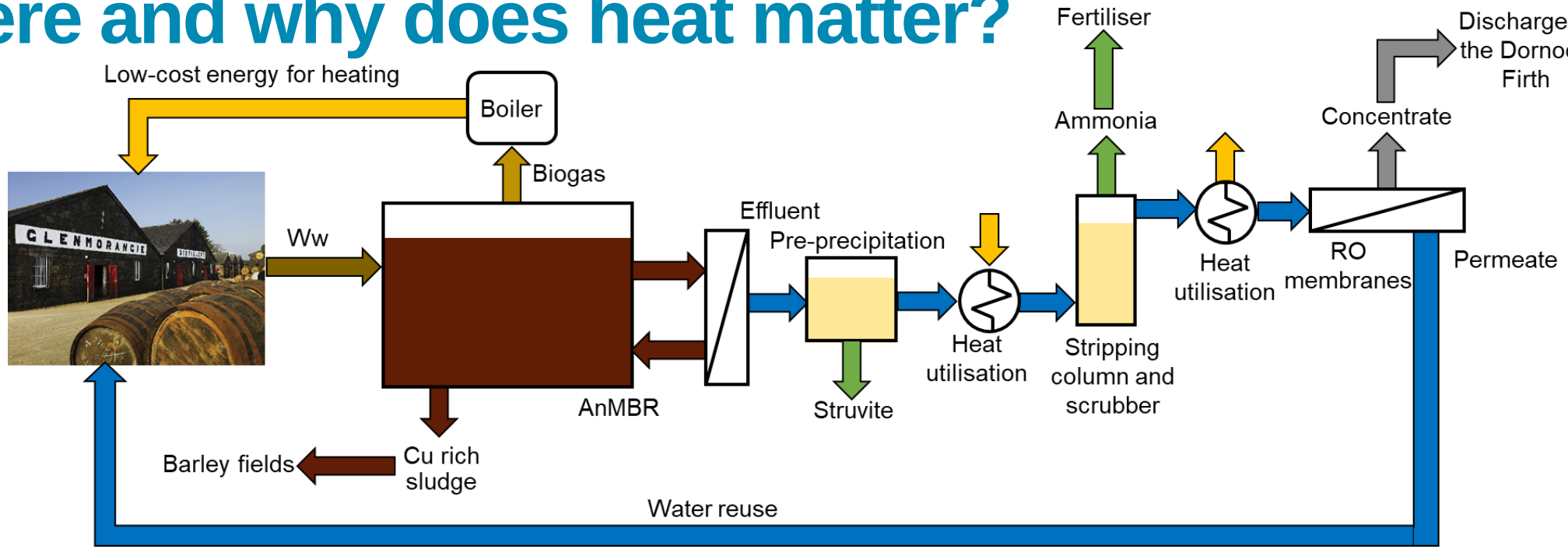




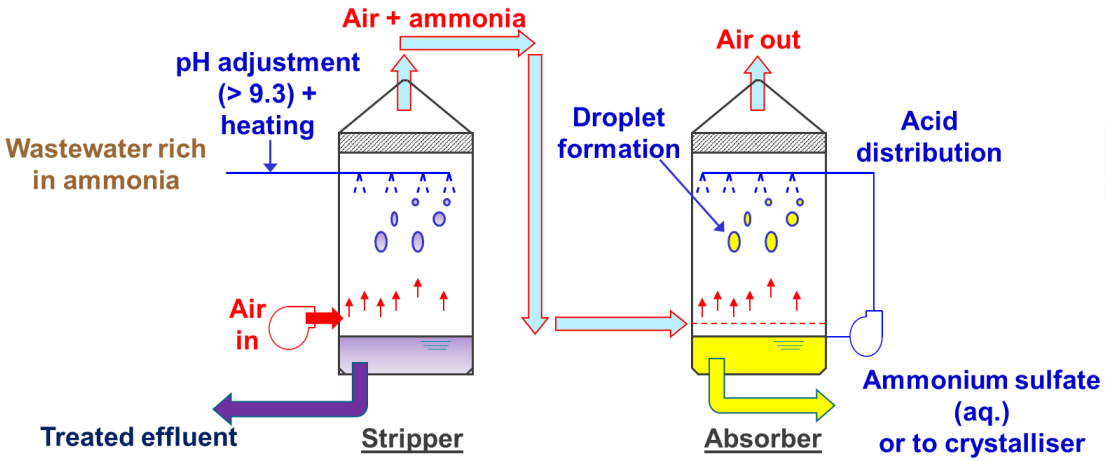
The solubility of struvite is affected by temperature

https://www.researchgate.net/figure/Solubility-of-Struvite-in-various-pH-of-solution-at-different-temperature-This-work-and_fig2_267784704#:~:text=The%20solubility%20of%20struvite%20in,to%20disrupt%20the%20crystal%20

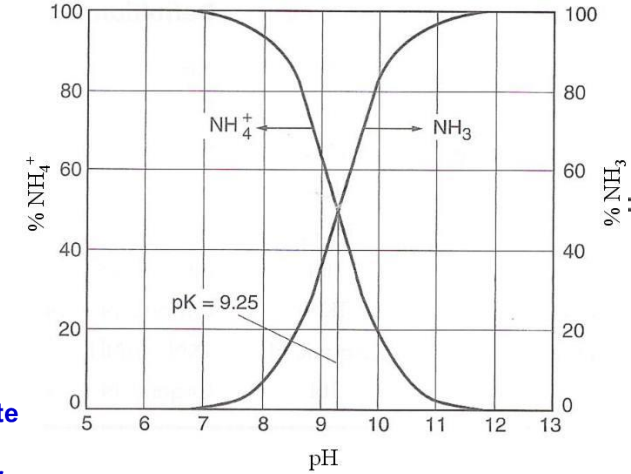
Where and why does heat matter?

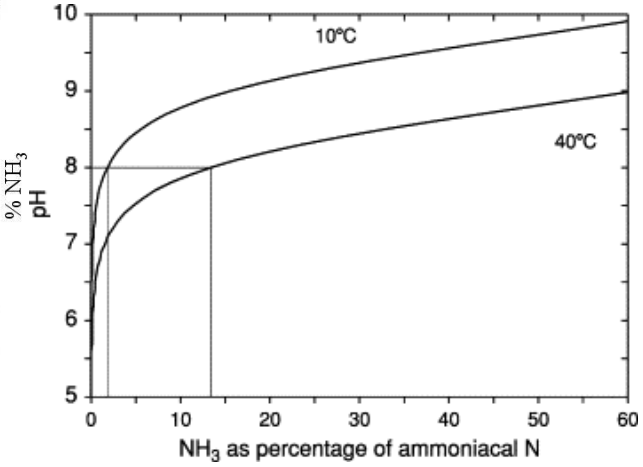


Stripping



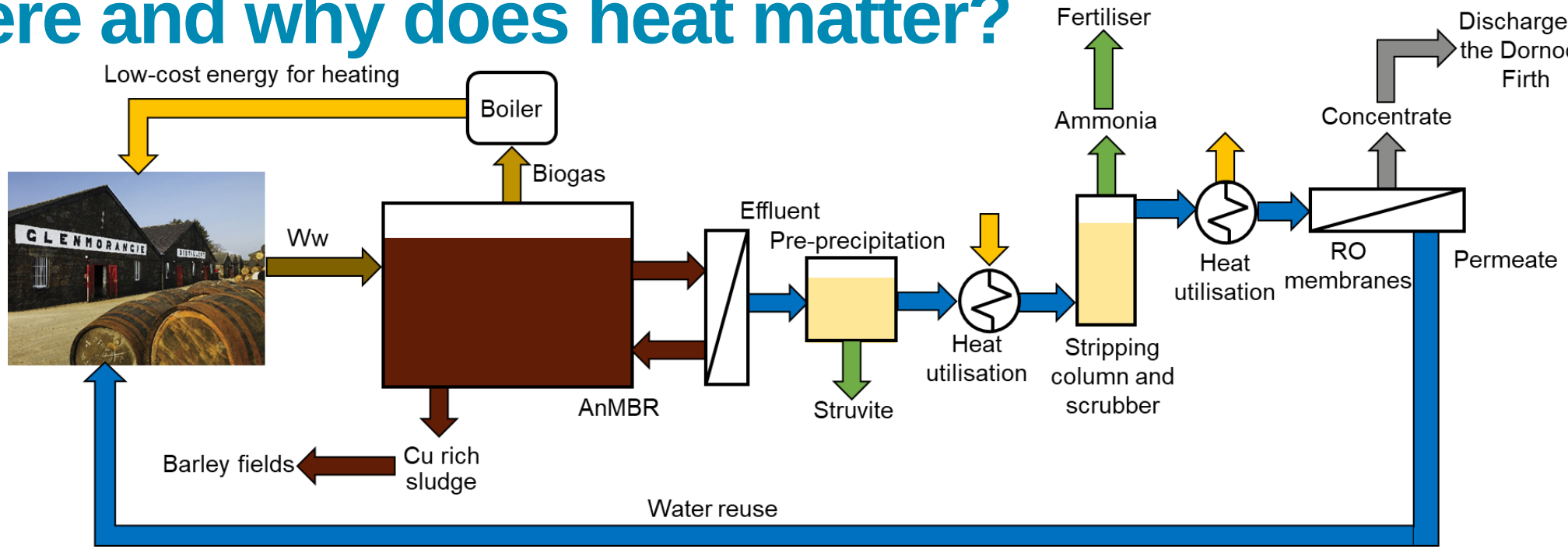
Higher temperatures helps with presence of NH_3





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

Where and why does heat matter?

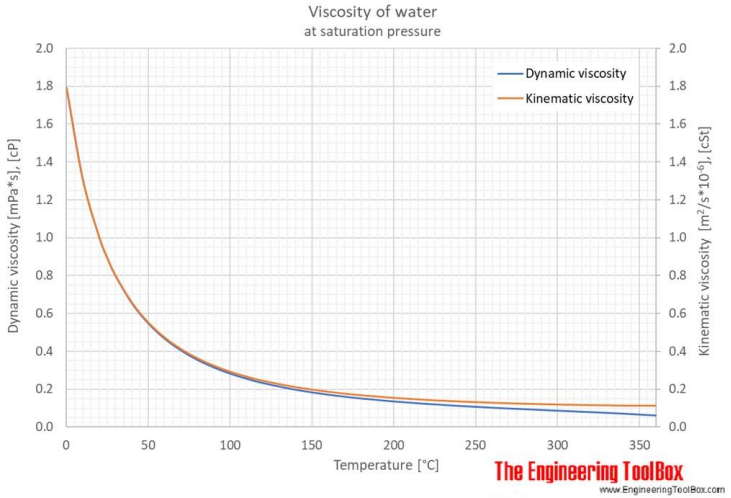


Filtration

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

Flux — Pressure — Resistance — Viscosity

Higher temperatures have the potential to improve filtration but reduce permeate quality



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.engineeringtoolbox.com/water-dynamic-kinematic-viscosity-d_596.html

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

In practice…









Low-cost energy for heating

Boiler

Biogas

Ww

AnMBR

32°C

Effluent

Pre-precipitation

Struvite

Heat utilisation

Heaters!

Stripping column and scrubber

22°C

Fertiliser

Ammonia

Heat utilisation

Concentrate

Discharge to the Dornoch Firth

RO membranes

Permeate

Barley fields

Cu rich sludge

Water reuse

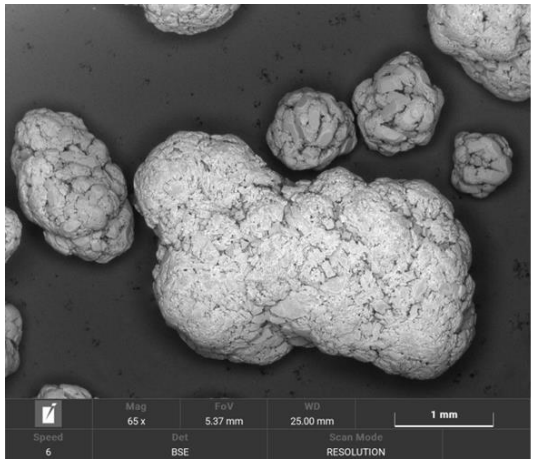
The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

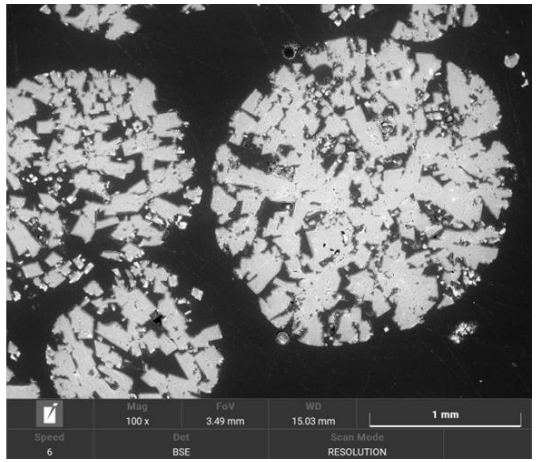
Precipitation

Struvite precipitation in FBR

- 7±5% TAN removal
- 62±15% PO_4-P removal



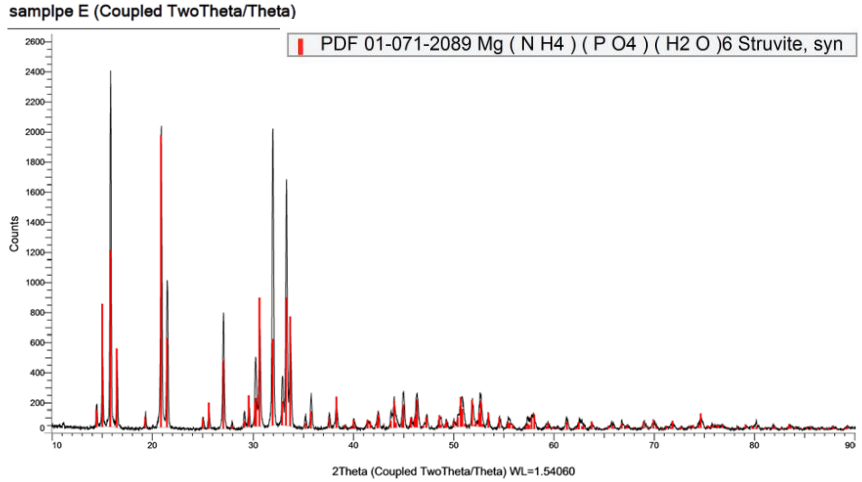




Elemental composition (%wt), n=26

	Theoretical	Granules
N	5.7	5.9±0.9
Mg	9.9	10.0±3.3
P	13.0	11.2±4.3
O	65.2	47.0±4.6

XRD analysis



Elemental composition of granules (%wt)

	[COD]	[Zn]	[Ni]	[Cu]	[Ca]	[K]	[Na]	[Cl]
Middle section	18.20%	0.00%	0.00%	0.00%	0.10%	0.30%	0.40%	0.90%
Bottom section	10.10%	0.00%	0.00%	0.00%	0.00%	0.50%	1.50%	1.20%

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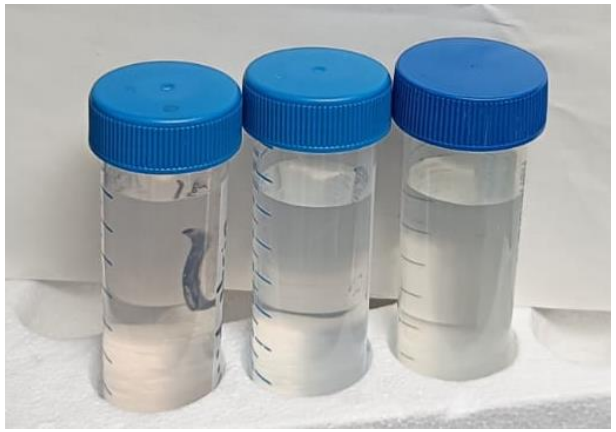
Stripping

Air stripping (and scrubbing)

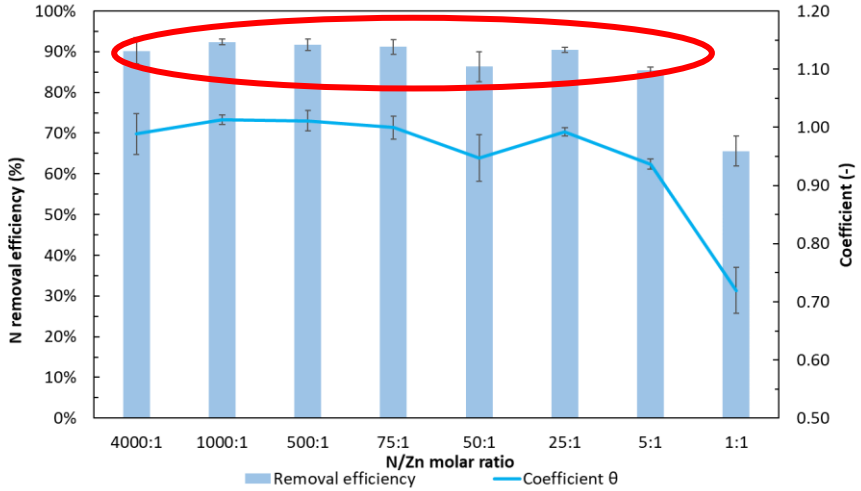
- 77±7% TAN removal



Lab-scale vacuum stripping at 67°C

- Up to 95% TAN removal





pH	EC	[TAN]	[SO4]	[COD]	[TOC]	[Mg]	[Ca]	[Na]
-	mS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1.93	57.3	10,230	21,652	681	30.81	0.0	3.89	0.0

Molar ratio
$SO_4/NH_4 = 0.4$

Organics contamination

Ammonium sulfate
$(NH_4)_2SO_4$
1 mol SO_4^{2-} : 2 mol NH_4^+ = 0.5

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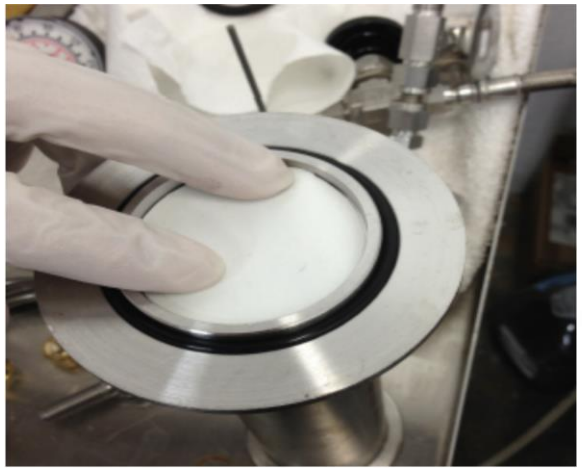
Reverse osmosis membranes





Flux	L/(m².h)
T = 20°C	7.3
T = 30°C	7.9
T = 40°C	8.2

	COD mg/L	TAN mg/L	PO4-P mg/L	TN mg/L	pH -	EC mS/cm
AnMBR effluent	523	920	193	900	7.87	2.1
Concentrate						
T = 20°C	1044 ± 174	1433 ± 86	343 ± 29	1460 ±139	8.29 ± 0.16	11.3 ± 2.7
T = 30°C	1157 ± 210	1493 ± 110	379 ± 26	1540 ±180	8.53 ± 0.02	13.7 ± 1.4
T = 40°C	985 ± 165	1393 ± 27	342 ± 8	1450 ± 50	8.52 ± 0.11	12.6
Permeate						
T = 20°C	20 ± 6	101 ± 5	4 ± 0.2	119 ± 25	8.56 ± 0.55	0.72 ± 0.4
T = 30°C	46 ± 40	147 ± 17	6 ± 1.3	151 ± 22	9.08 ± 0.1	1.1 ± 0.1
T = 40°C	31 ± 15	137 ± 29	5 ± 1.8	96 ± 54	9.10 ± 0.22	1.0

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WATER SMART INDUSTRIAL SYMBIOSIS

Thank you!

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Ultimate Webinar / Workshop

Heat recovery and reuse



CS8 - SUEZ RR IWS CHEMICALS

CS8: Heat recovery

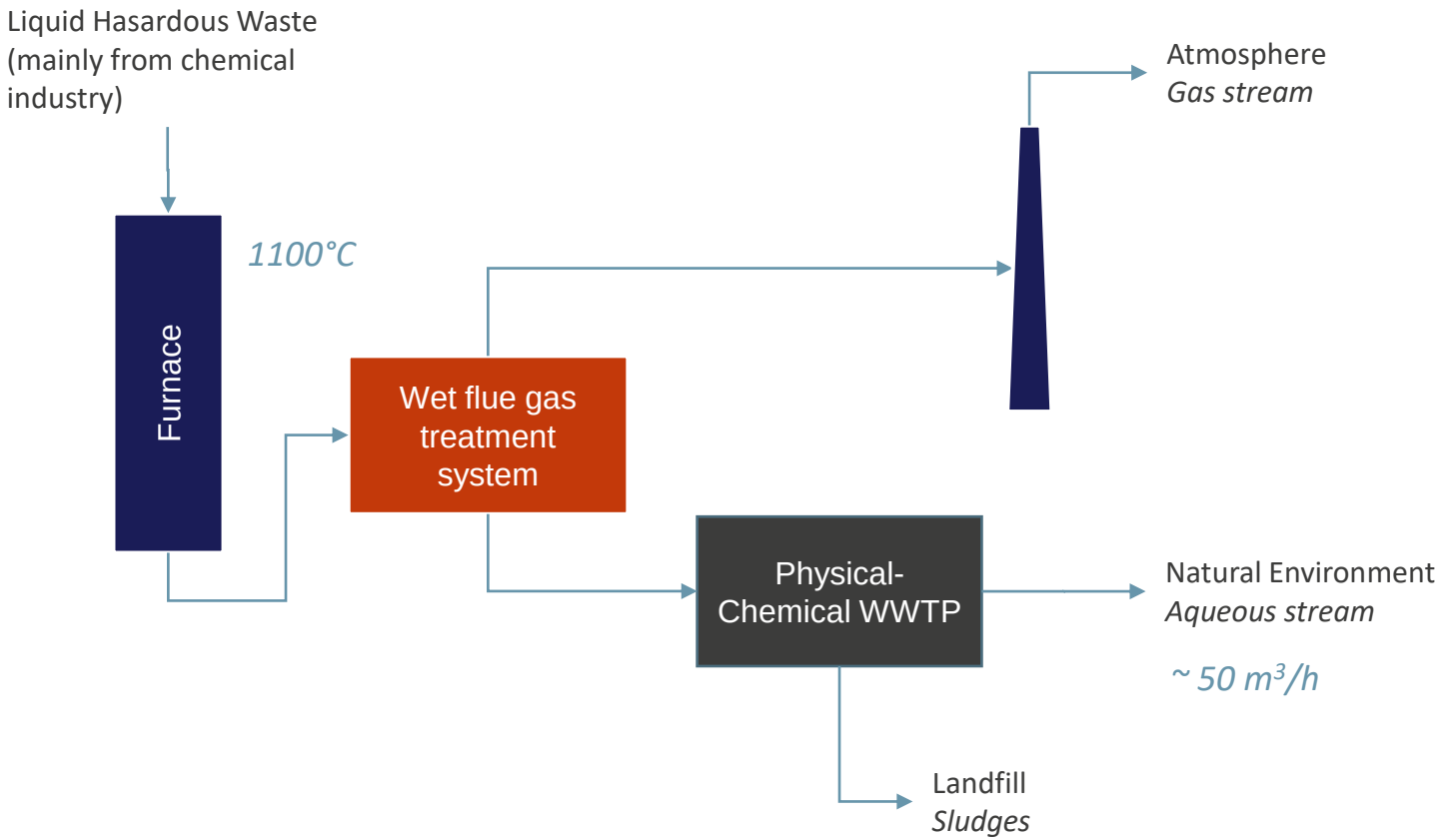
Subtask: **1.3.6 Feasibility study for recovery of heat from flue gas washing water at the chemical platform of Roussillon**

Context :

Hasardous waste incineration unit on the chemical platform of Roussillon

Specialised in aqueous waste with high salt content.

This particularity results in a flue gas containing a large amount of dust, mainly composed of molten salts, which are not compatible with the installation of a boiler for steam production.



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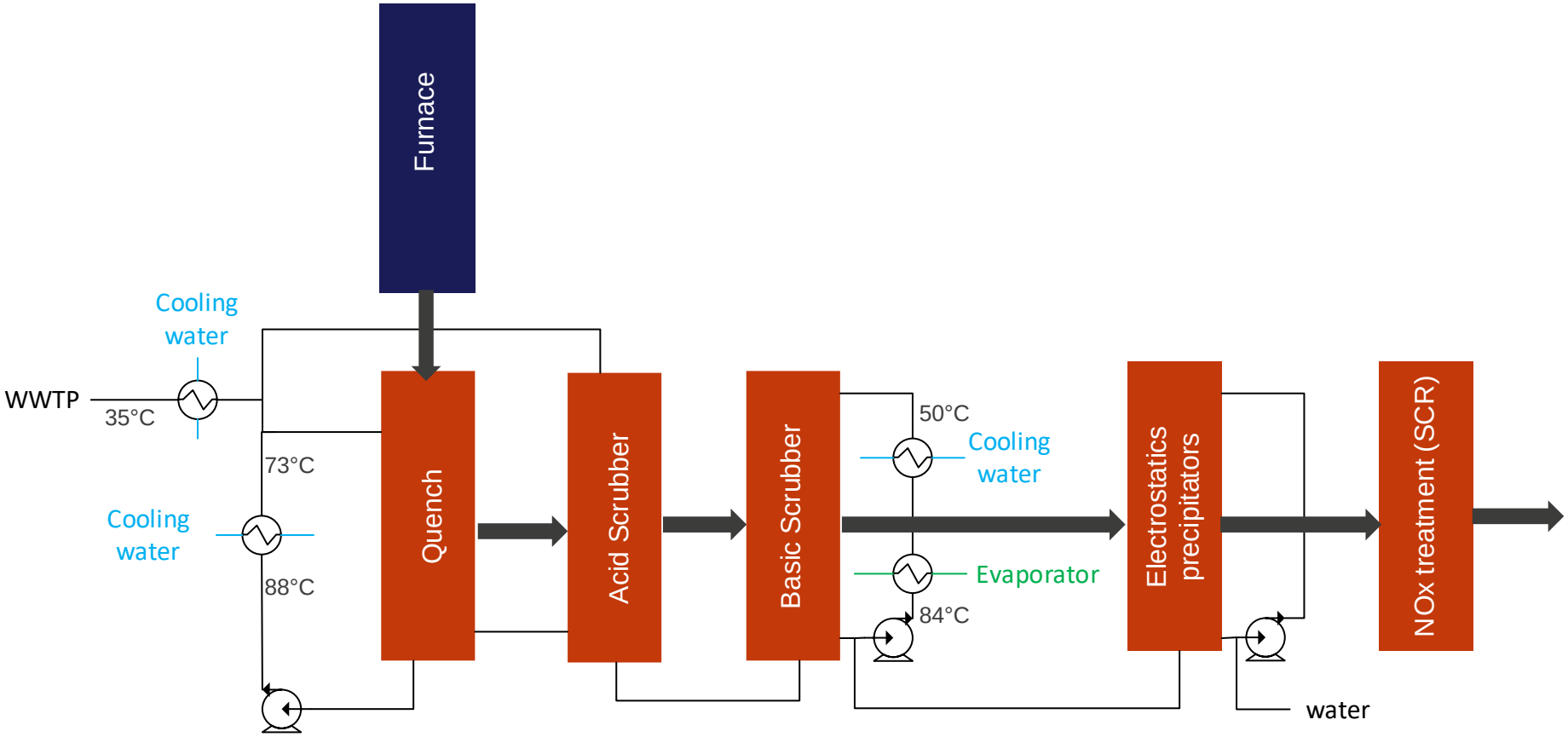
CS8: Heat recovery

Subtask: **1.3.6 Feasibility study for recovery of heat from flue gas washing water at the chemical platform of Roussillon**

What's in place ?

Implementation in 2013 of a vacuum evaporator.

Heat containing in washing water is used to increase the temperature of aqueous waste in the evaporator.



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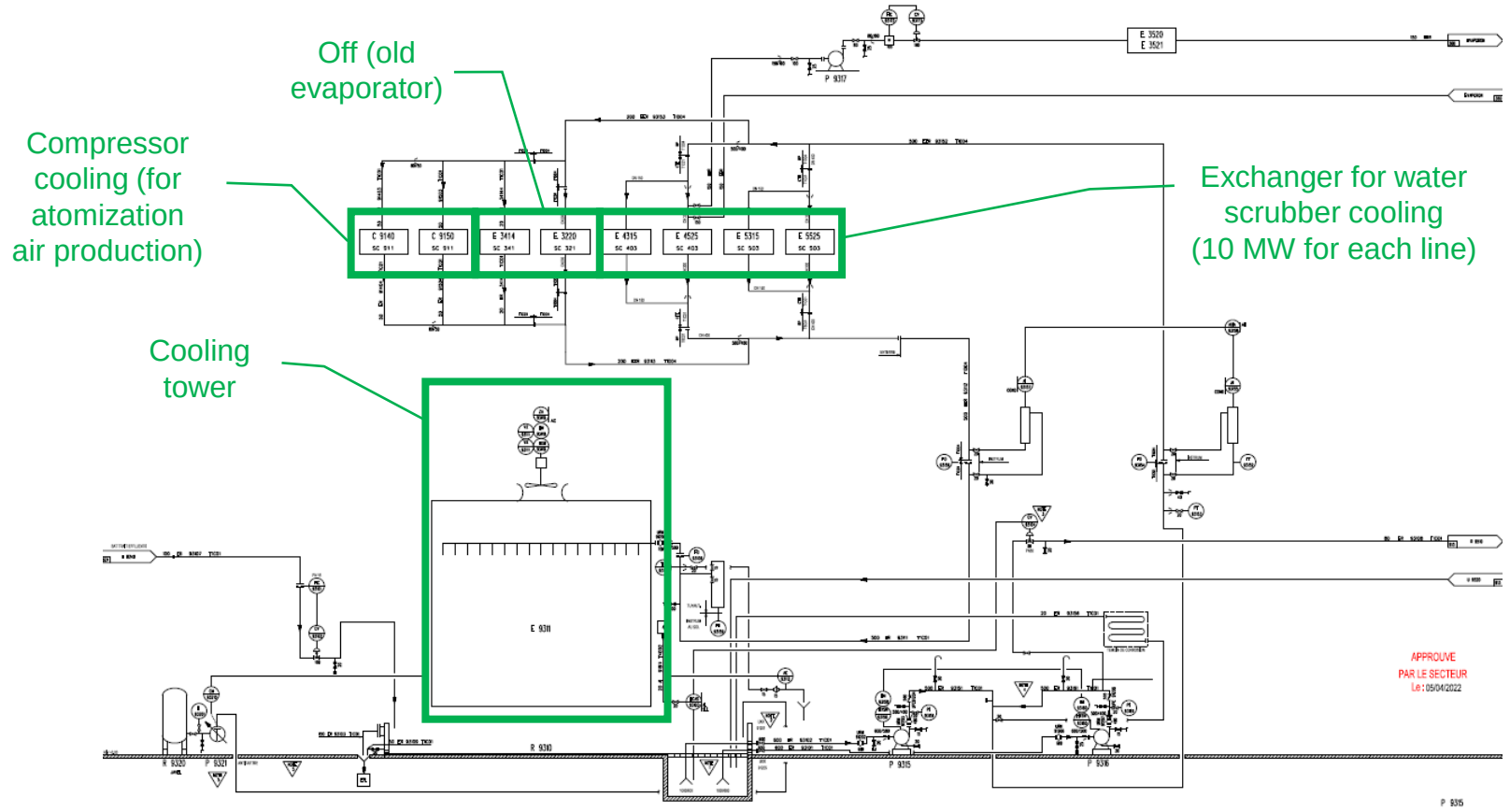
CS8: Heat recovery

Subtask: 1.3.6 Feasibility study for recovery of heat from flue gas washing water at the chemical platform of Roussillon

Energy recovery studies :

Characteristics of washing water is still a technical obstacle for direct heat recovery (risk of clogging and corrosion due to very high salt content).

Energy recovery studies focused on cooling water.



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CS8: Heat recovery

Subtask: 1.3.6 Feasibility study for recovery of heat from flue gas washing water at the chemical platform of Roussillon

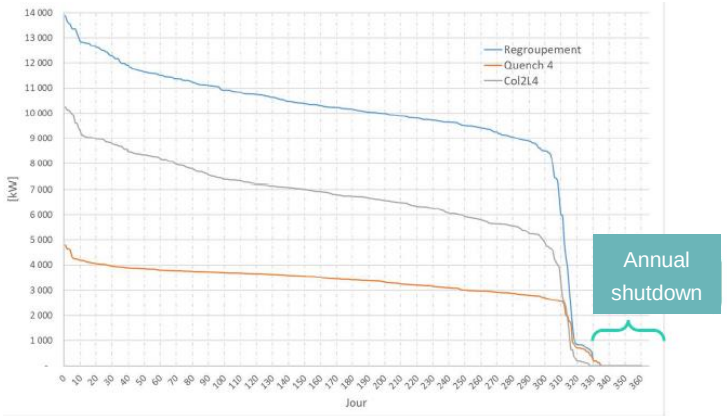
Step 1 : Assessment of energy recovery potential

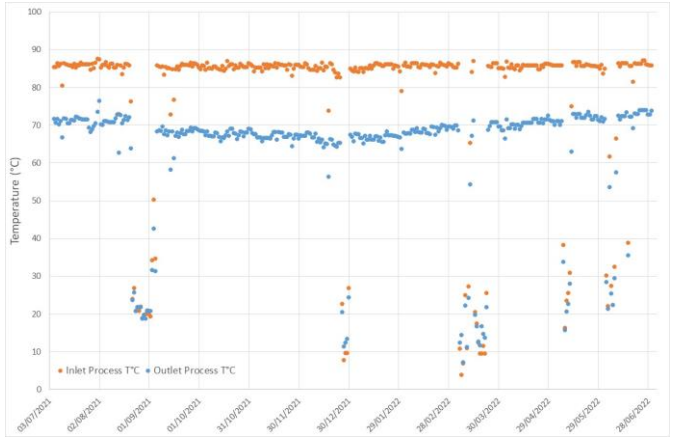
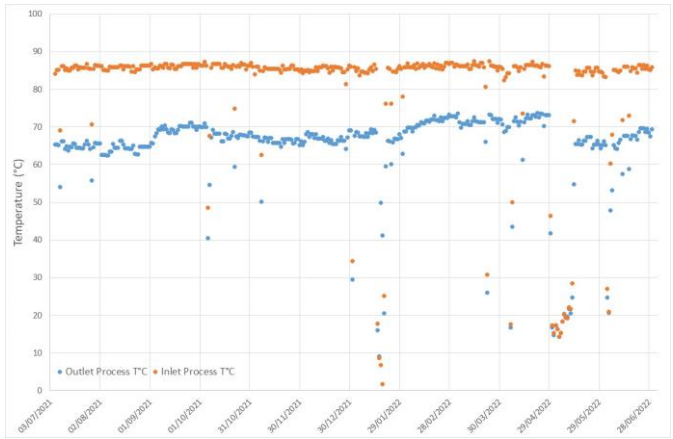
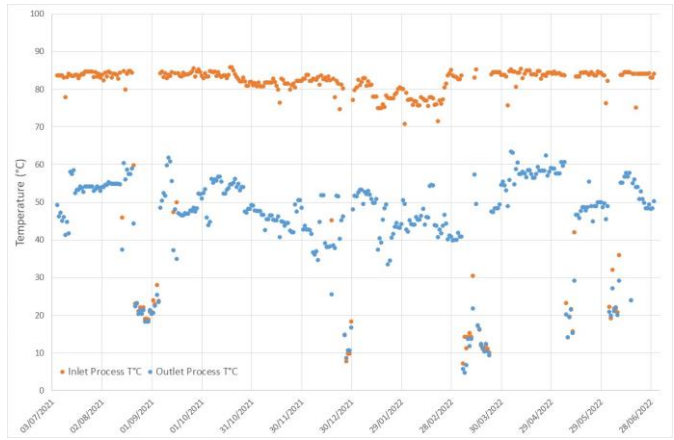
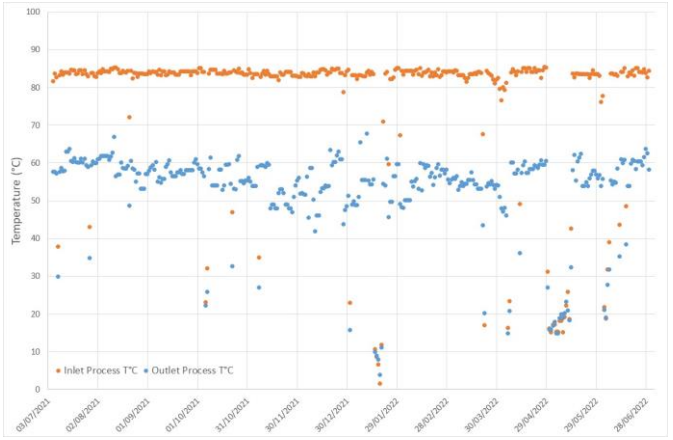
One year data analysis :

- Inlet and outlet process temperatures and washing water flow of each heat exchanger
- Inlet and outlet temperatures of the cooling tower

Results :

- About 10 MW on each incineration line



Quench and Acid scrubber heat exchanger		
Basic scrubber heat exchanger		

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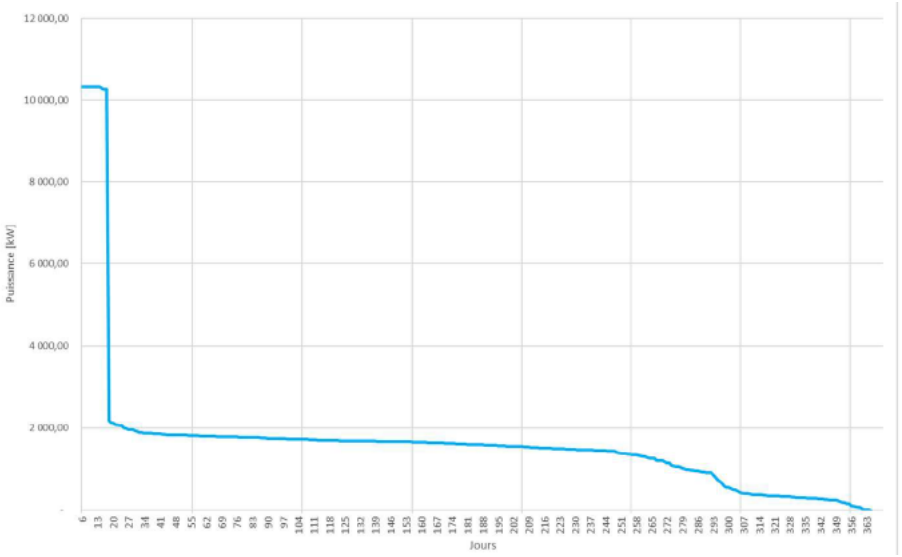
CS8: Heat recovery

Subtask: **1.3.6 Feasibility study for recovery of heat from flue gas washing water at the chemical platform of Roussillon**

Step 2 : assessment of energy consumption

- 6 bar steam regular consumption for :
  - Air combustion preheating
  - Injection of vent (gas)
  - Temperature control of some storages

- 2 bar steam irregular consumption for :
  - Pipe tracing
  - Feeding of tank heating coil



Self-consumption scenarios aren't sufficient to reach the 25% energy recovery target.
It is essential to find additional consumers.

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CS8: Heat recovery

Subtask: 1.3.6 Feasibility study for recovery of heat from flue gas washing water at the chemical platform of Roussillon

Step 3 : which technologies ?

Heat pump for steam production

Calculation assumptions

2 technologies in series :

- A heat pump for simultaneous heating and cooling
- A vapor-compression heat pump

Heat sources :

- Recovery on 1 or 2 heat exchangers
- Recovery on 1 or 2 incineration lines

Recovery form :

- 6 bar steam
- 4 bar steam
- 2 bar steam

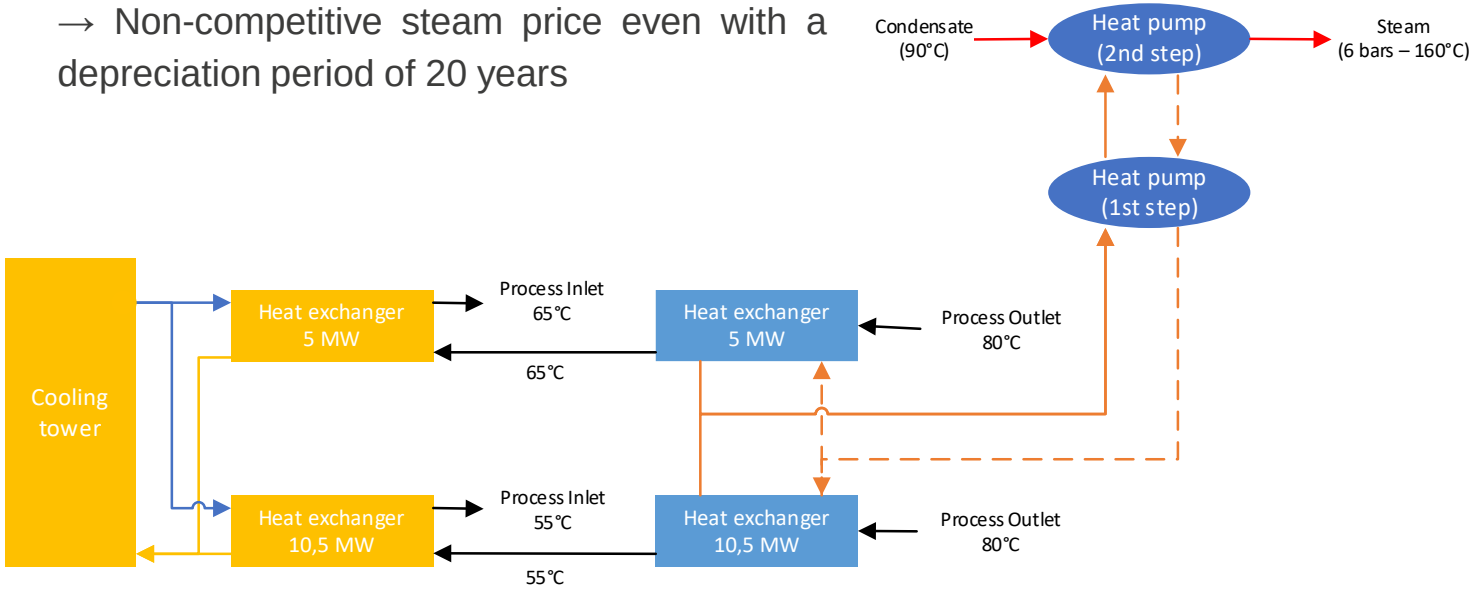
Results :

- High estimated OPEX : 0,5 to 1 MW of electricity consumed for 1 MW of heat recovered

→ Unsatisfying overall energy performance

- High estimated CAPEX : from 13 to 38 M€

→ Non-competitive steam price even with a depreciation period of 20 years



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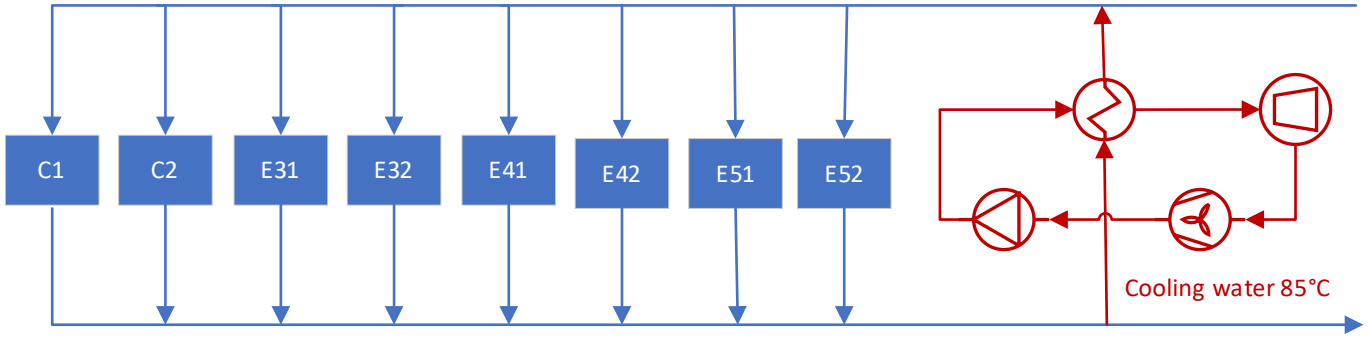
CS8: Heat recovery

Subtask: 1.3.6 Feasibility study for recovery of heat from flue gas washing water at the chemical platform of Roussillon

Step 3 : which technologies ?

ORC for electricity production - Energy recovery from the cooling water of the exchangers



Calculation assumptions :

- Water temperature = 85°C
- Water flow for one ORC = 80 m^3/h

Results :

- Electricity production of one ORC : 40 kW
- Maximal electricity production : 340 kW
- Estimated CAPEX for one ORC (without implementation) : 400 k€

→ Insufficient return on investment

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CS8: Heat recovery

Subtask: 1.3.6 Feasibility study for recovery of heat from flue gas washing water at the chemical platform of Roussillon

Step 3 : which technologies ?

ORC for electricity production - Energy recovery from the flue gas

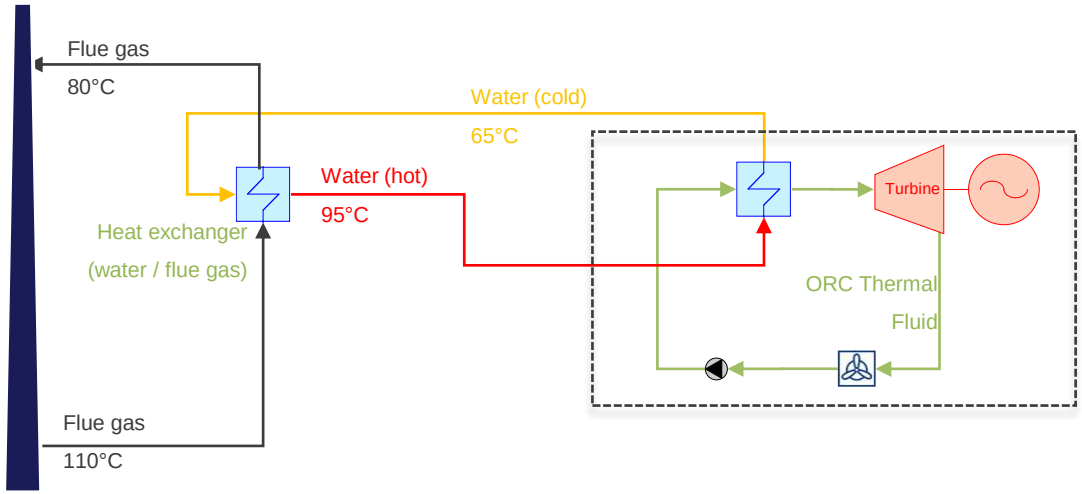
Calculation assumptions :

- Flue gas temperature = 110°C
- Flue gas flow (for the 2 incineration lines) = 50 000 Nm^3/h

Results :

- Electricity production : 40 kW
- Estimated CAPEX (without implementation) : 400 k€

→ Insufficient return on investment



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CS8: Heat recovery

Subtask: 1.3.6 Feasibility study for recovery of heat from flue gas washing water at the chemical platform of Roussillon

Conclusion on the task of energy recovery

Context :

- Roussillon site is today a hazardous waste treatment plant without energy recovery
- The site want to implement an energy recovery process, with a target of 25% of the heat exchangers energy recovered

Consequences :

The technologies studied for energy recovery from washing water either :

- do not meet the recovery target
- have a too high return on investment time
- are highly energy demanding to achieve a usable form of energy

Studies must be reoriented.

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WATER SMART INDUSTRIAL SYMBIOSIS

Contacts

anne.reguer@suez.com

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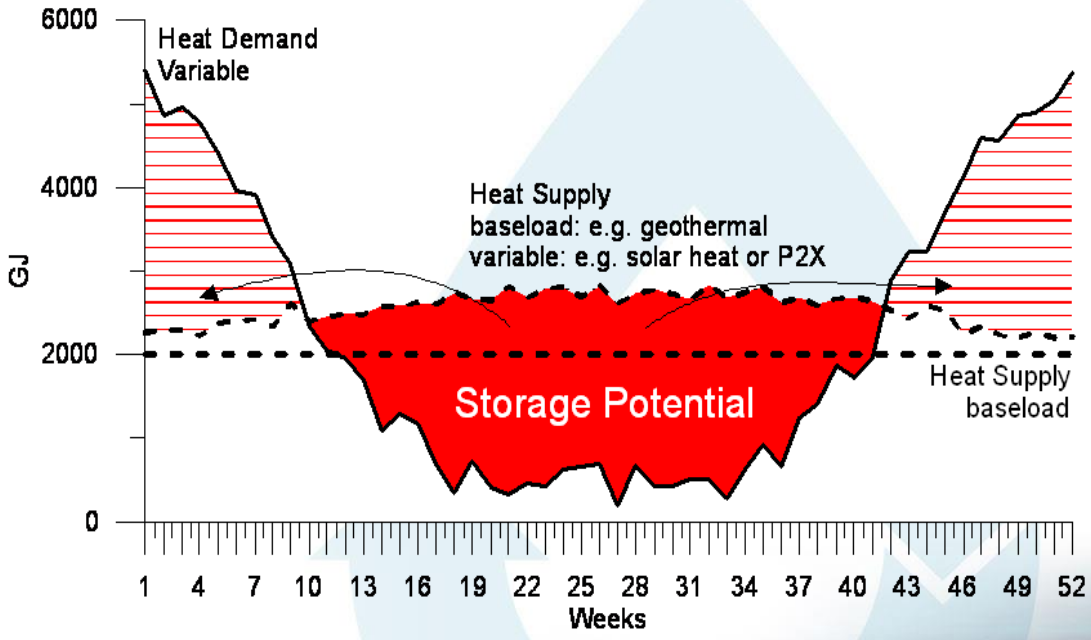


Heat storage in aquifers

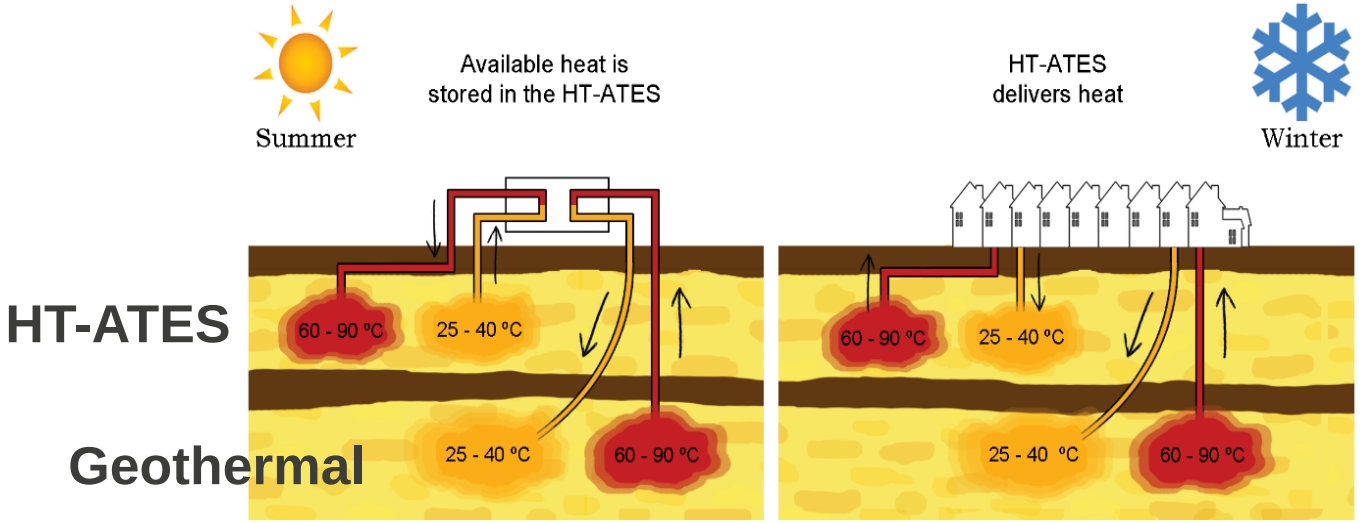
Symbiosis between geothermal heat and heat storage for greenhouses

Dr. M. Bloemendal, S. Beernink

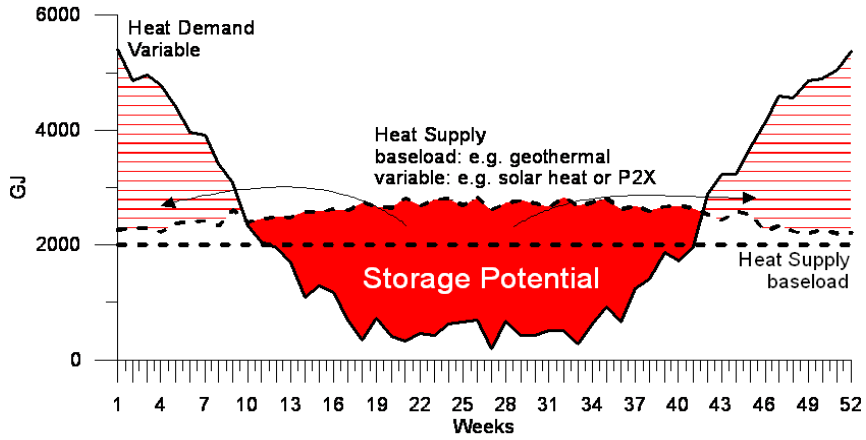


Introduction

- Geothermal doublets deliver baseload renewable heat



- Heat storage in aquifers (HT-ATES) allows to:
  - Decrease needed geothermal capacity
    → increase project lifetime and reduce investment costs
  - Deliver more heat year round for (additional) greenhouses



- General potential for combining geothermal and HT-ATES is high. However, subsurface suitability for HT-ATES application is uncertain in many places, because deeper and less favourable aquifers are targeted for this.

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GOALS

1. Demonstrate potential and benefit of HT-ATES for greenhouses heated by geothermal energy, by carrying out a HT-ATES feasibility study for TRIAS Westland greenhouse area.
2. Demonstrate a cost-effective method to identify and characterize suitable aquifers for HT-ATES, by combining the drilling of a geothermal well with logging and screening of potential HT-ATES aquifers

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

→ HT-ATES is technically and economically feasible at the TRIAS Westland case.

- Aquifer with suitable thickness and depth is available in the local subsurface
- Given the high baseload heat demand at this site, the relative contribution is limited. Which indicates that feasibility is generally better at other sites.

→ Combination of geothermal conductor drilling and subsurface exploration drilling for HT-ATES is a cost-effective win-win combination

- At an additional cost of about 30 k€ subsurface feasibility for HT-ATES was obtained.
- The required investment is about 3-6 times cheaper than a dedicated test drilling and the costs are <1% of the drilling costs for the geothermal doublet.

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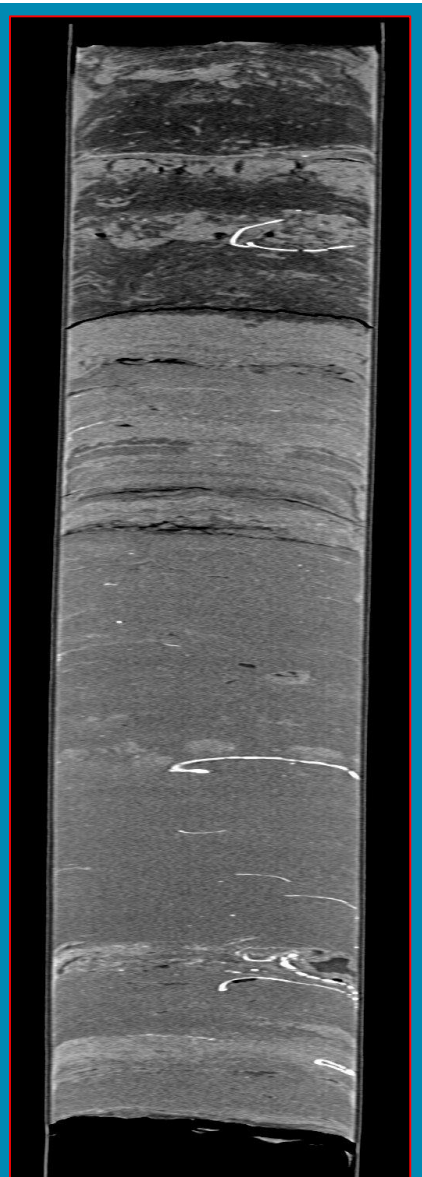
Data acquisition for HT-ATES during geothermal drilling





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GOAL

1. Demonstrate a cost-effective method to identify and characterize suitable aquifers for HT-ATES, by combining the drilling of a geothermal well with logging and screening of potential HT-ATES aquifers

Approach

Develop a (combination of) method(s) for logging and screening of possible suitable layers while drilling geothermal wells

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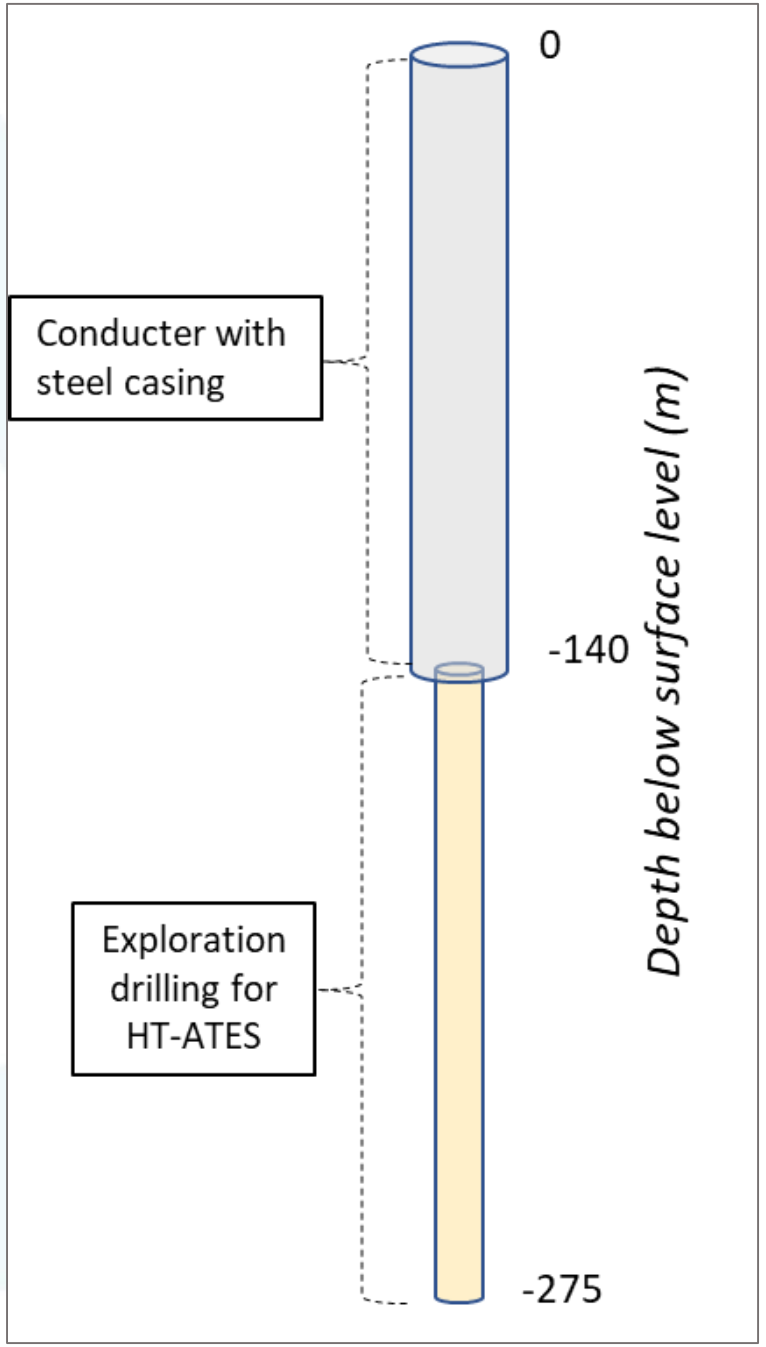
Rationale behind approach

- Geothermal wells are drilled in multiple sections with decreasing diameter with increasing depth.
- Upper most section is often drilled with a smaller rig.

  Such rigs usually have a daily rate which is a factor 10 smaller than the rate of the rig need to drill the geothermal wells to several km depth (~5k€ vs ~50k€ per day, resp.)
- Using that smaller rig or the time window between changing rigs allows for cost effective data gathering
- Dedicated test drilling would require an investment of about 100-200 k€, depending on local conditions and required logging/testing.



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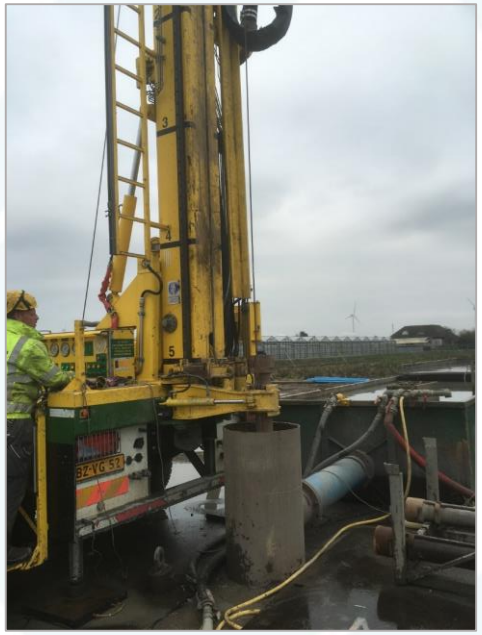
Exploration drilling

- Innovative method: integration of data acquisition for HT-ATES with geothermal well (conductor) drilling
- Drilling performed in Q1 2022



Picture of the drilling rig in action



Location of drilling

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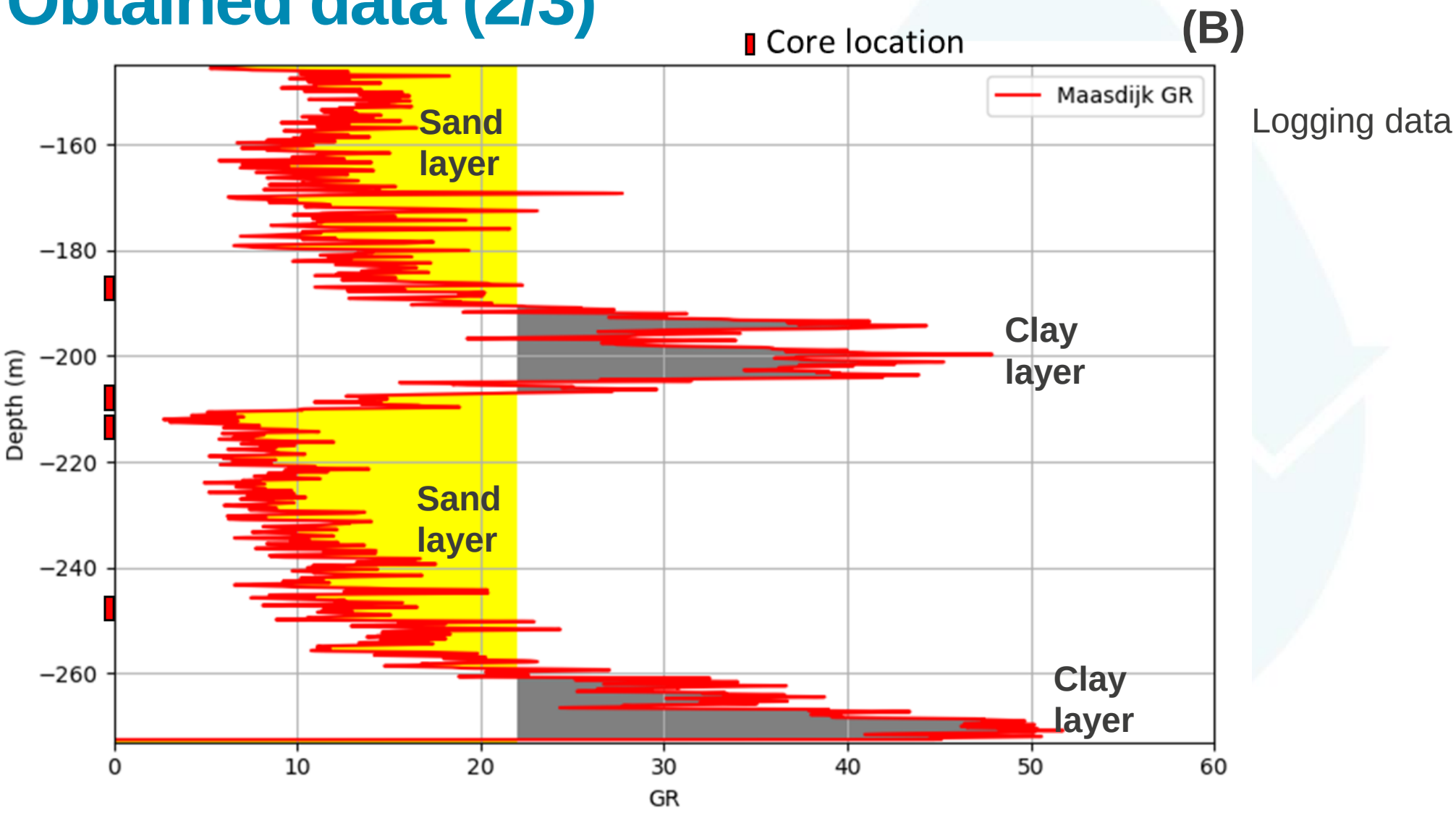
Obtained data (1/3)

Sediment cuttings at 1m accuracy



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

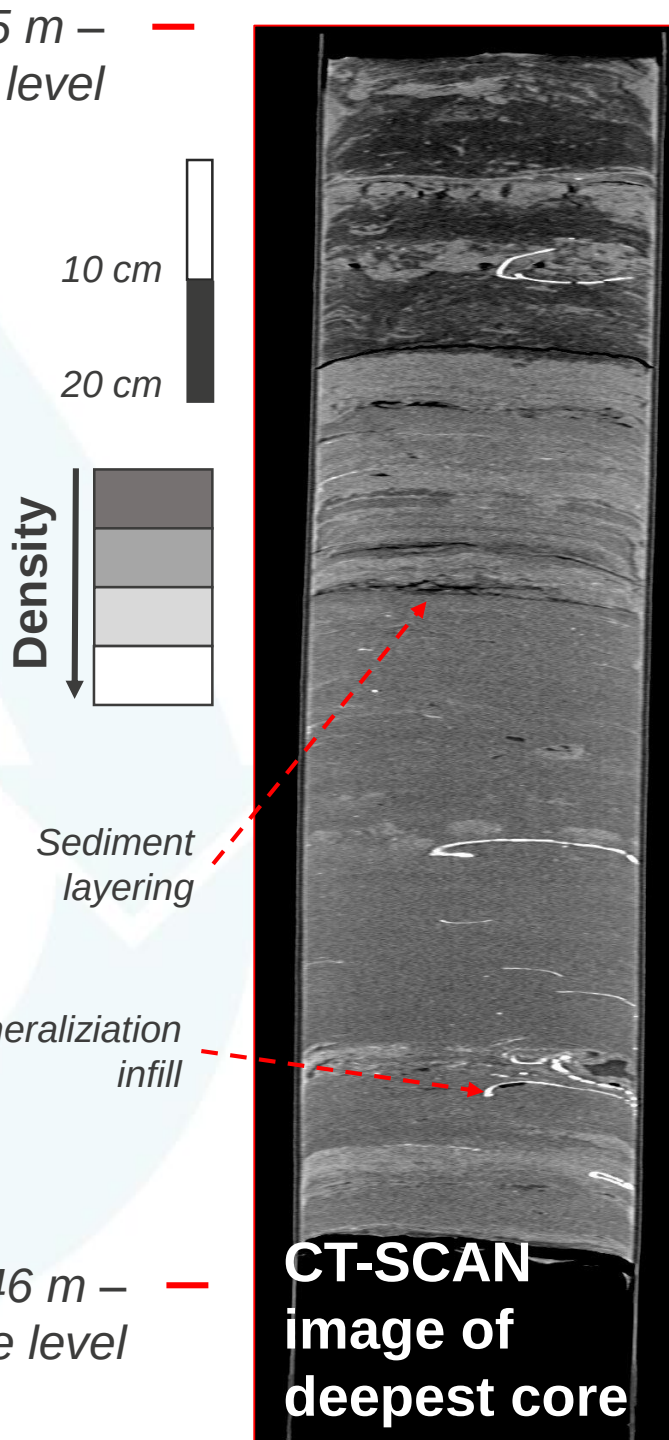
Obtained data (2/3)



Logging data

Obtained data (3/3)

Cores for scanning and experiments



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

Obtained insights

→ Insight in variability of subsurface properties on multiple scales:

- → Logging data & cuttings: 1m to 10m scale
- → Sediment cores: mm to m scale

→ Combination of geothermal conductor drilling and subsurface exploration drilling for HT-ATES is a cost-effective win-win combination

- → At an additional cost of about 30 k€ subsurface feasibility for HT-ATES was obtained.
- → The required investment is about 3-6 times cheaper than a dedicated test drilling and the costs are <1% of the drilling costs for the geothermal doublet.

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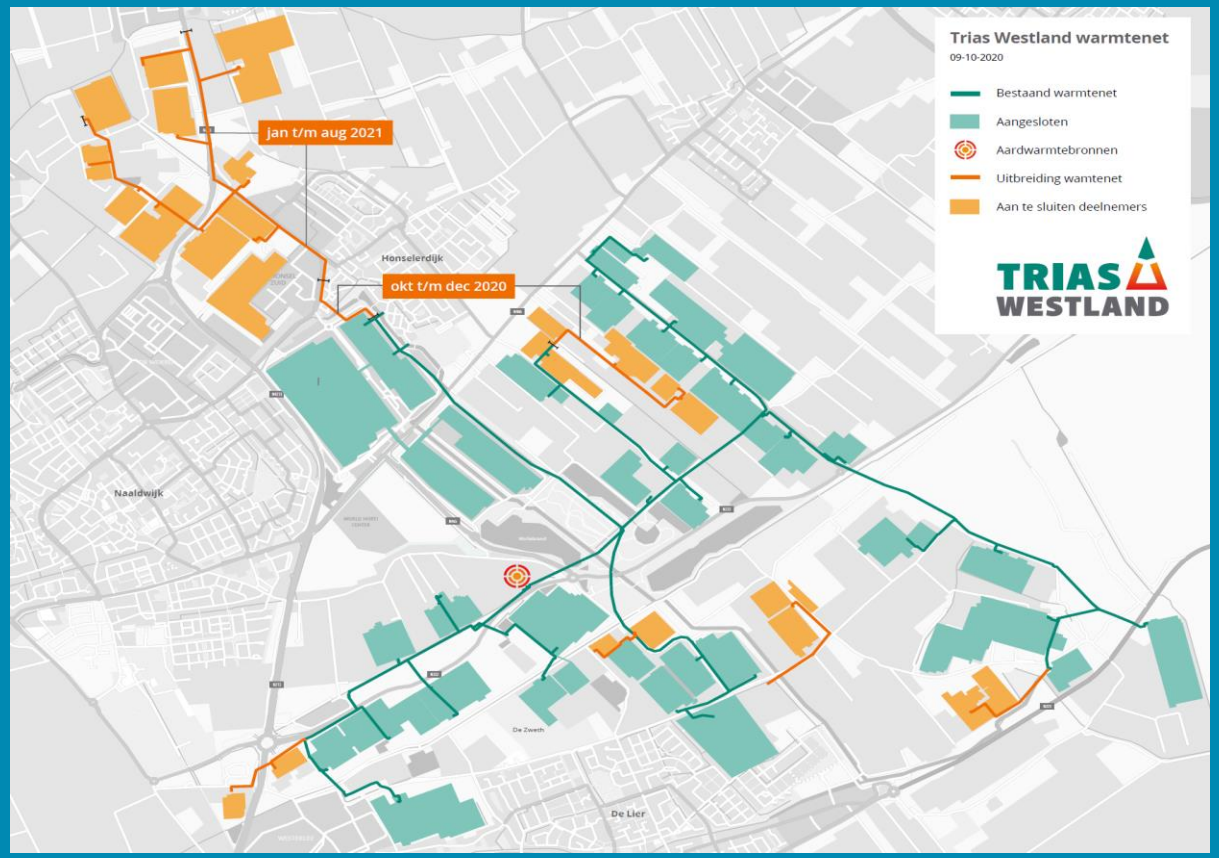
HT-ATES Feasibility for greenhouses TRIAS Westland



TRIAS Westland heat grid and connected users

GOAL

Demonstrate potential and benefit of HT-ATES for geothermal heated greenhouses, by carrying out a feasibility study for TRIAS Westland greenhouse area.

Approach

Identify the (technical, economic, legal, environmental) feasibility of HT-ATES for the TRIAS Westland project. This is assessed together with the site developer/owner (HVC). This includes:

- Identification of the required HT-ATES characteristics.
- Identification of most suitable layers and establishment of a preliminary design of the wells.
- Cost-benefit and legal analysis

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

Heat supply and demand

- Heat demand is large
  + Enough possibility to supply heat
  - also in summer months still >20MW heating demand. Hence, uncertainty to be able to have enough heat available to store in Summer
- Depending on conditions, HT-ATES could be 40-75 TJ of total storage volume,
  + facilitating an addition 6% of total heat delivery
  + 60 TJ is most likely scenario, resulting in required 430,000 m^3 storage volume and 244 m^3/h well capacity

Scenario	GT [MW]	Total heat utilised* [TJ] [%]***	Utilised from HT-ATES** [TJ]	HT-ATES Volume [Mm^3]	HT-ATES capacity [MW – m^3/hr]
0.No HT-ATES	45	1 315 92%	-	-	-
1.HT-ATES	45	1 390 98%	75	0.52	25 - 410
2.HT-ATES with min 30 MW delivery	45	1 375 96%	60	0.43	15 - 244
3. HT-ATES with GT 35 MW in summer	45-35	1 355 98%	40	0.31	25 - 410

*please note that at 45MW 24/7 the total yield from the geothermal wells is 1420 TJ/year. When GT production is reduced to 35MW in July and August, total yield is 1370 TJ/year.
**taking into account an initial estimation of the losses in HT-ATES: 30% for case 1 and 35% for case 2, and 40% for case 3.
***total percentage of heat coming from GT utilised

Subsurface feasibility

Required characteristics for HT-ATES aquifer

	Shallow	Deep
Pro	Cheap drilling Hell known layers High capacity	Higher ambient groundwater temperature, fewer losses Less impact to other groundwater users Low hydraulic conductivity, limiting buoyancy flow Less change for microbiological effects
Con	Potential negative impact to other groundwater users More heat losses Change for microbiological activity	Low hydraulic conductivity, limiting capacity, increasing costs Extra regulations concerning the Mining law. Higher drilling costs More uncertainties about characteristics

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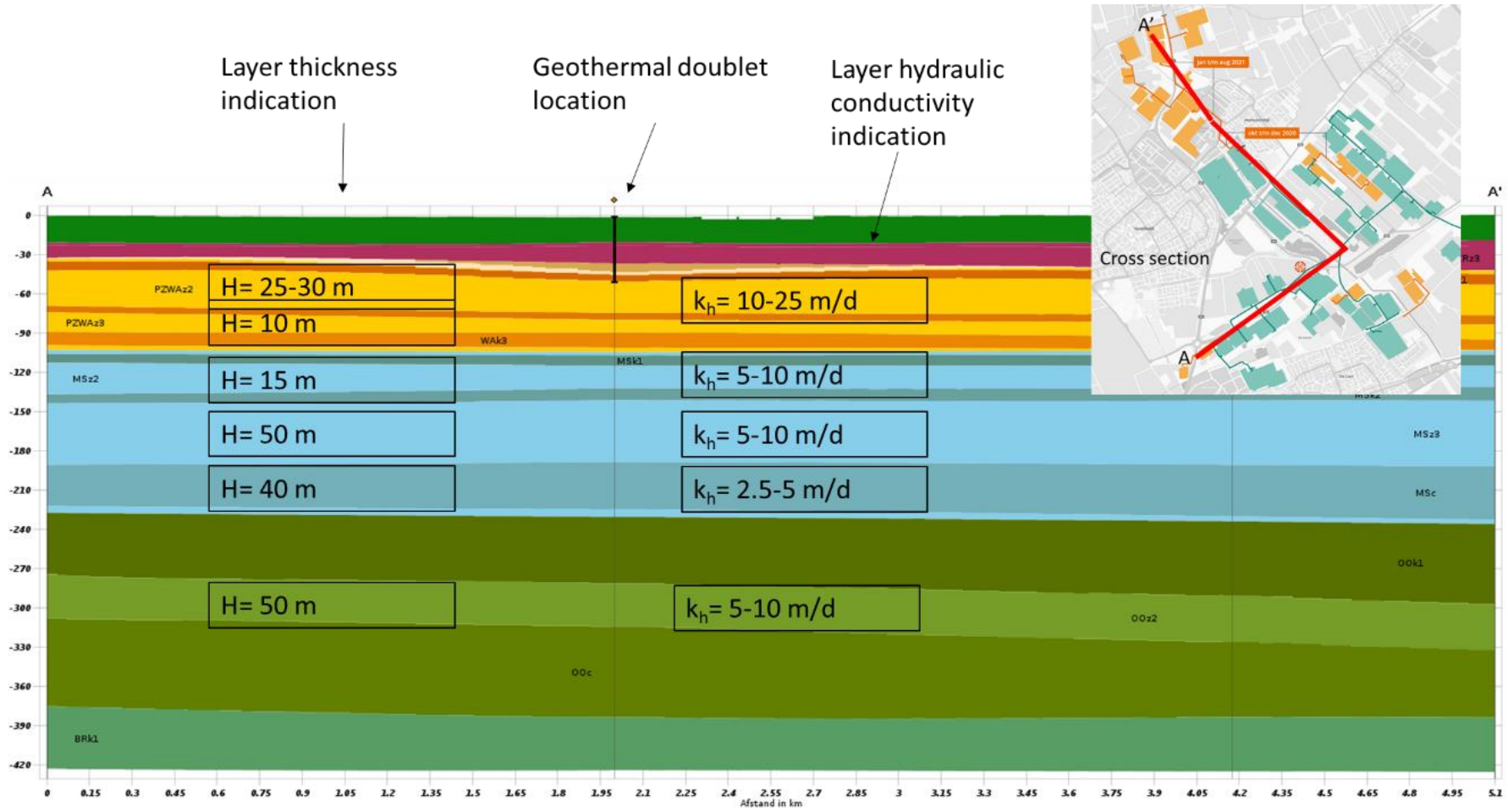
Subsurface feasibility

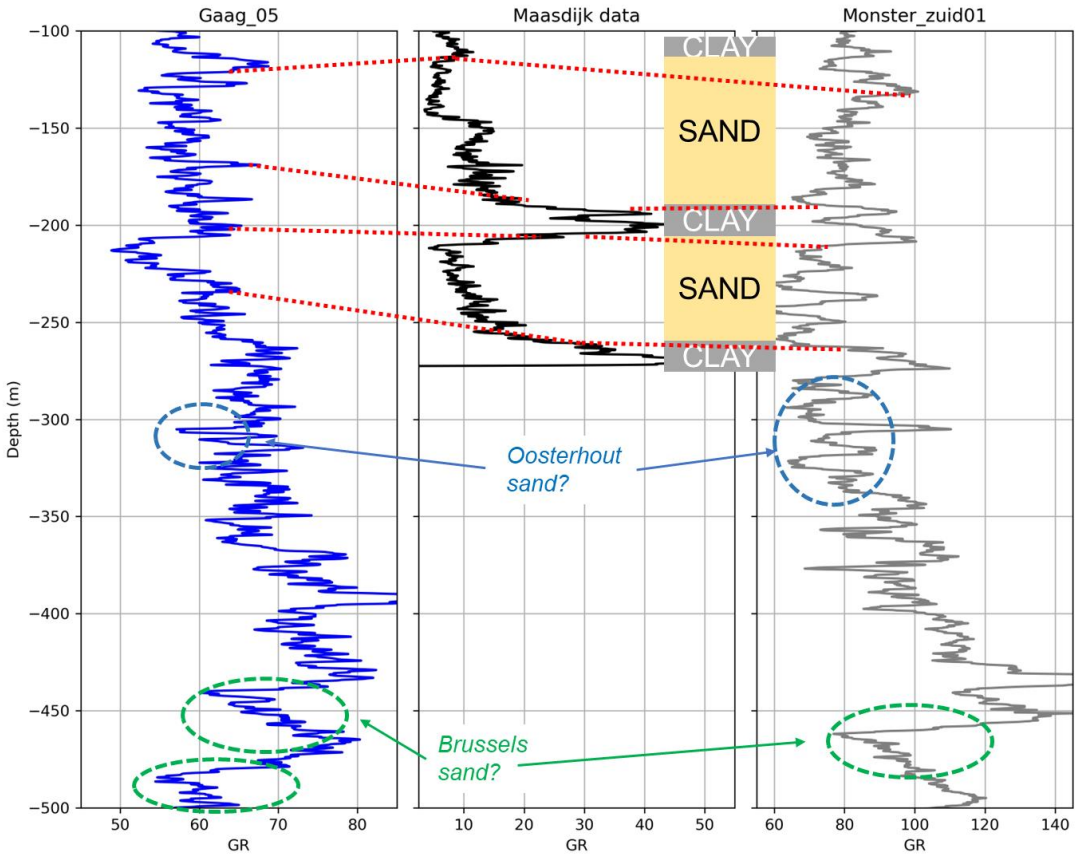
Known subsurface composition



Shallow aquifers (<150m depth) cannot not be used

Composition, thickness and depth of deeper layers strongly uncertain

After data acquisition



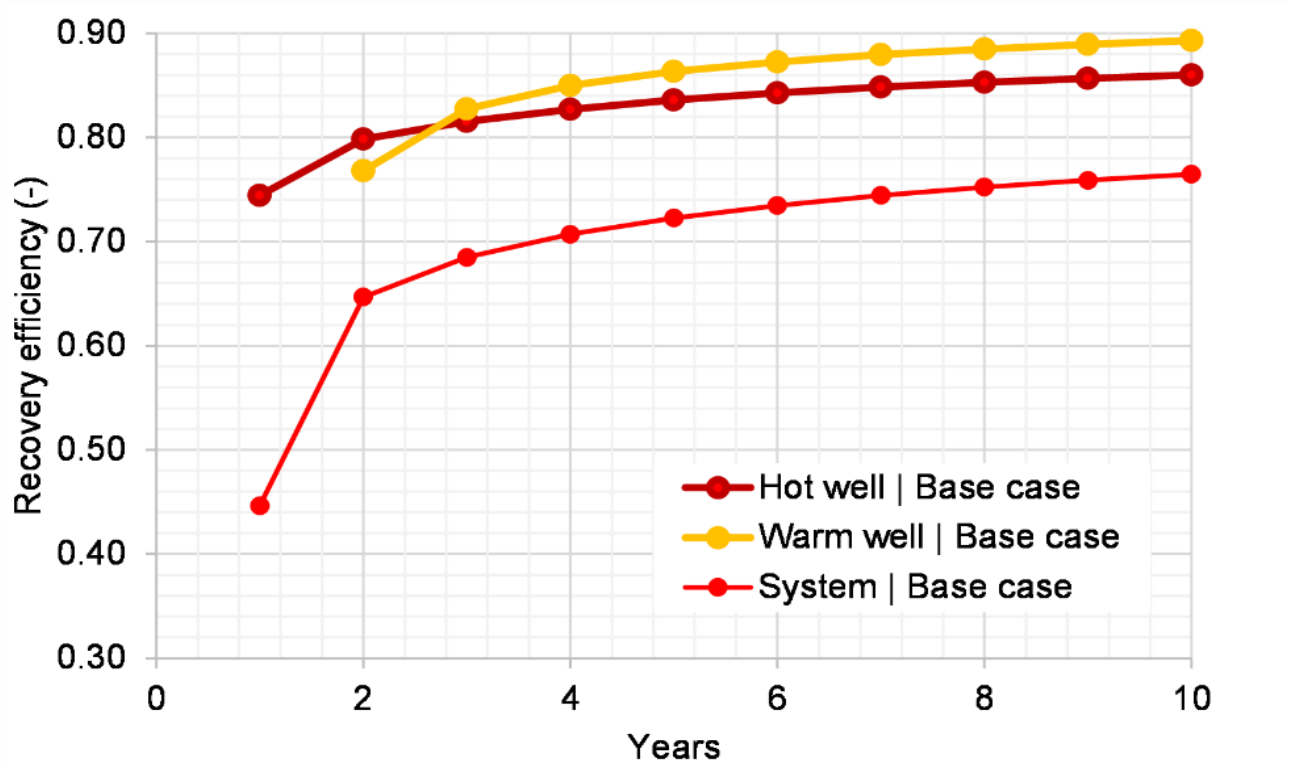
Clarity on thickness and composition of layers between 150-300m depth.

Layer of 210-240m depth is most suitable.

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

Simulation results

- All HT-ATES sizes with best estimate subsurface conditions gives good expected recovery efficiency
- Only with higher than expected vertical permeability system efficiency drops below 60%



Financial feasibility

Required upfront investment: 3-5 M€

Savings / year: ~1 M€

COSTS	75 TJ	60 TJ	
Total OPEX costs	664	528	k€/year
(based on total maintenance + electricity)			
Yearly depreciation	853	571	k€/year
(CAPEX is written of over 5 years)			
Total	1,517	1,099	k€/year

REVENUES	75 TJ	60 TJ	
Total emission reduction savings	106	85	k€/year
Total natural gas purchase reduction savings	2,381	1,905	k€/year
Total savings due to HT-ATES installation	2,487	1,989	k€/year

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Legal feasibility

- HT-ATES is allowed, but requires special permit from province
- Province of Zuid-Holland is open for HT-ATES pilots to explore use, effects and contribution to the energy transition

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Conclusions HT-ATES suitability TRIAS Westland

→ Enough heat available in Summer for creating an efficient HT-ATES

→ Sand aquifer with suitable thickness is available in Maassluis formation

→ HT-ATES is financially feasible with an ROI of about 3-5 years

→ Timely coordination with Province is needed to obtain clarity on permit

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ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

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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

water mining
value for society

Heat recovery for brine treatment – **WATER-MINING**

Presenter: Dr. Dimitris Xevgenos, Exec. Project Coordinator, TU Delft
Dr. Alessandro Trezzi, SWS - Saline Water Specialists, A division of SOFINTER SpA

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

water mining

value for society

Next generation water-smart management systems: large scale demonstrations for a circular economy and society

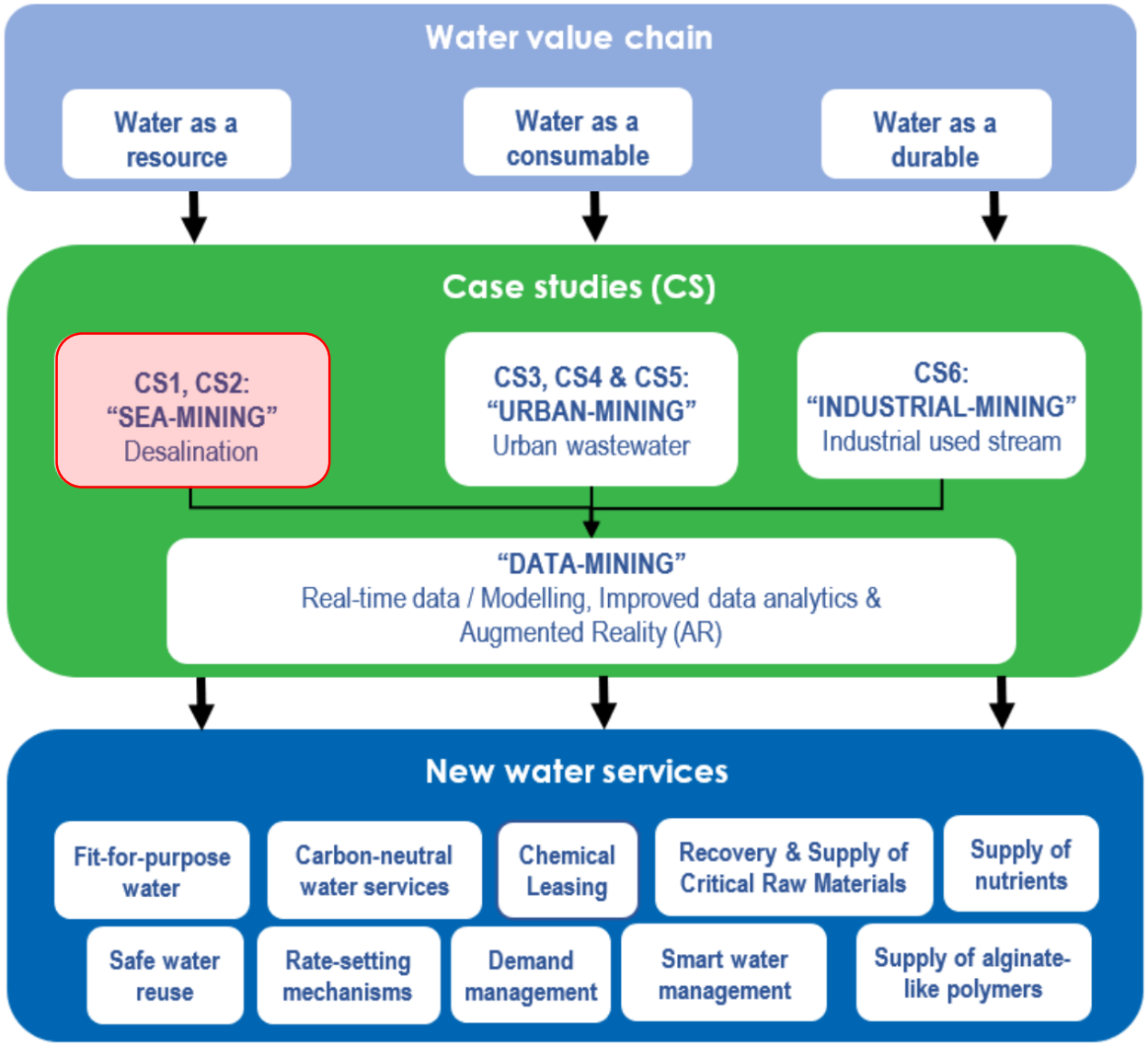
WATER-MINING: Overview

- **Partners:** **38** (from 12 countries)
- **Coordination:** **TU DELFT** (Applied Sciences faculty)
- **Project Budget:** **19,174,543.75 €**
- **EC Funding:** **16,876,959.63** (~88% of total budget)
- **Duration:** **48 months**
  - **Start date:** **01/09/2020**
  - **End date:** **31/08/2024**

WATER-MINING: Partners



WATER-MINING: Concept



SEA-MINING



ITALY - see Table 2



SPAIN, see Table 3

URBAN-MINING



NETHERLANDS – see Table 4



PORTUGAL – see Table 4



CYPRUS – see Table 5



SPAIN – see Table 6

INDUSTRIAL-MINING



NETHERLANDS – see Table 7



INDIA – see Table 7

CS1: Waste heat driven desalination & sustainable brine management



- Location: Mediterranean Sea
- Population: 6,556 residents
- Desalination: 3,500 m3/day (covering **100%** of drinking water needs, accounting for **10%** of total energy consumption)
- Power: 22 MWe (diesel power engines)

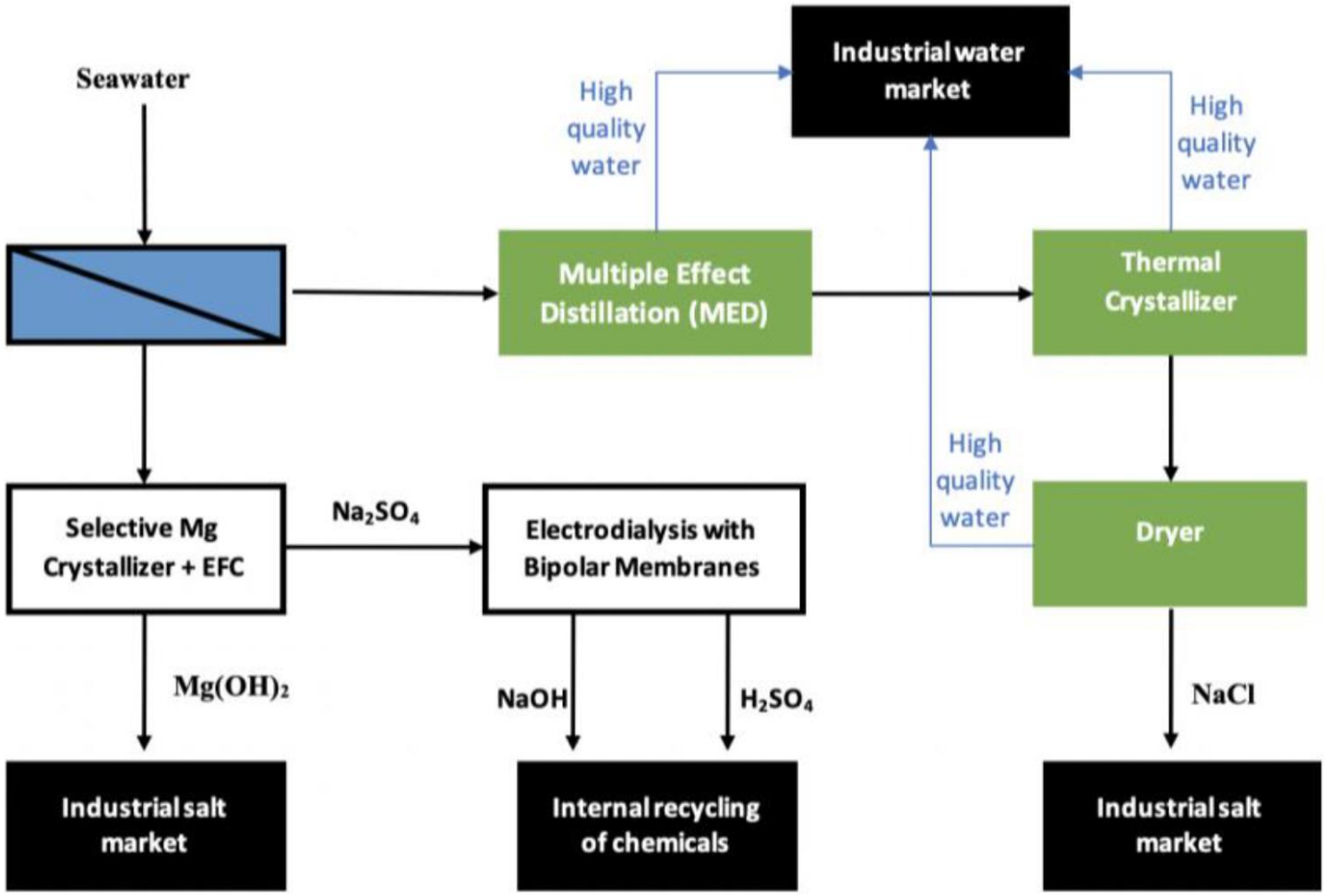
CS1

Italy

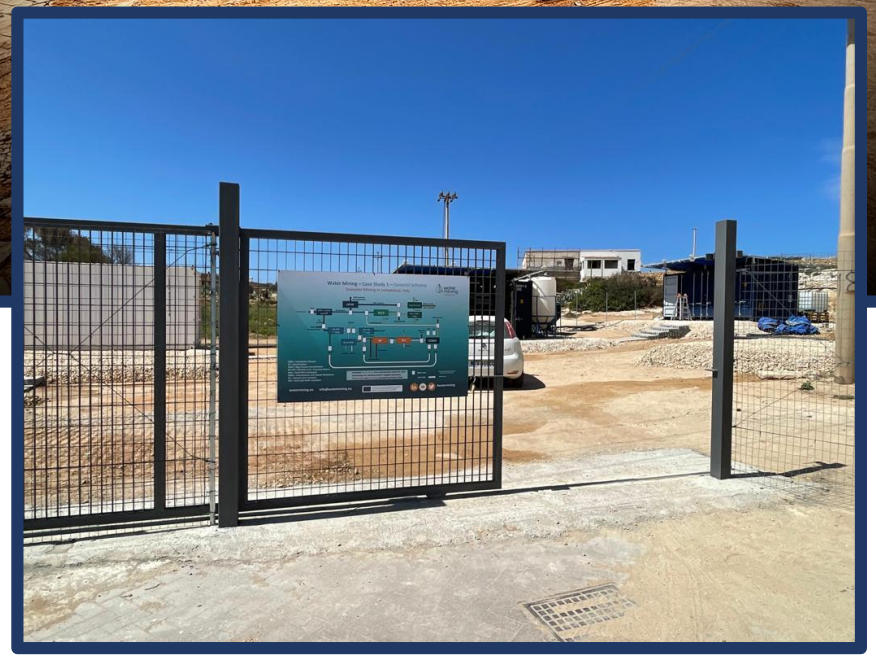
BLOCK FLOW DIAGRAM

2 m^3/h

SEAWATER INLET




NF
MF-PFR
EDBM





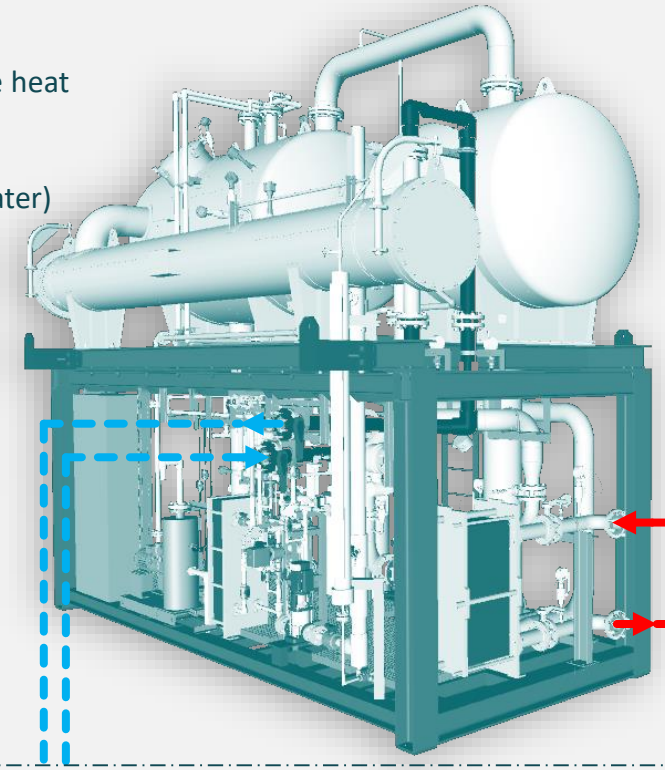

NF, MF-PFR AND EDBM ARE READY AND HAVE BEEN OPERATING FOR THE PAST THREE WEEKS


THERMOSSOL

WATER-MINING: CS1 – MED UNIT

TARGETS:

- Exploitation of low temperature waste heat
- Low temperature vacuum operation
- High recovery ratio (NF on the feed water)
- High distilled water quality
- Self adjusting process







SEA WATER

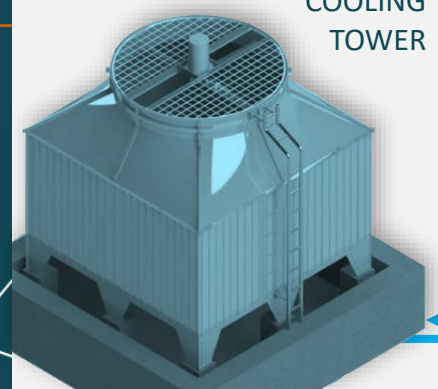
PURE WATER

HIGH SALINITY BRINE

MED UNIT

POWER PLANT

COOLING TOWER



COOLING WATER

40°C

30°C

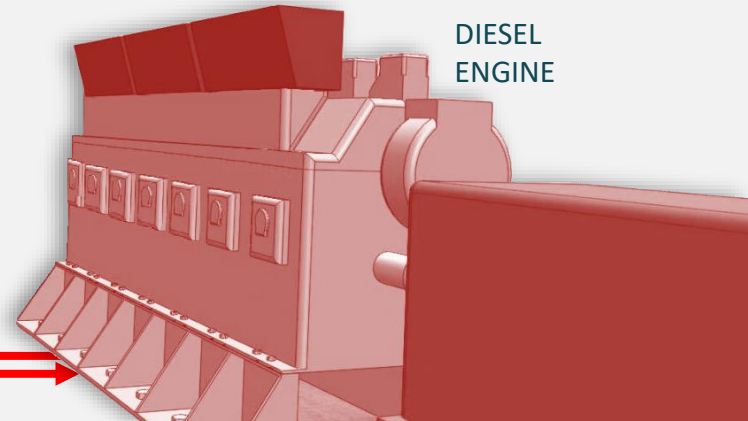
HEAT EXCHANGER

JACKET WATER

70°C

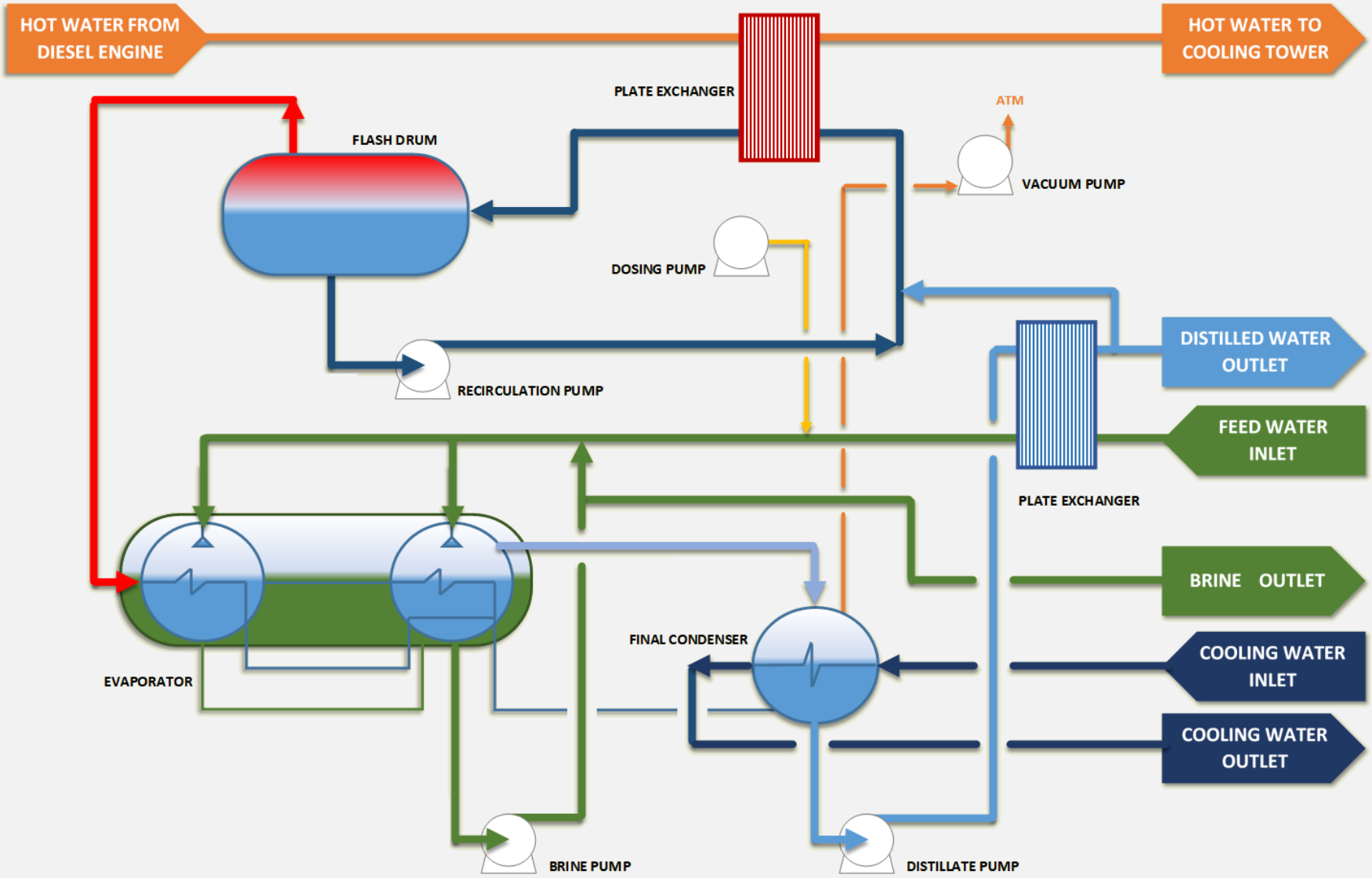
60°C

DIESEL ENGINE



WATER-MINING: CS1 – MED UNIT

PROCESS LAYOUT AND DATA



- Q_m 20 m³/h
- T_{in} 80 °C
- T_{out} 60°C

- Q_m 1,5 m³/h
- TDS < 10 ppm

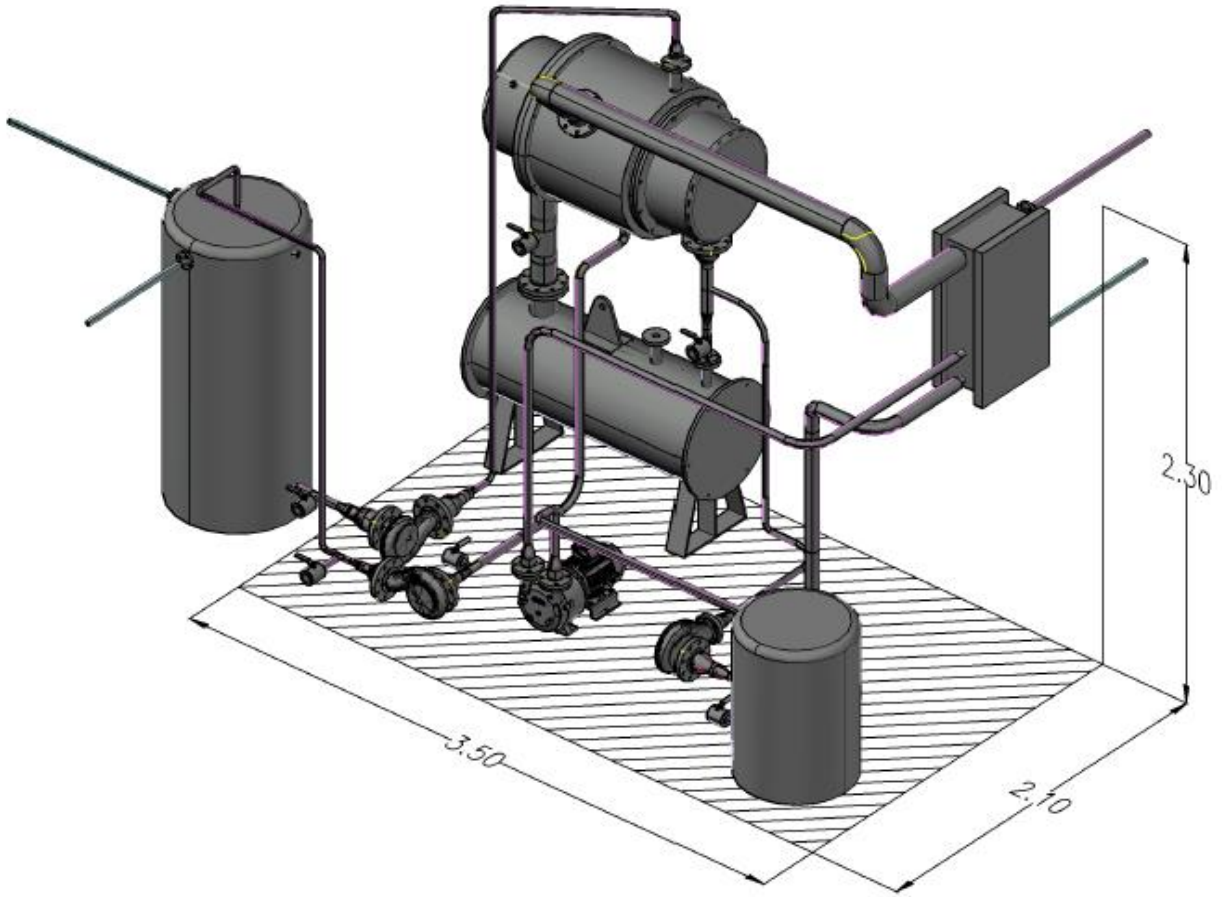
- Q_m 1,7 m³/h
- TDS 28 g/lt

(from Nano-Filtration)

- Q_m 0,2 m³/h
- TDS 240 g/lt

- Q_m 40 m³/h
- T_{in} 17 °C
- T_{out} 26°C

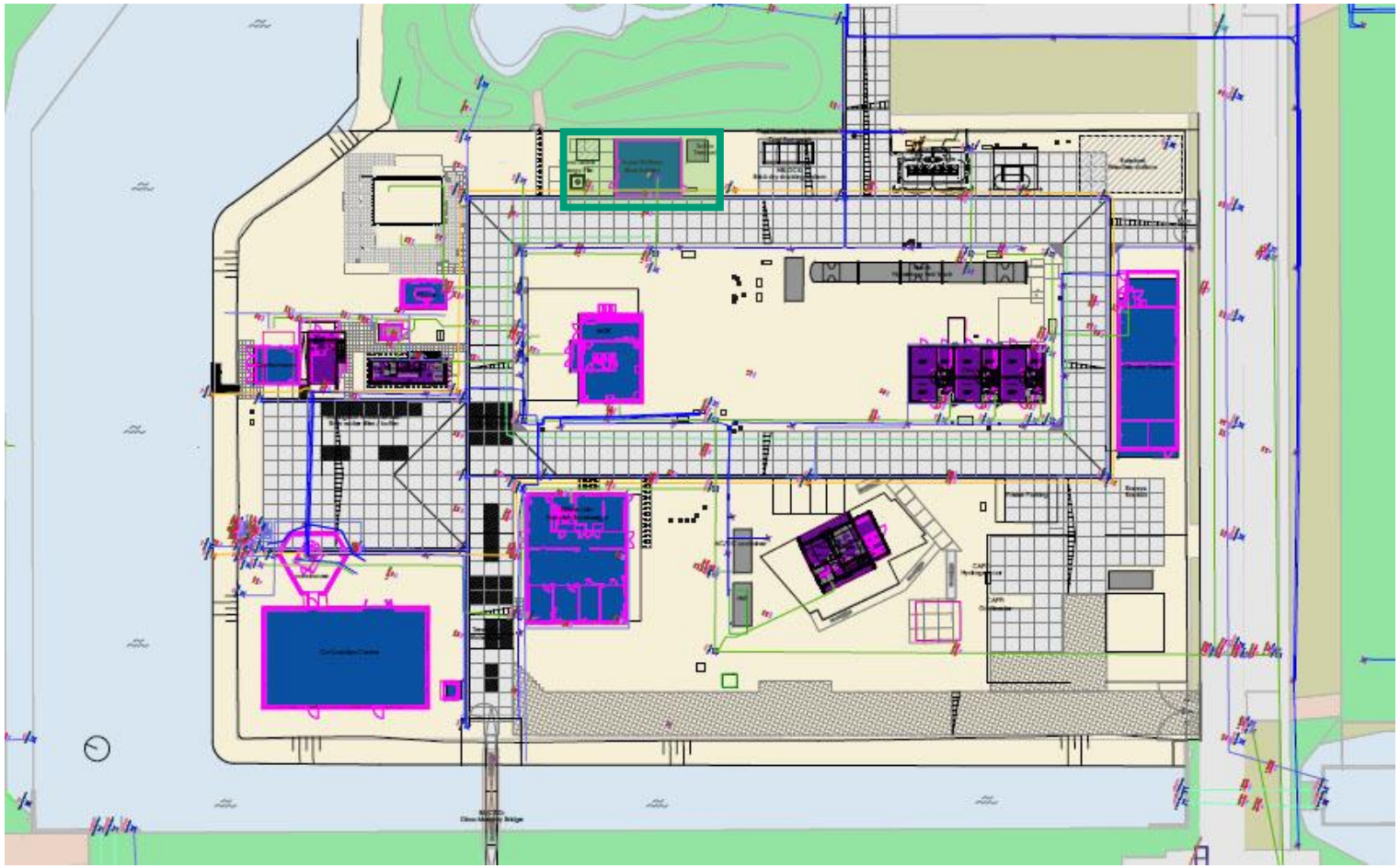
Small pilot evaporator (100 l/h)





THE GREEN VILLAGE

Brine Treatment Living Lab (BELL)







Ready to address your brine treatment requests

Operations start ~mid April





Circular Desalination: Value Chains & Sustainability

22 March 2023

Thank you very much for your attention!



Dr. Dimitris Xevgenos
Assistant Professor
Circular Value Chains & Sustainability
Technology, Policy & Management faculty
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Dr. Alessandro Trezzi
SWS - Saline Water Specialists
A division of SOFINTER SpA

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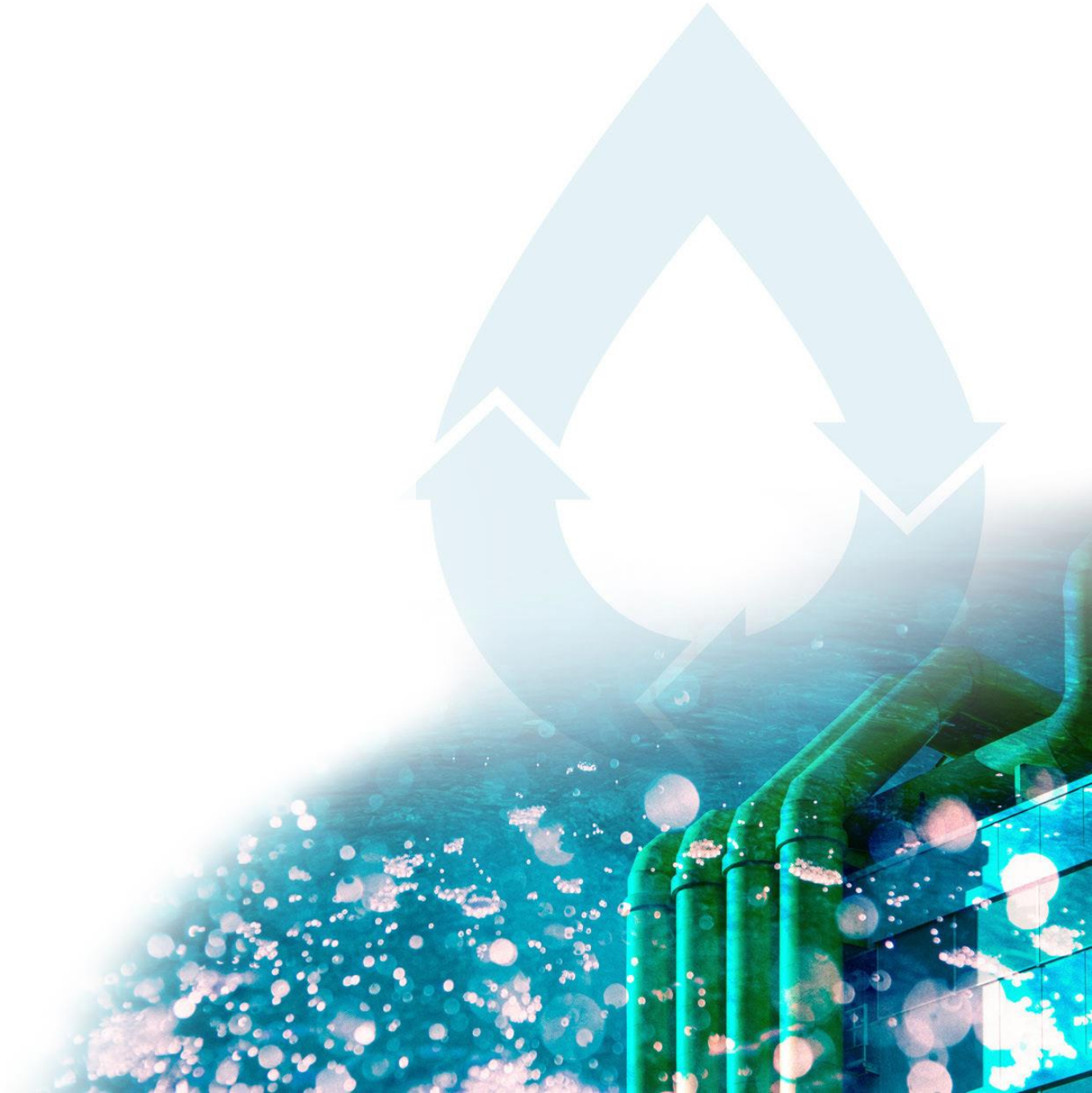
ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

Online seminar
Nutrient recovery

F. Fatone, C. Bruni

May, 2nd 2023.



Key ULTIMATE Information

Call	2017 - H2020 – Greening the economy in line with the Sustainable Development Goals (SDGS) - H2020-SC5-2018-2019-2020
Topic	CE-SC5-04-2019 - Building a water-smart economy and society
Budget	**TOTAL:** Budget 16.614.814€
Duration	48 months (01/06/2020 – 31/05/2024)
Partners	27 (12 private companies; 8 non-profit/private centers; 7 public centers) from 11 countries
Coordinator	KWR WATER (NL)

Website: https://ultimatewater.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



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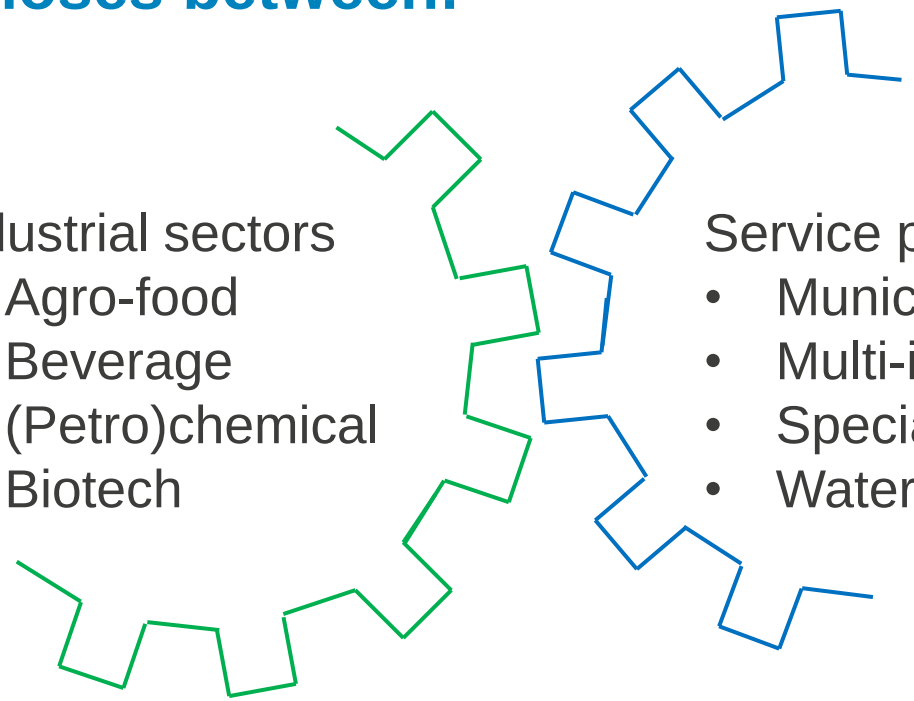
Ultimate (June 2020 – May 2024)

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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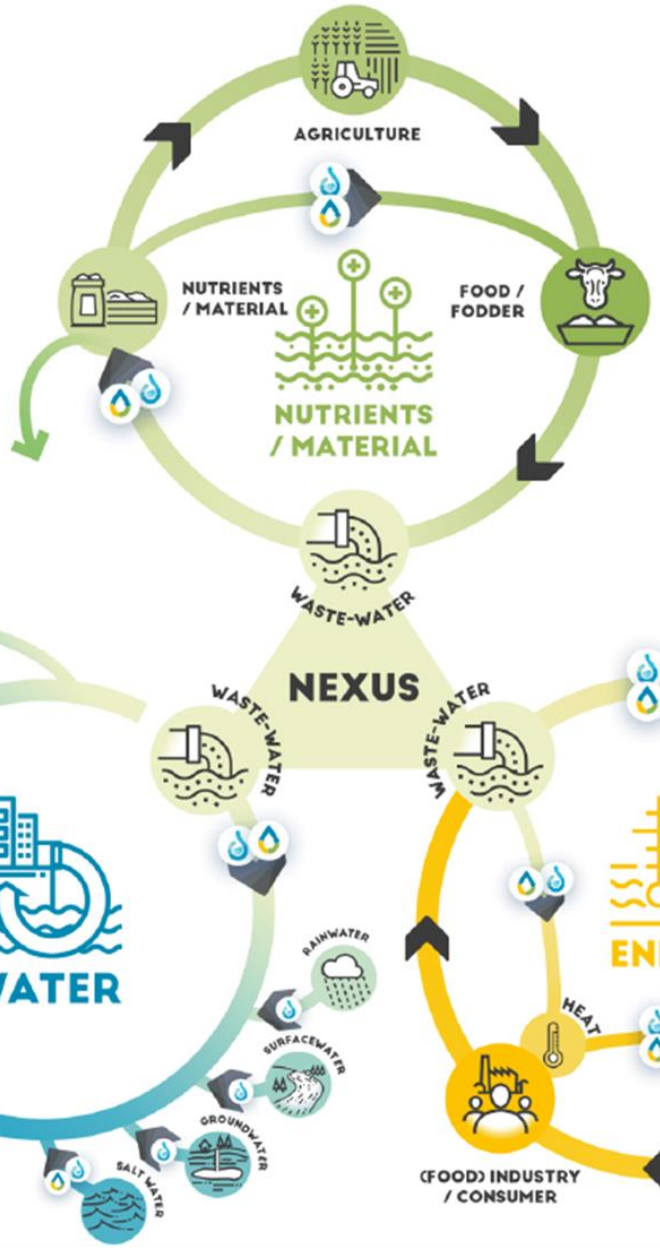
3 Cross-cutting Technology Groups: 7 Topics



UNIVERSITÀ POLITECNICA DELLE MARCHE





F. Fatone C. Bruni

- Nutrient recovery
- Material recovery & reuse

eurecat
Centre Tecnològic de Catalunya





A. Naves S. Casas

- Membrane technologies
- Adsorption and AOP technologies

KOMPETENZZENTRUM WasserBerlin



A. Kleyböcker

- Biogas technologies
- Heat Recovery
- Digitalization

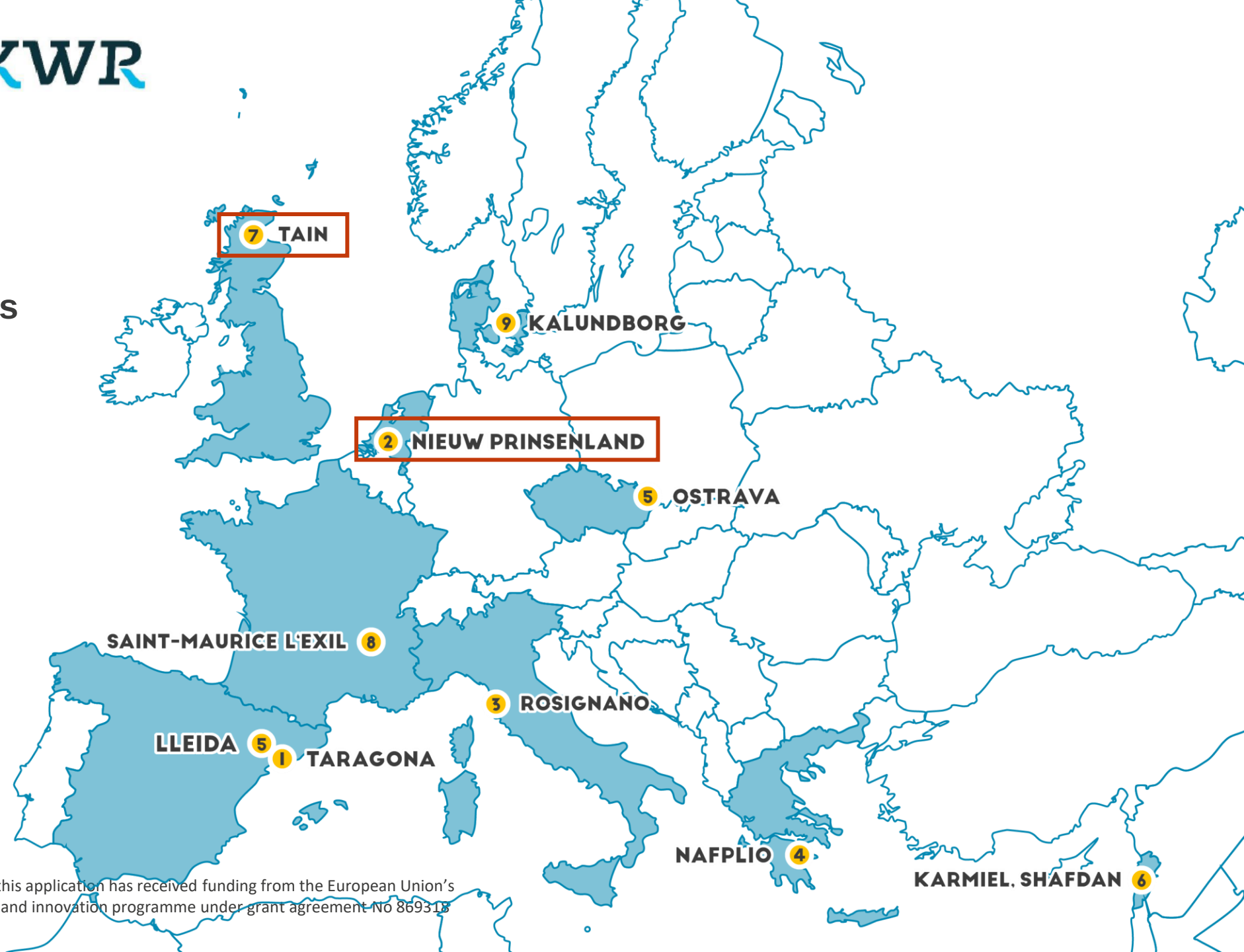
The project leading to this applic
Horizon 2020 research and innovation programme under grant agreement No 869318

Coordinator: KWR

9 Case Studies

27 Partners

37 Technologies



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Agenda

14:30	**Introduction** *Francesco Fatone (UNIVPM)*
14:40	**Nutrient recovery in H2020 ULTIMATE Case Study 2:** Nutrient concentration for recovery from greenhouse wastewater by electrodialysis. *Tavishi Guleria (KWR)*
15:00	**Nutrient recovery in H2020 ULTIMATE Case Study 7** *Marc Pidou (Cranfield University)*
15:20	**Nutrient recovery in H2020 B-WaterSmart**: Venice case study *Patrizia Ragazzo (Gruppo Veritas)*
15:40	**Nutrient recovery in H2020 REWAISE:** Vigo case study *José R. Vázquez Padín (Aqualia)*
16:00	**Nutrient recovery in H2020 WATER-MINING:** Future Scheme of aerobic granular sludge WWTPs *Nouran Bahgat (Wetsus / TUD)*
16:20	**Final discussion**
16:30	**End**

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ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

KWR GHENT UNIVERSITY Coöperatieve Tuinbouw Water Zuivering De Vlot NIEUW PRINSENLAND Glastuinbouw Nederland

CS2: Nutrient Concentration for Recovery from Greenhouse Wastewater by Electrodialysis

Tavishi Guleria
Researcher, Innovation and Valorisation
KWR

2nd May 2023



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)



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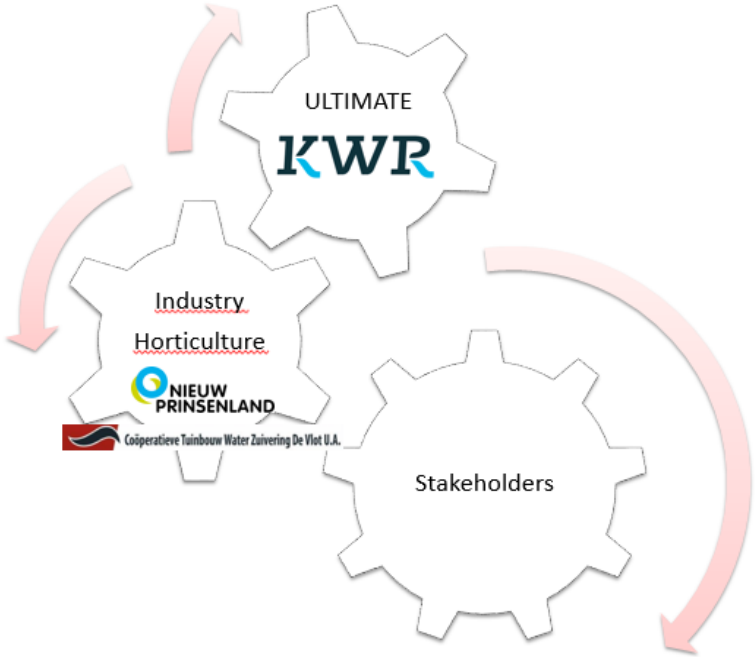
Horticulture – Industry Symbiosis

- Netherlands is the **second largest exporter** of agriculture products (large share from greenhouse horticulture)
- High resource efficiency & production rates – **advanced sector!**
- **Challenges** – water scarcity (alternative sources), restrictions in concentrate disposal, strict legislation for effluent quality







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

Case Study

- Coöperatieve Tuinbouw Water Zuivering de Vlot
- 60 greenhouses (160 ha) with a collective treatment facility at a maximum capacity of 40-60 m^3/h
- Recycling would be provided internally in the summer and externally in winter
- De Vlot has ambitions to reach zero liquid 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

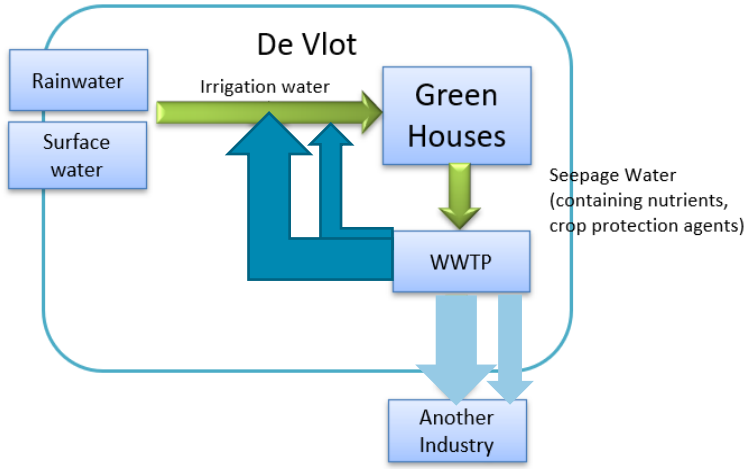
Current and Proposed Treatment

- Currently, the treatment is linear with discharge into the sewer

- Proposed treatment is circular to enable irrigation water and fertilizer reuse

    - Sodium removal which is harmful for plant growth

    - **Recovery/reuse of valuable fertilizers for fertigation**



Source	NH_4^+ (mg/L)	K^+ (mg/L)	Na^+ (mg/L)	Ca^{2+} (mg/L)	Mg^{2+} (mg/L)	NO_3^- (mg/L)	Cl^- (mg/L)	SO_4^{2-} (mg/L)	$H_2PO_4^-$ (mg/L)	EC (mS/cm)	pH
De Vlot	2,16	73,70	162,09	195,74	52,21	215,52	271,21	211,90	3,95	1,9	7,3
Voogt 2009	8,51	273,7	138	320	85,06	1054,08	212,71	576,36	67,89	3	5,5

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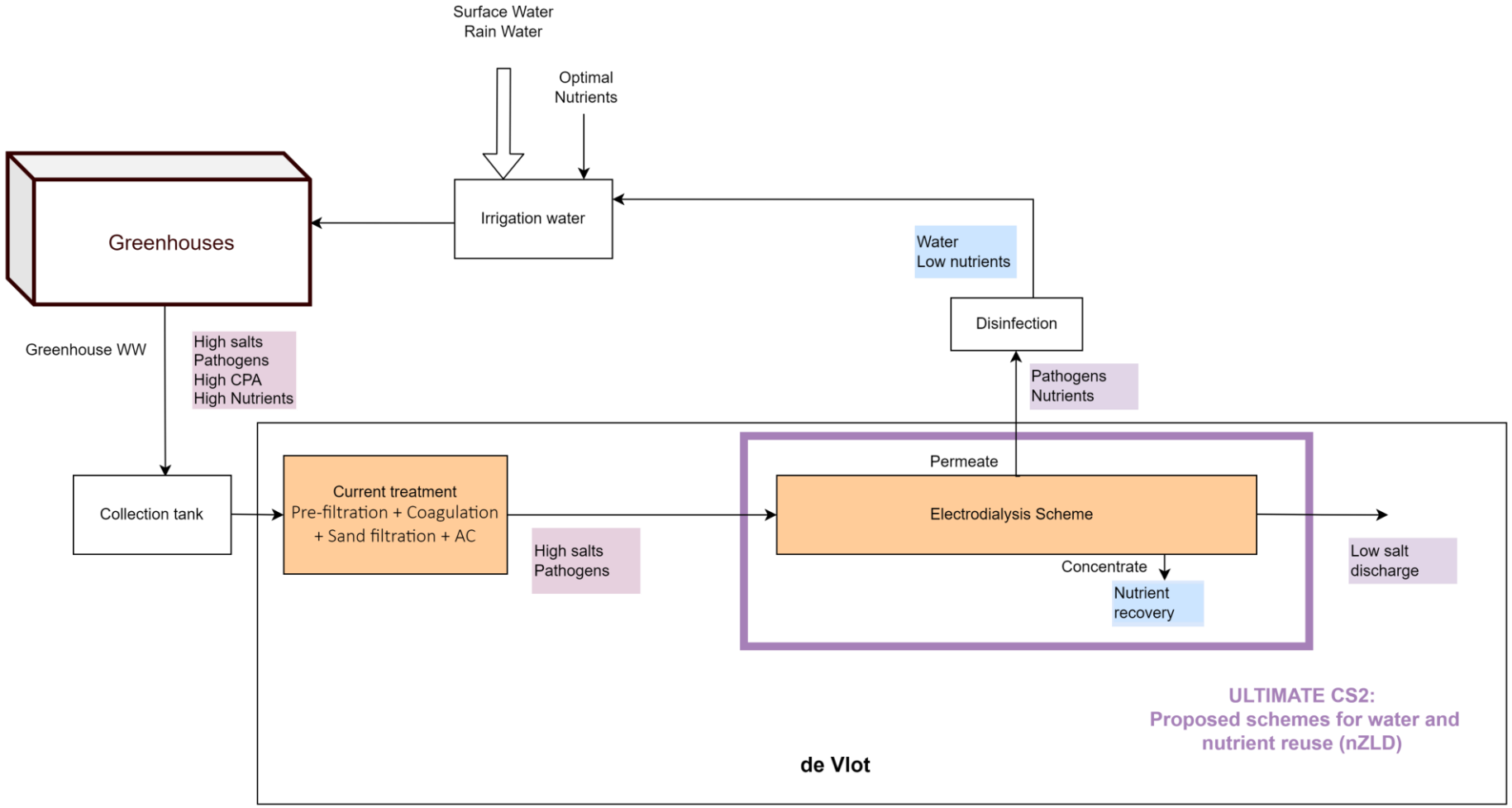
Flow Scheme



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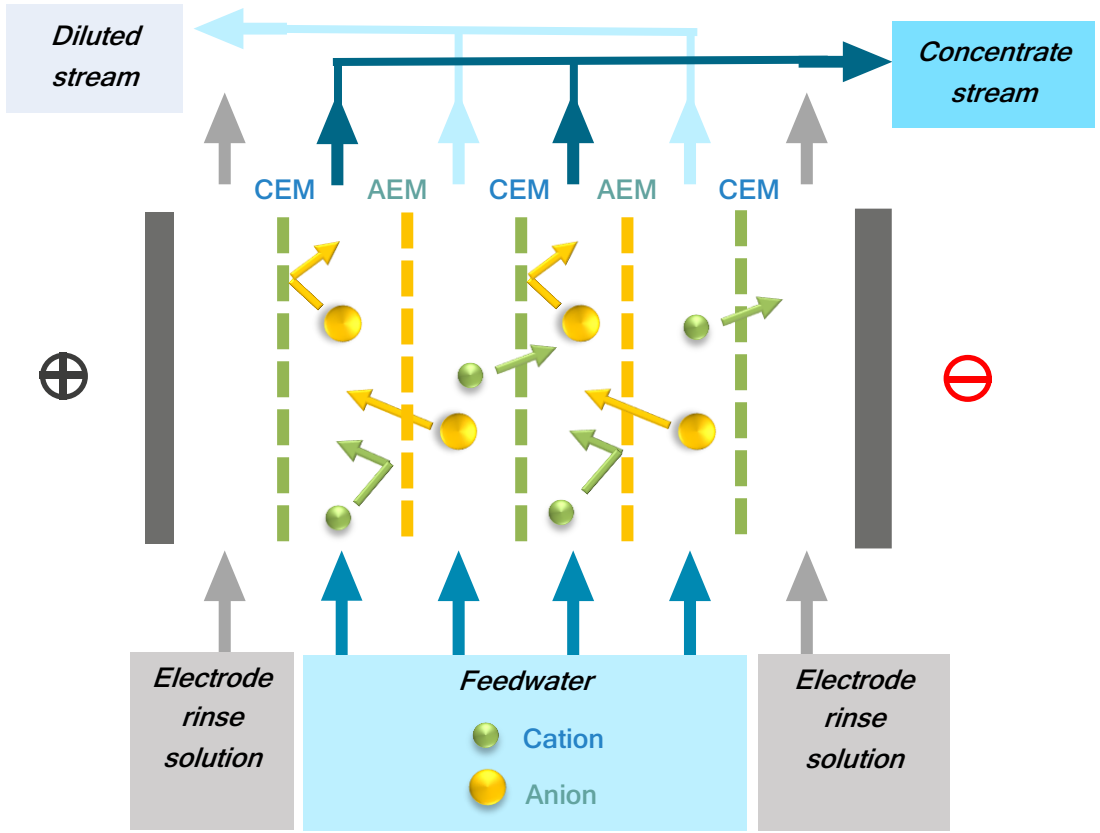
Electrodialysis

Advantages of ED (compared to SOTA)

- Potential for ion-selective recovery
- Tunable production
  - → Prevent sodium accumulation in effluent prior to recirculation
  - → Ion concentration
  - → Fits the needs of greenhouse horticulture

Challenges

- Process optimization for nutrient recovery



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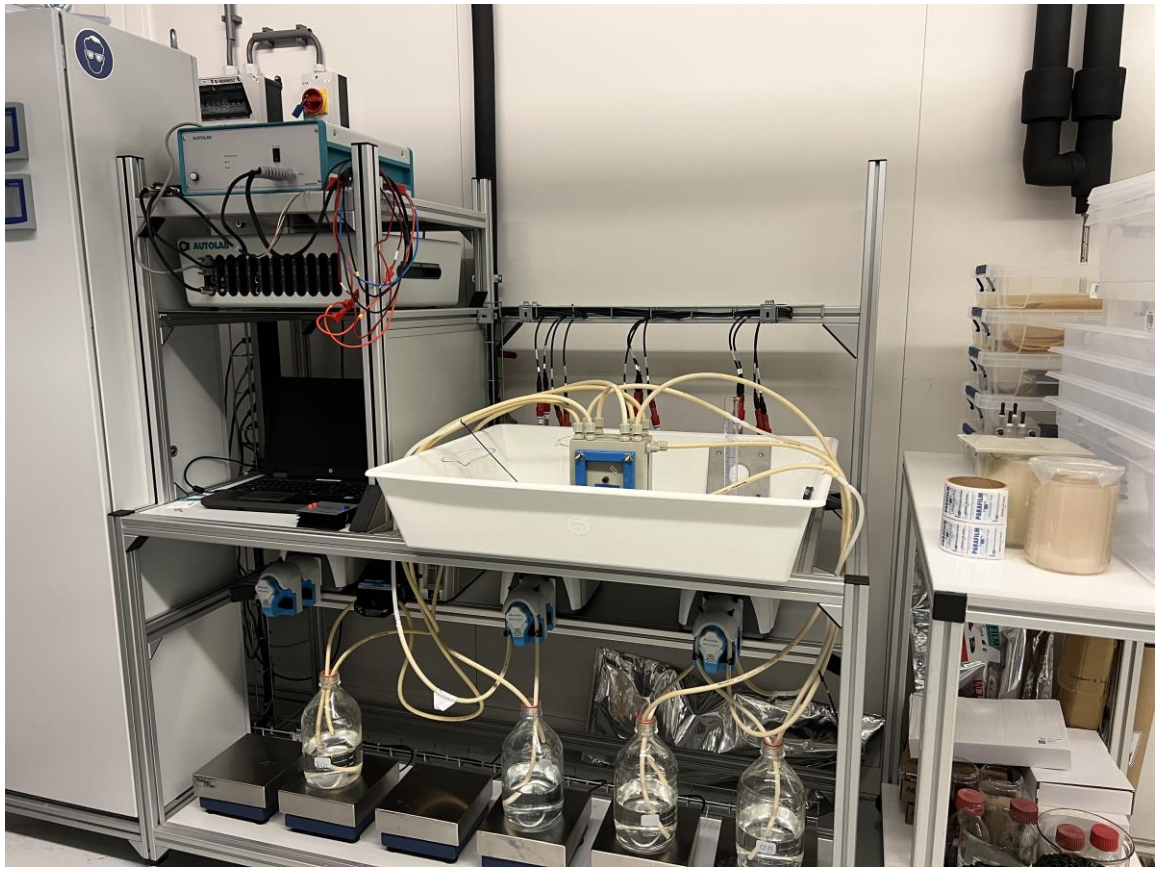
Electrodialysis Set-up



Main Parameters:

- 10 – 20 cell pairs (scalable)
- Membrane area 0.01 m^2
- 3 streams: Diluate, Concentrate, electrode rinse solution
- Fujifilm Type 10 IEMs
- Batch and one-pass

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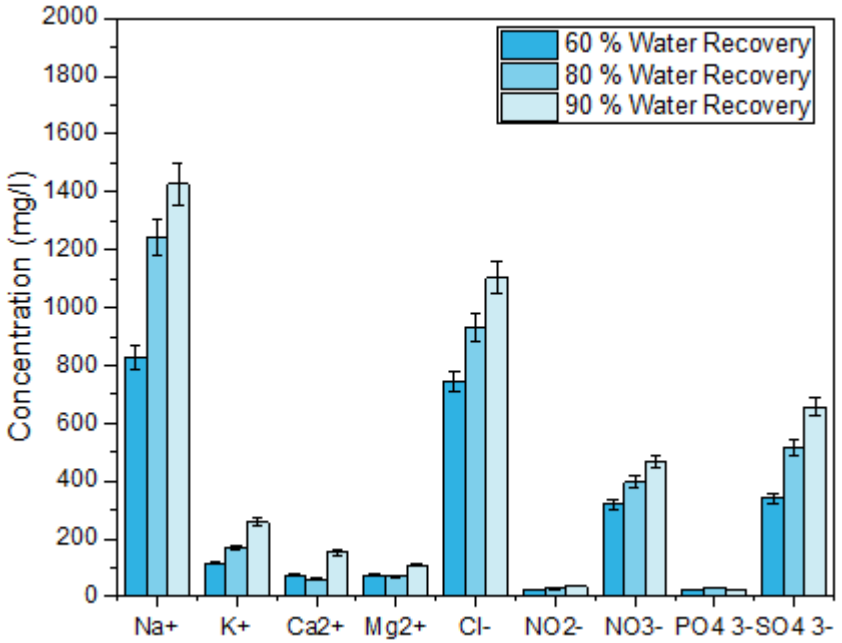
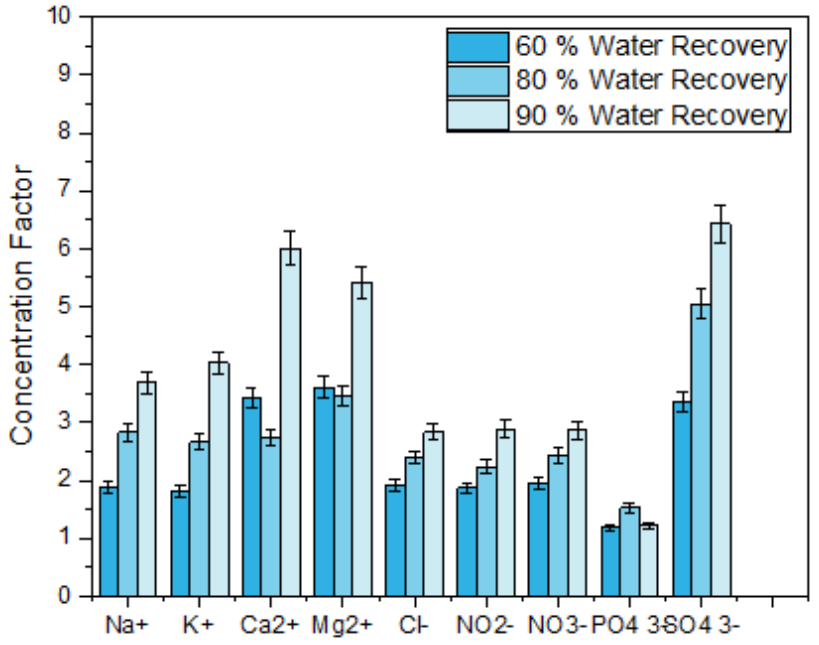
Initial Results

- Lower range EC 1.9 mS/cm
- K^+ upto 250 mg/l, NO_3^- upto 450 mg/l, $H_2PO_4^-$ upto 50 mg/l
- Optimum concentration at 90% water recovery
- Concentration factors of divalent ions > monovalent ions

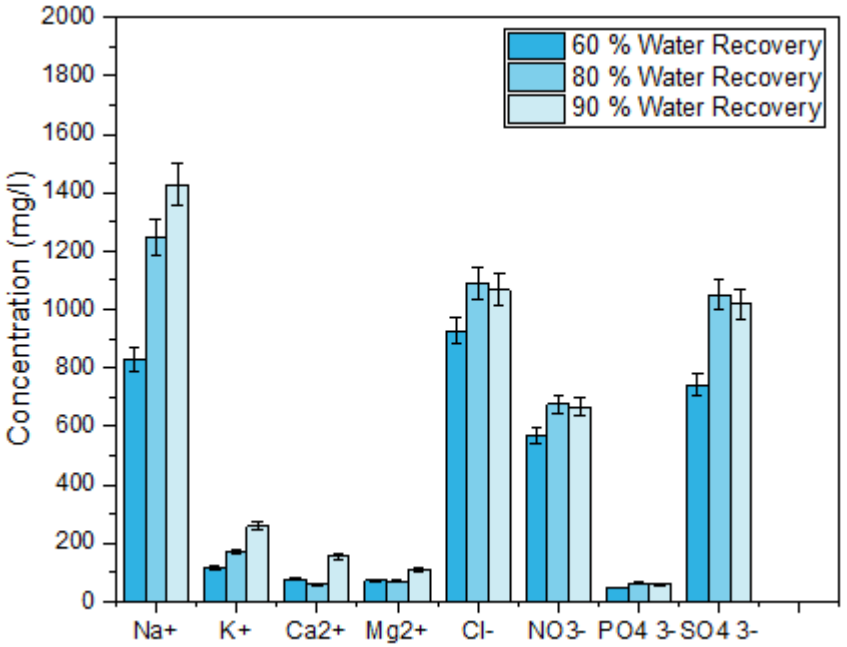


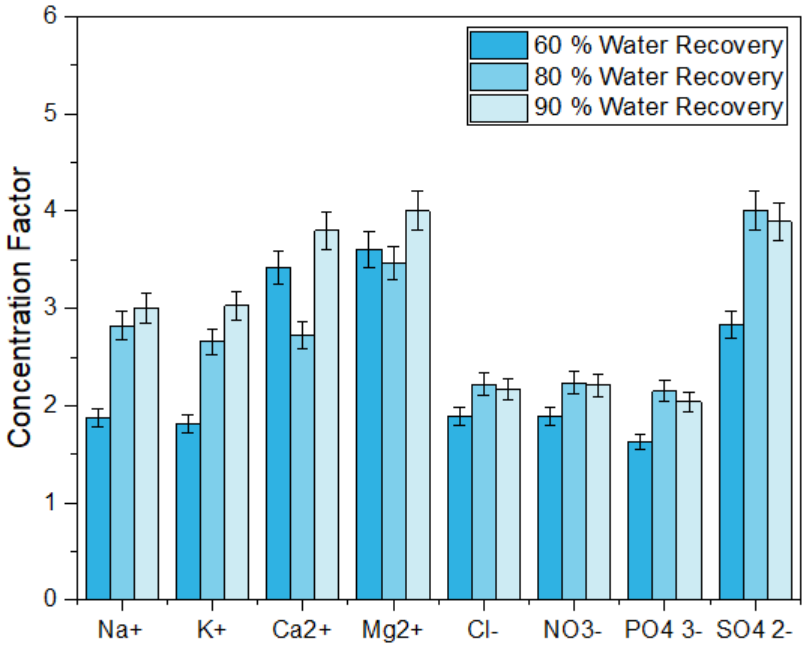


The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

Initial Results

- Higher range EC 3 mS/cm
- K^+ upto 300 mg/l, NO_3^- upto 650 mg/l, $H_2PO_4^-$ upto 100 mg/l
- Optimum concentration at 80% water recovery
- Concentration factors of divalent ions > monovalent ions





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

Future Work

- Electrodialysis is a effective nutrient concentration technology, however additional steps needed for complete valorization
- Further selective separation from concentrated stream with additional technologies such as mono-selective electrodialysis, ion exchange and donnan dialysis
- Long term pilot testing at case study site



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

- Initial pilot runs with a range of ionic compositions demonstrated **concentration of nutrients** K^{+}>3, Ca^{2+}>5, Mg^{2+} >4, NO_3^{-}>2.5, SO_4^{2-}>4 times
- **Energy consumption** was 1.2 (+/- 0.5) KWh/g NO_3^{-} (without pumping)
- The **diluate** produced had acceptable **irrigation water** quality for greenhouse application
- Further testing with **additional technologies** and **long-term pilot testing** at case study site
- **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

ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

Thank You!

Tavishi Guleria Tavishi.Guleria@kwrwater.nl

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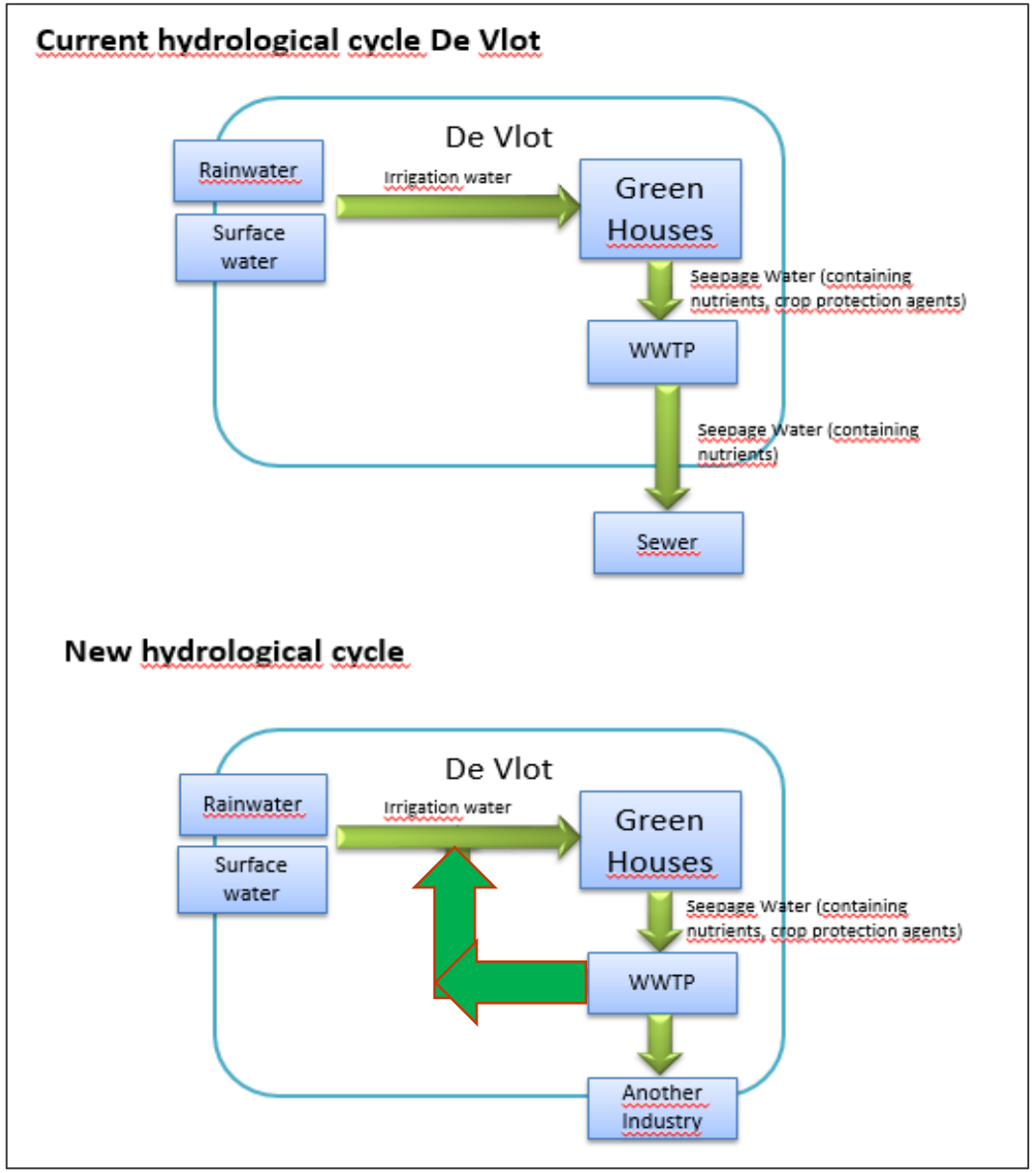
The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

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



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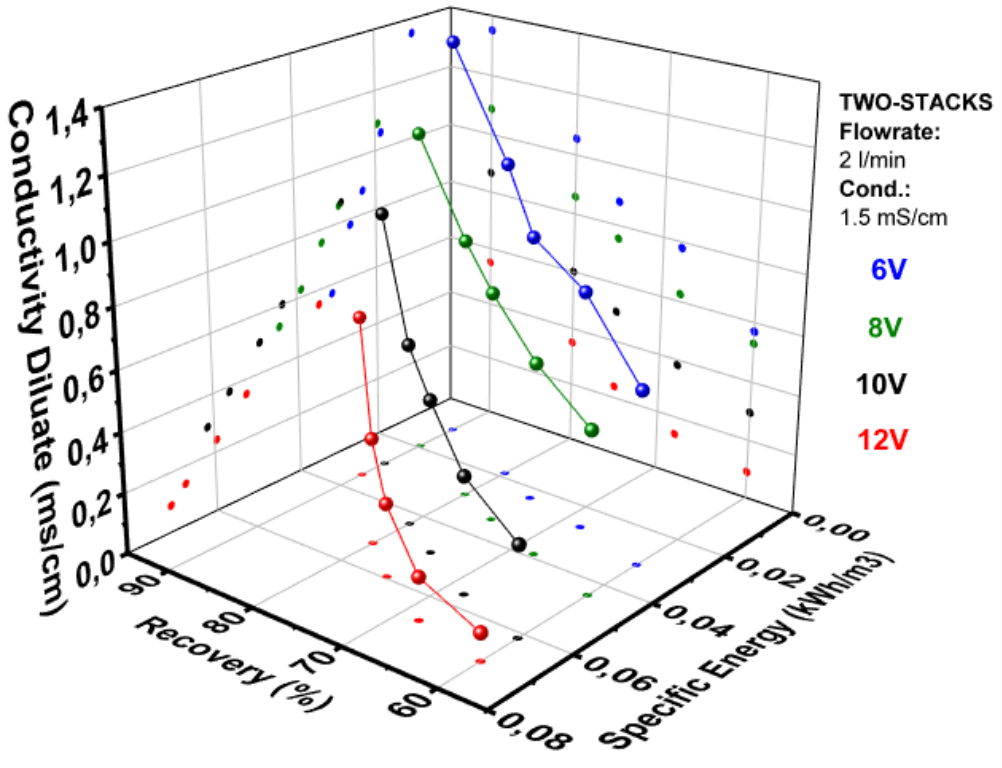
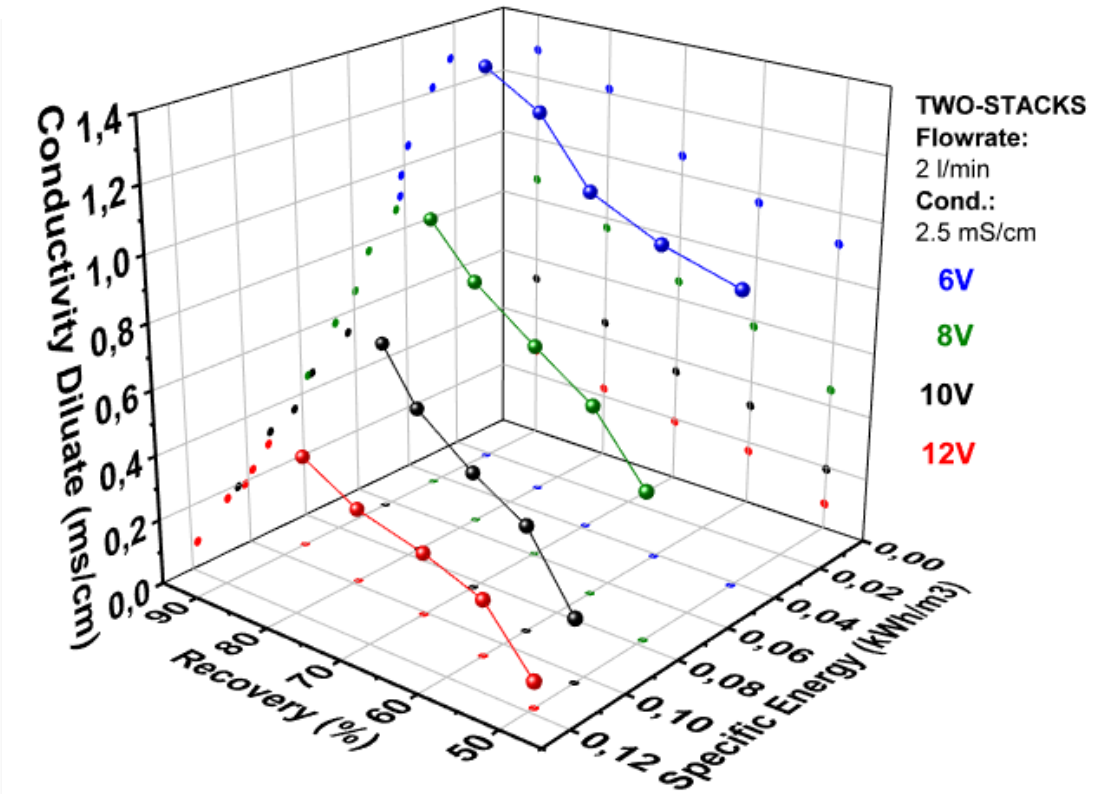
Results





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ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

CS 7 – Nutrients recovery from distillery wastewater

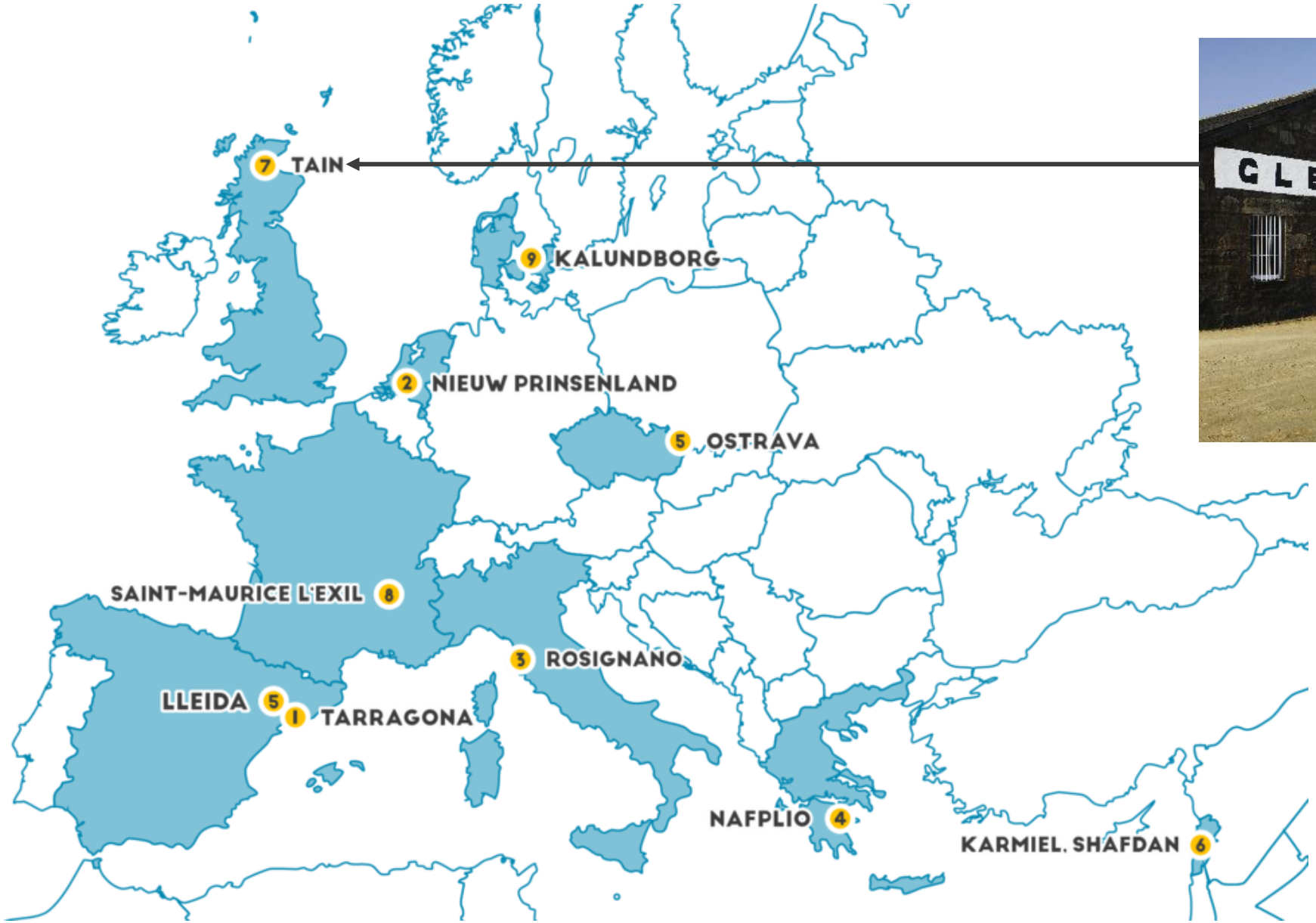
Cranfield University

Aquabio

Marc Pidou – Cranfield University, UK



CS7 - Glenmorangie distillery







CS7 - Glenmorangie distillery

Partners:

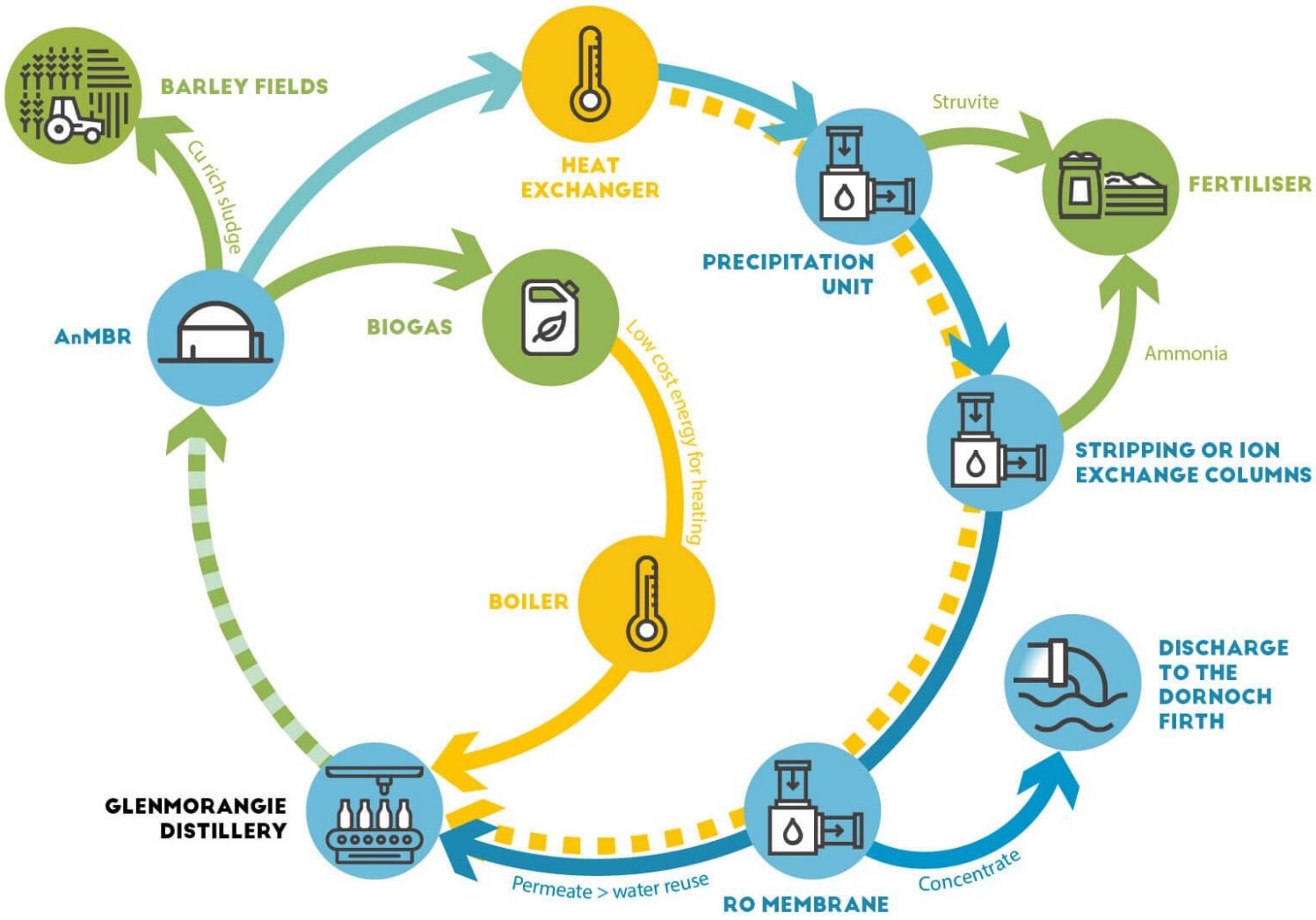
Aquabio

Cranfield University

With the support of:

The GLENMORANGIE COMPANY

Alpheus
part of the Anglian Water Group



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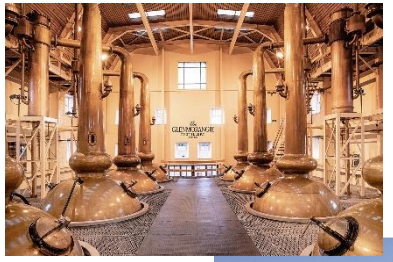
Current system

Reduces the dependence in fossil fuel

of the distillery by 15%











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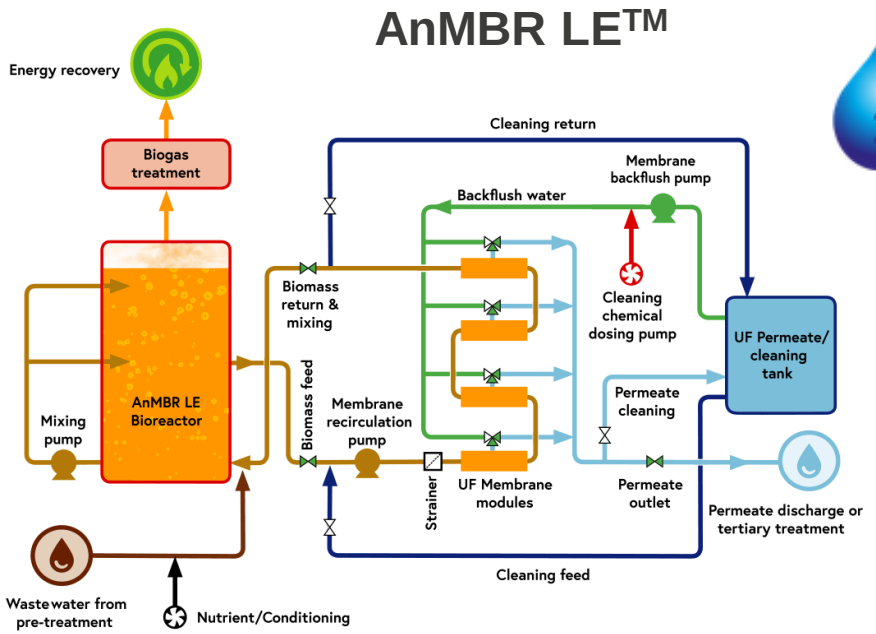
Current system

Peak/average AnMBR Feed flow rate (m^3/d)	467/377
Design COD load (kg/d)	14,527



Parameter	Unit	Raw waste	AnMBR effluent
Chemical oxygen demand (COD)	mg/l	33247	673
Total suspended solid (TSS)	mg/l	8380	3
pH		4.44	7.03
Ammonia (N-NH4)	mg/l	39	789
Nitrates (N-NO3)	mg/l	41	5.6
Phosphate (P-PO4)	mg/l	289	236
Magnesium (Mg)	mg/l	107	43

98% removal

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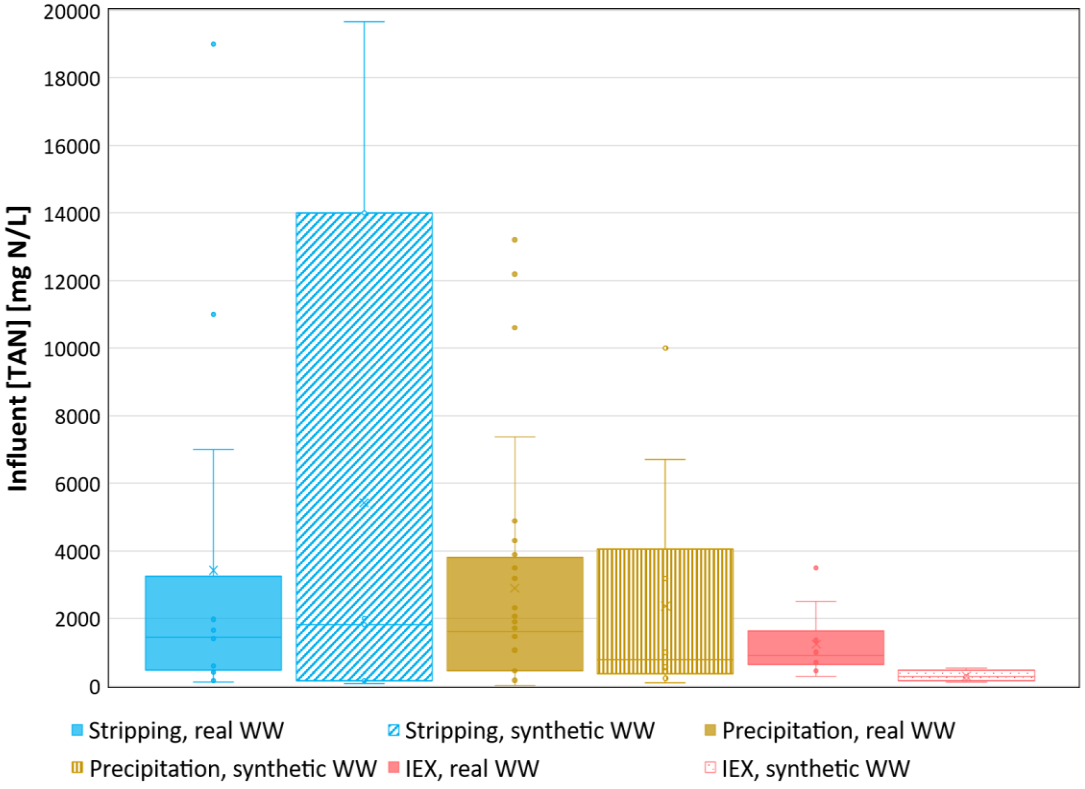
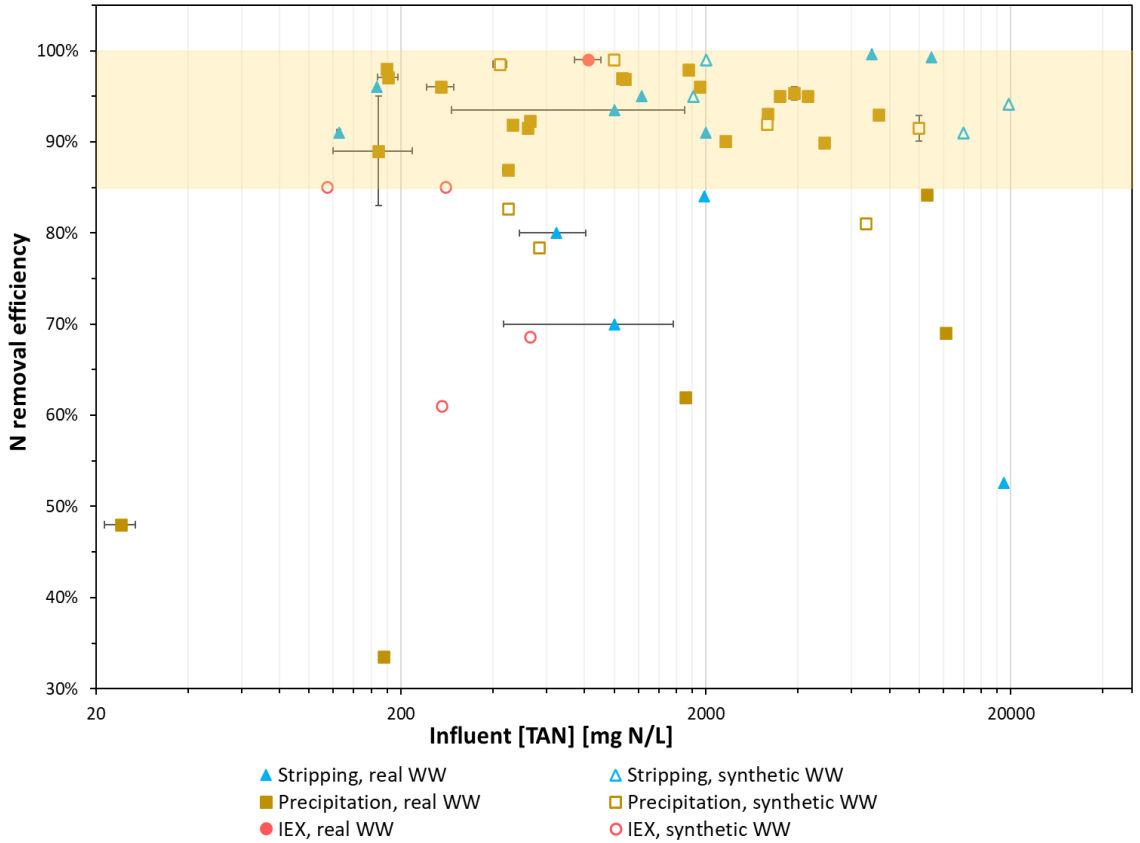
Review of existing technologies





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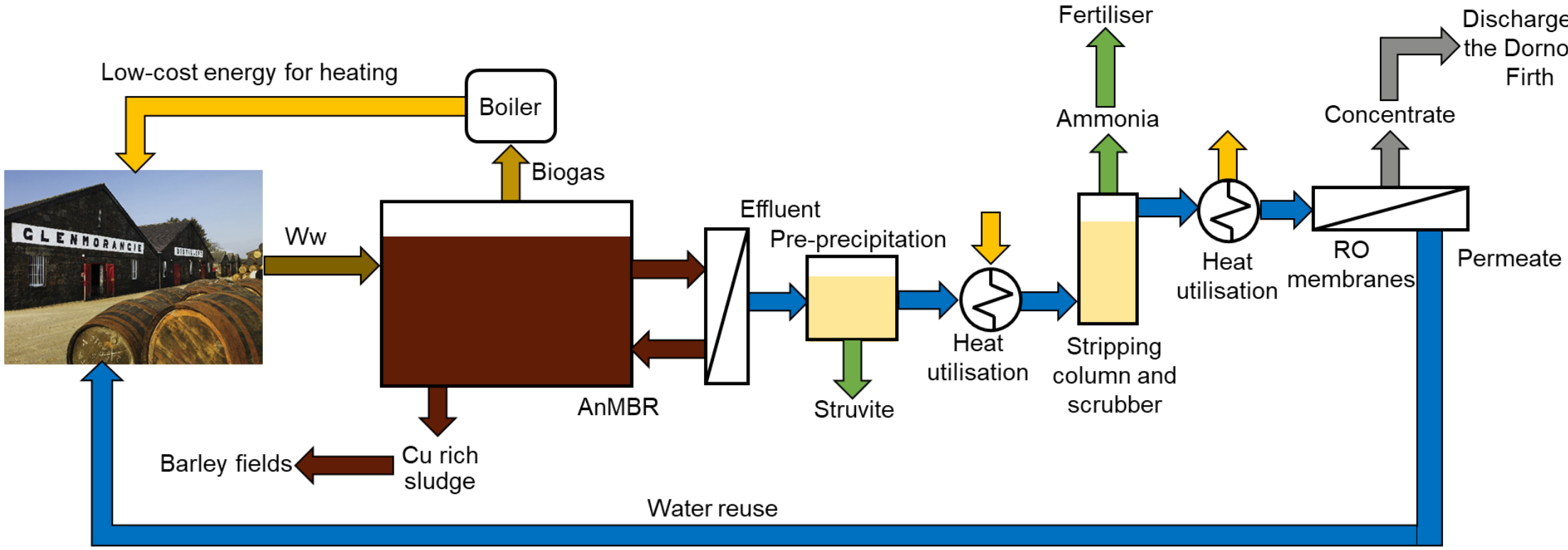
Investigation for new developments



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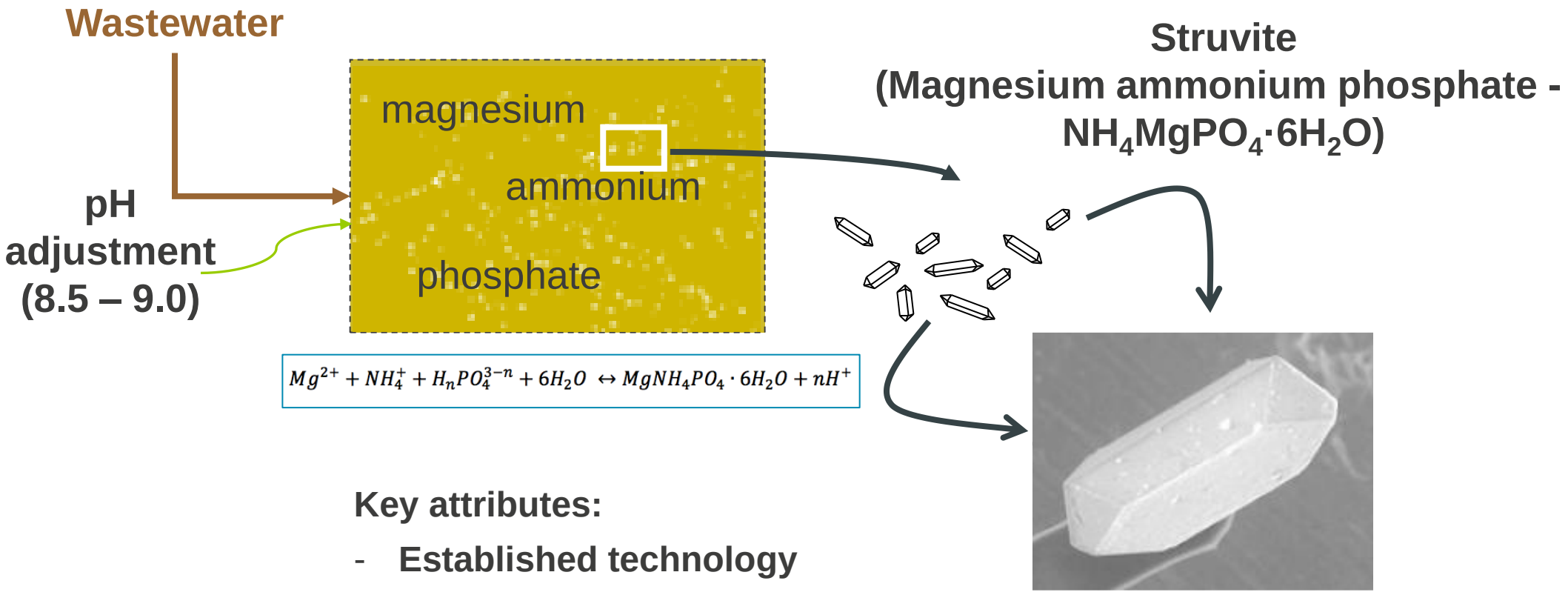
Precipitation - Struvite



Key attributes:

- **Established technology**
- **Simple configuration**
- **Availability of Mg?**
- **Chemical use**

Parameter	Unit	Raw waste	AnMBR effluent
Chemical oxygen demand (COD)	mg/l	33247	673
Total suspended solid (TSS)	mg/l	8380	3
pH		4.44	7.03
Ammonia (N-NH4)	mg/l	39	789
Nitrates (N-NO3)	mg/l	41	5.6
Phosphate (P-PO4)	mg/l	289	[illegible]
Magnesium (Mg)	mg/l	107	43

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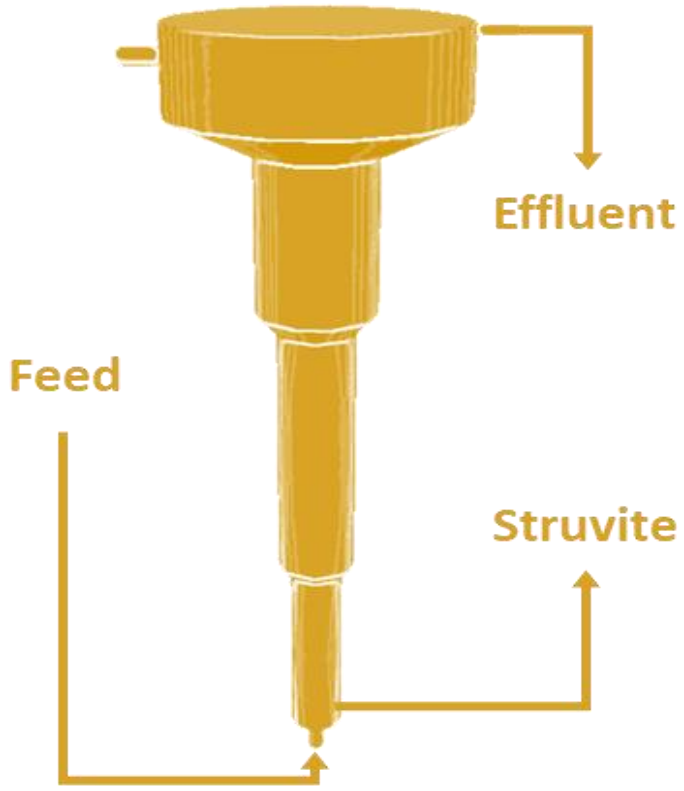
Precipitation - Struvite

Fluidised bed reactor



PRECIPITATION



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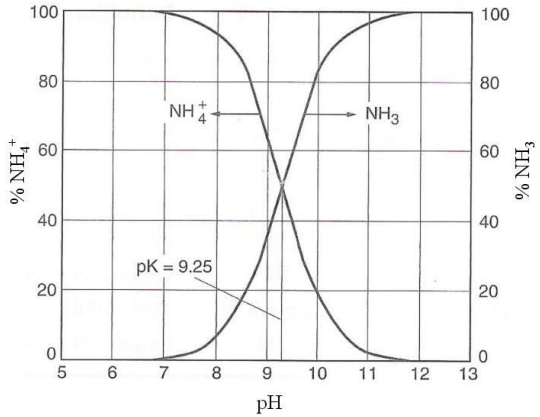
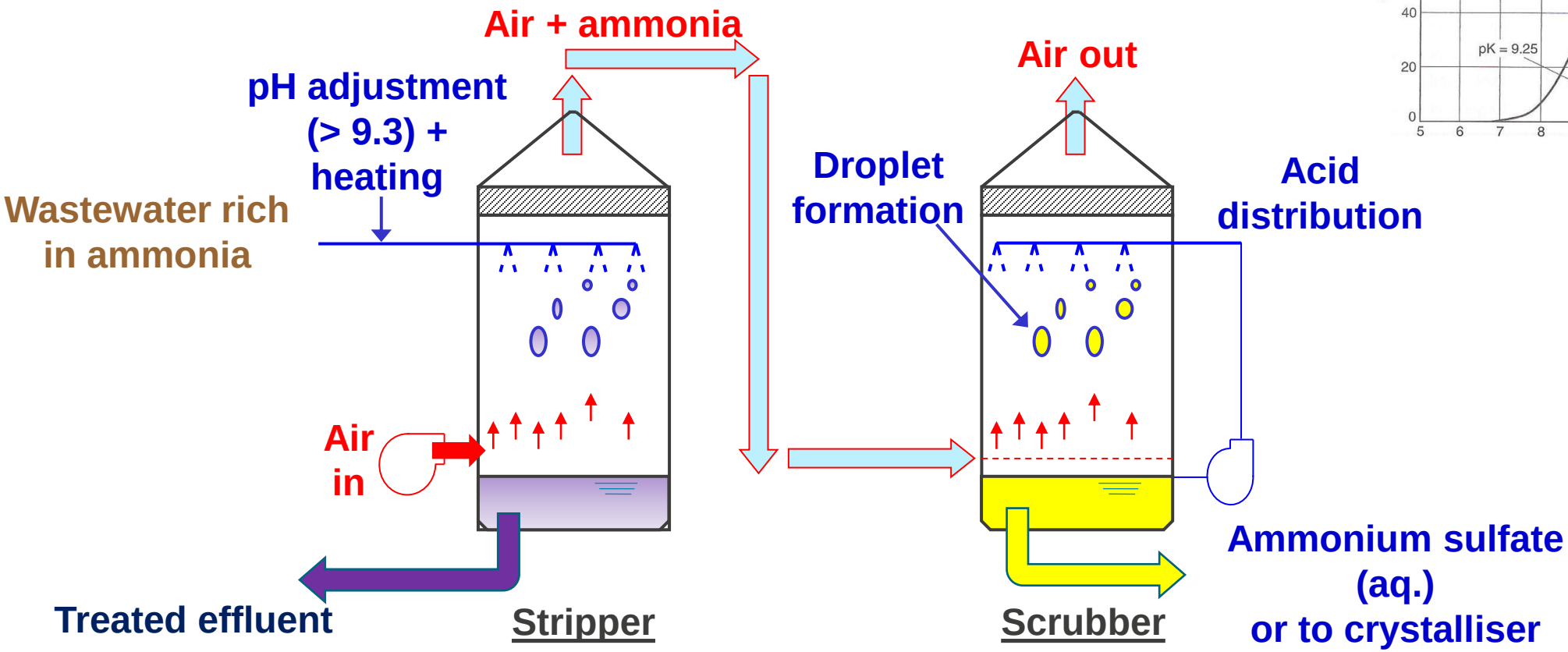
Stripping columns





Key attributes:

- **Established technology**
- **Large footprint**
- **Energy intensive**

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Stripping columns



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

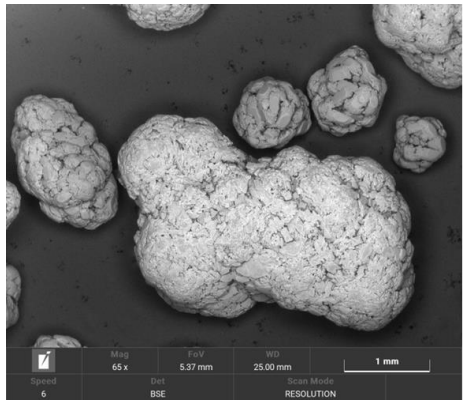
Precipitation – key results

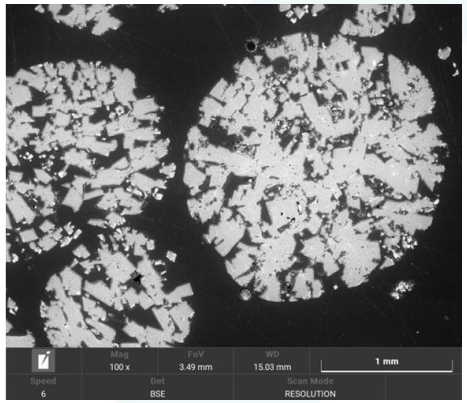
Treatment performance

- 62±15% PO4-P removal; maximum η: 75%
- theoretically 18.6 kg struvite/d
- 7±5% TAN removal
- 2±6% COD removal

Product recovered



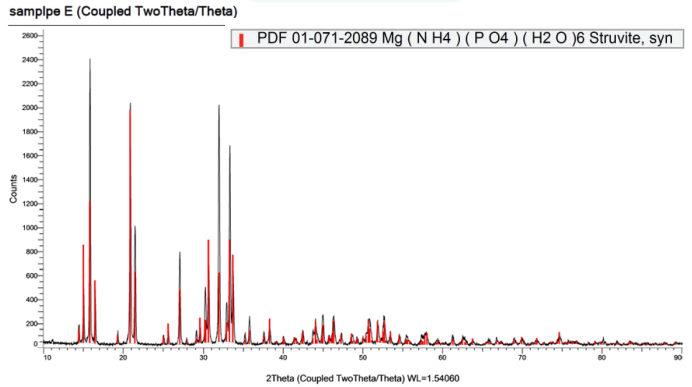






Elemental composition (%wt)

	Theoretical	Granules
N	5.7	5.9±0.9
Mg	9.9	10.0±3.3
P	13.0	11.2±4.3
O	65.2	47.0±4.6



Contamination: none from Cu, Zn, Ni; 10-18% wt COD.

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Challenges









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Stripping – key results

Treatment performance

- ✓ 69±16% TAN removal; maximum η: 80%
- ✓ Fluctuating P removal



[TAN]	pH	EC	[SO_4]
g/L	-	mS/cm	g/L
10.23	1.93	57.3	21.65

[COD]	[TOC]	[Mg]	[Ca]
mg/L	mg/L	mg/L	mg/L
681	36.0	nd	3.89

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

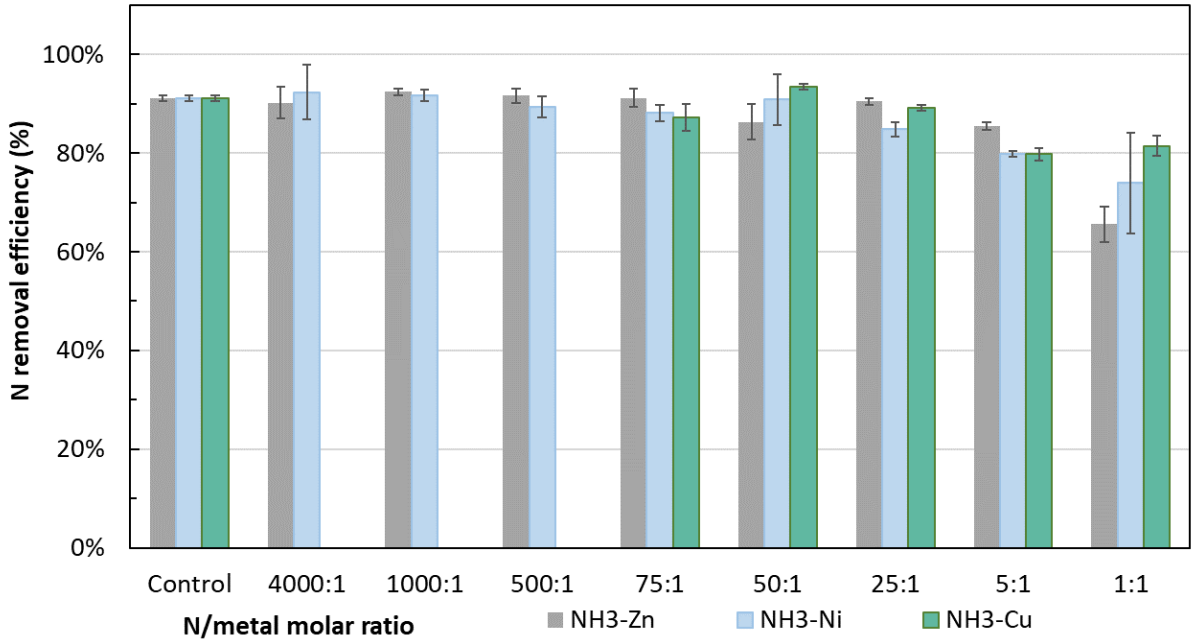
Stripping – lab-scale experiments

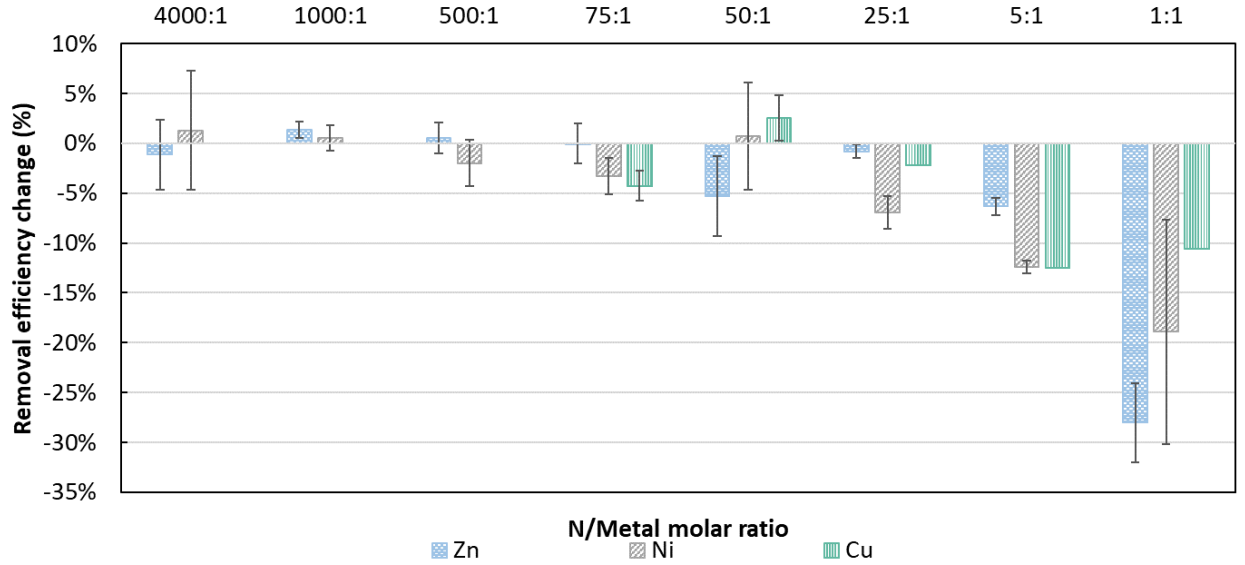
- Assess and quantify impact of controlled parameters on AP (N: metals/organics) and product quality during vacuum thermal stripping
- Tested species: transition metals (Cu, Ni, Zn), dissolved organics (humic and fulvic acids)
- Triplicate tests and analyses on feed pre/post treatment and condensate, and on precipitates.

- Mass balances (TAN, metals/organics, H_2O)
- NH_3 mass transfer coefficient (Kla)
- Coefficient of strippable ammonia (compared to theoretical initial [free ammonia])
- Impact on technology performance: N removal, condensate quality.



Stripping – lab-scale experiments





Conclusions

- ≥ 75% P and N removal and recovery is currently achievable in the combined FBR/stripping processes
- High quality products with limited contamination are generated
- FBR effectively protects the stripping unit from scaling
- The dosing points design and position, the mixing and the pH are critical factors to control the precipitation in the reactor and limit scaling elsewhere
- Metals should have limited influence on ammonia removal and recovery in current conditions

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

Thank you

Marc Pidou – m.pidou@cranfield.ac.uk

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 Recovery in H2020 B-WaterSmart: Venice case study

ULTIMATE & SISTER PROJECTS Workshop

2nd May 2023

Patrizia Ragazzo
Living Lab coordinator, VERITAS S.p.a.
Omar Gatto
Living Lab partner, ETRA S.p.A.

b-watersmart.eu

SOME RAPID INFROMATION ABOUT BWS AND ITS STRATEGIC GOALS ….



B-WaterSmart H2020

IWW Zentrum Wasser · adelphi · adene Agência para a Energia · Águas do Tejo Atlântico · AA · Aquafin · baseform · bodø kommune · CETAQUA · De Watergroep · depuracque servizi · dmk Group · ENGINEERING · ENVIROCHEMIE · ETRA · eurecat · HYDROTECH · i-SENSE GROUP · ICS Lisboa · KRÜGER KALDNES · KWR · LNEC · LISBOA · MECHELEN · nordkontakt · NTNU · OOWV · PROEFSTATION · SINTEF · TECHNI · TURBULENT · UNED · VERITAS · vito · Water Europe

VERITAS

1 Alicante

Challenges

*Large **semi-arid area**,*
NO local water resources
Drinking-water from sea water
Water reuse critical need: technical-governance barriers

Innovations & Goals

- *Improve WATER REUSE*
- *Reduce **WWT** ENVIRON. FOOTPRINT(↓waste↓ energy ↑recovery) → self-sufficient DIGITAL for SW allocation & Negotiation*

2 Bodø

Challenges

***Large urban development project**,*
Infrastructure CAPACITY inadequate to heavier rain.
Water leakages in piping.

Innovations & Goals

- *Sustainable & cost-efficient **WATER SUPPLY** systems:, **SMART-METERS** in pipelines;*
- ***SEWAGE** = cost-efficient source of ENERGY,*
- *DIGITAL platform at district Level*

3 East Frisia

Challenges

*Very **large area** with **INCREASING water demand***
Limited ground water resource
Need for alternative water supply.

Innovations & Goals

- *WATER REUSE (drinking quality) within **milk INDUSTRY**.*
- *DIGITAL tools to model and assess **short** & **medium-term regional** WATER DEMAND; & **alternative resources***

4 Flanders

Challenges

***Strongly urbanized** Area*
LIMITED groundwater R.,
INTENSIVE use of RIVERS,
Soil SEALING & Quant.-Qualit.-issues

Innovations & Goals

- *Improving **DRINKING WATER** (DW) installations,*
- ***WASTEWATER** as indirect alternative for DW*
- *Buffering **storm water** RUN-OFFS→ ↑ Soil Infiltration,*
- *DIGITAL water models*

5 Lisbon

Challenges

*- Water **demand** & **drought** Issues: in act Green strategies for **URBAN WATER** use & water Efficiency & Reuse*
- Reduce pressure on resources

Innovations & Goals

- *Consolidate the STRATEGY*
- *Technologies Protocols & DIGITAL models/tools for: Water-Energy-P Balance; Risk Assessment – Reclaimed Water - Climate certification*
- *DW in Beverage **INDUSTRY***

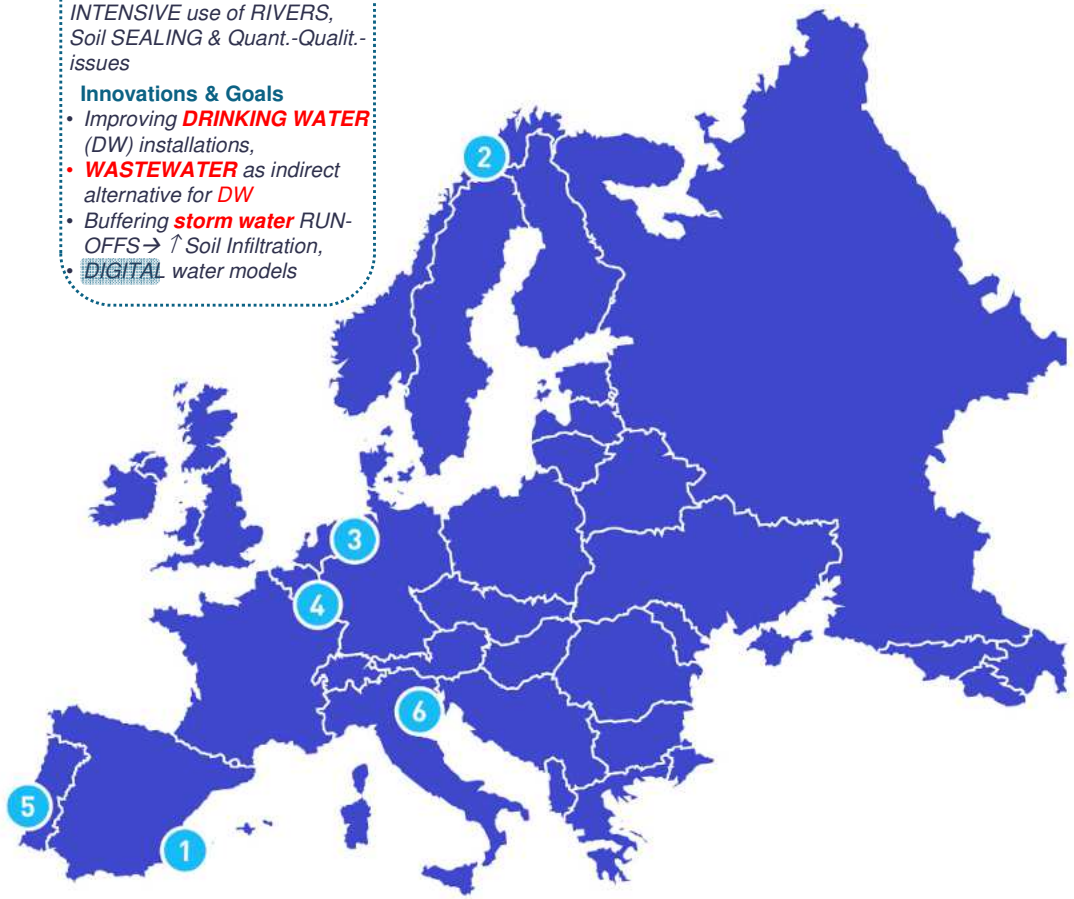
6 Venice

Challenges

Fragile ecosystem,
***Exploit REUSE potential** from **WWT** - Completing the PIF goals - Improve KNOWLEDGE on RISKS connected to REUSE*

Innovations & Goals

Effluent REUSE - pilot for INDUSTRIAL reuse; N-Recovery from [conc] stream
DIGITAL platform as DSS for WATER reuse opportunities & SLUDGE management,

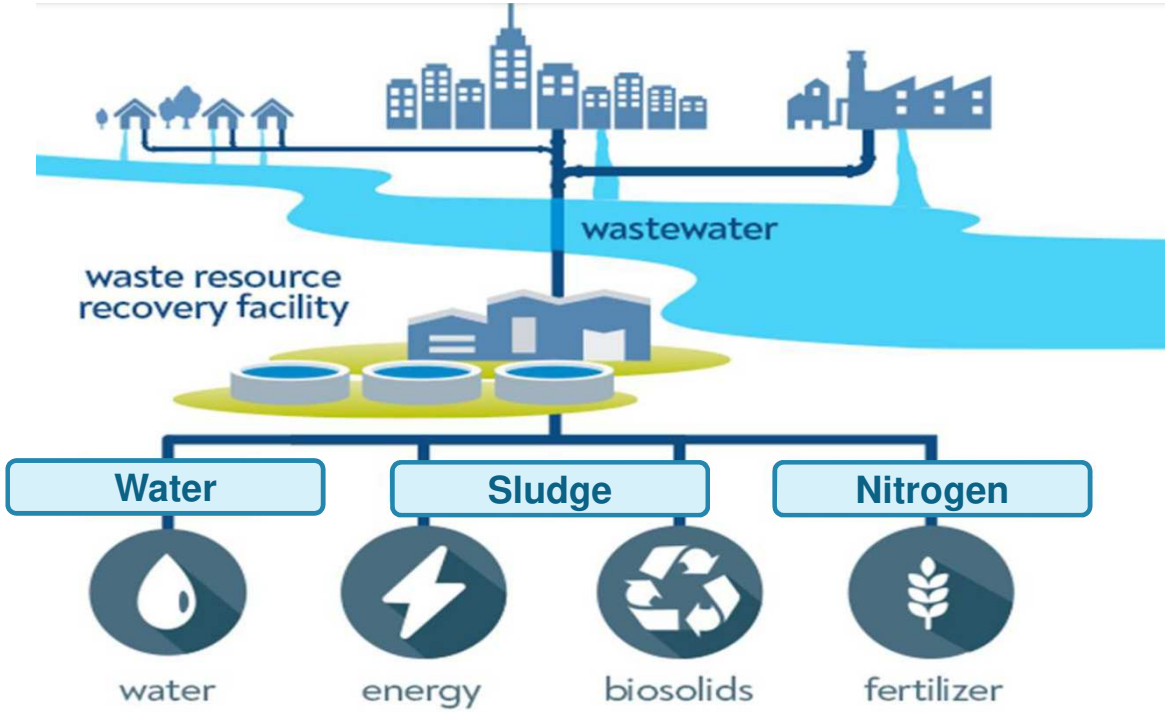


The VENICE LIVING LAB (LL)

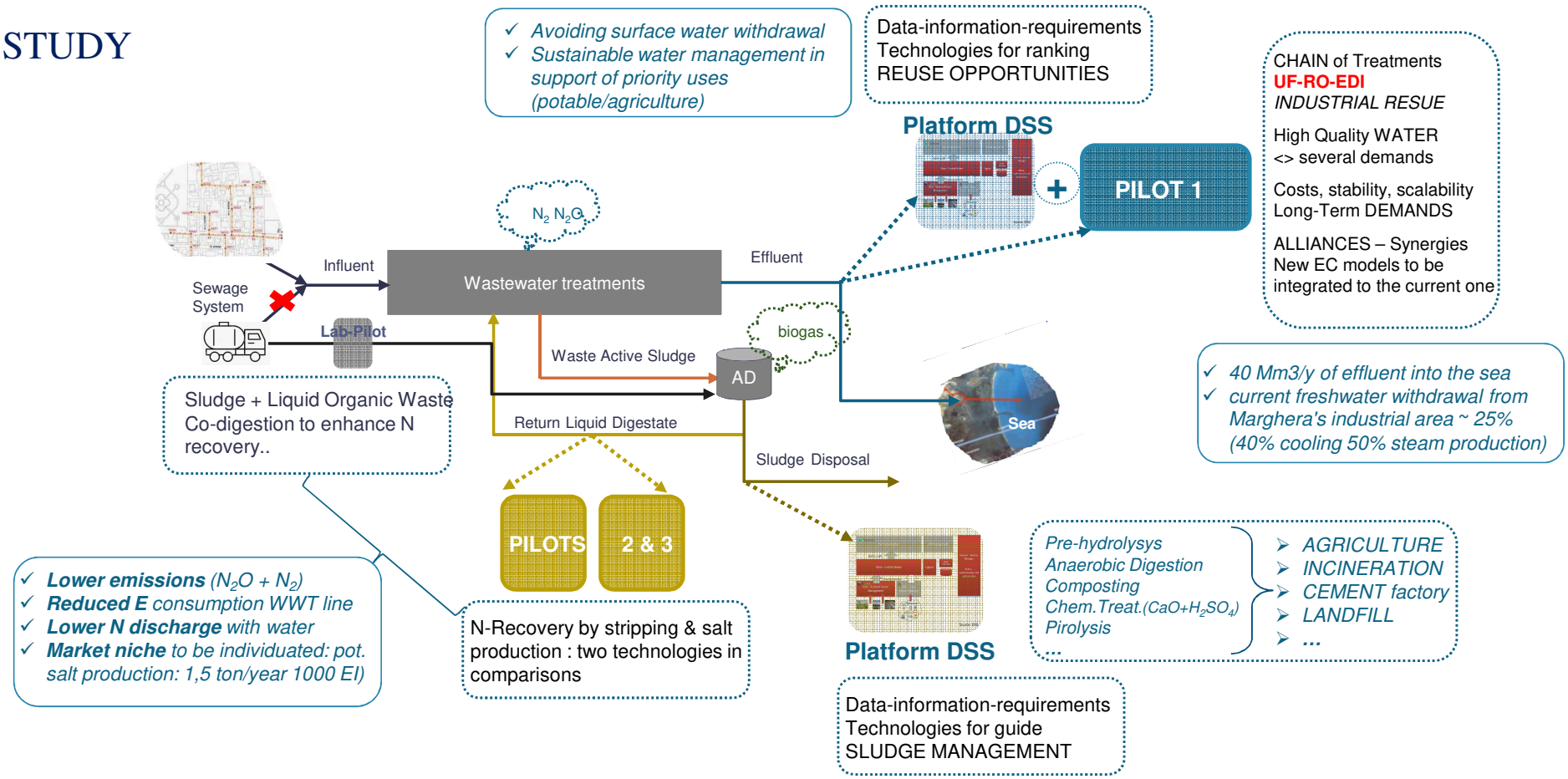
6 PARTNERS

- **VERITAS**
- **SINTEF**
- **ENGINEERING**
- **ETRA**
- **HYDROTECH**
- **DEPURACQUE**

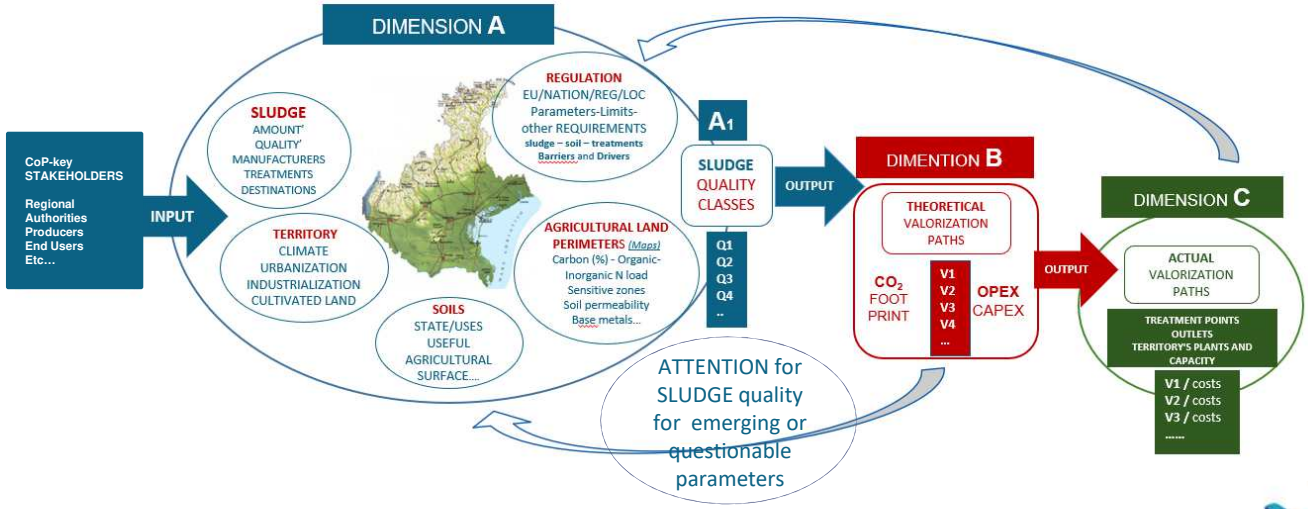
INTERCEPTING WASTEWATER *and FOSTER the WATER REUSE and WATER RELATED RESOURCES VALORIZATION*



THE CASE STUDY

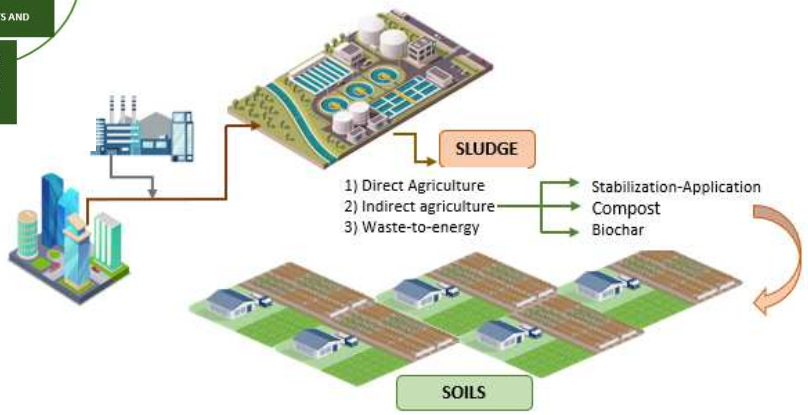


FOSTERING the nutrient RECOVERY from SLUDGE – the DSS tool



2020

50% AGRICULTURE
44% LANDFILL
5% THERMAL VALORIZATION



- About 60.000 ton/y SS in VENETO
- The management remains complicated
- Unfair Regulations - deep-rooted prejudices
- Lack of knowledge on risks and opportunities

JUST TO PROVIDE AN EXAMPLE of MATCH form Product & territory– the DSS tool

UTILITY	WWTP with AN.D.	E.H.	INDUSTRIAL RISK	Sludge TQ Ton/year	Sludge SS%	Sludge SS Ton/year
5	with AN.D. - 13	2.001.380	LOW	56.692	28%	13.627
9	with A.D. - 87	2.749.158	LOW-MEDIUM	117.347	21%	24.842
10	without any Digestion - 129	3.753.113	HIGH *(60-70%)*	67.921	22%	25.939
						64.409

Note: Overestimated production (NOT eliminated internal displacements), values used only to weight the industrial risk associated with the production.

Demo video – next slide

QUALITY DATA MANAGEMENT

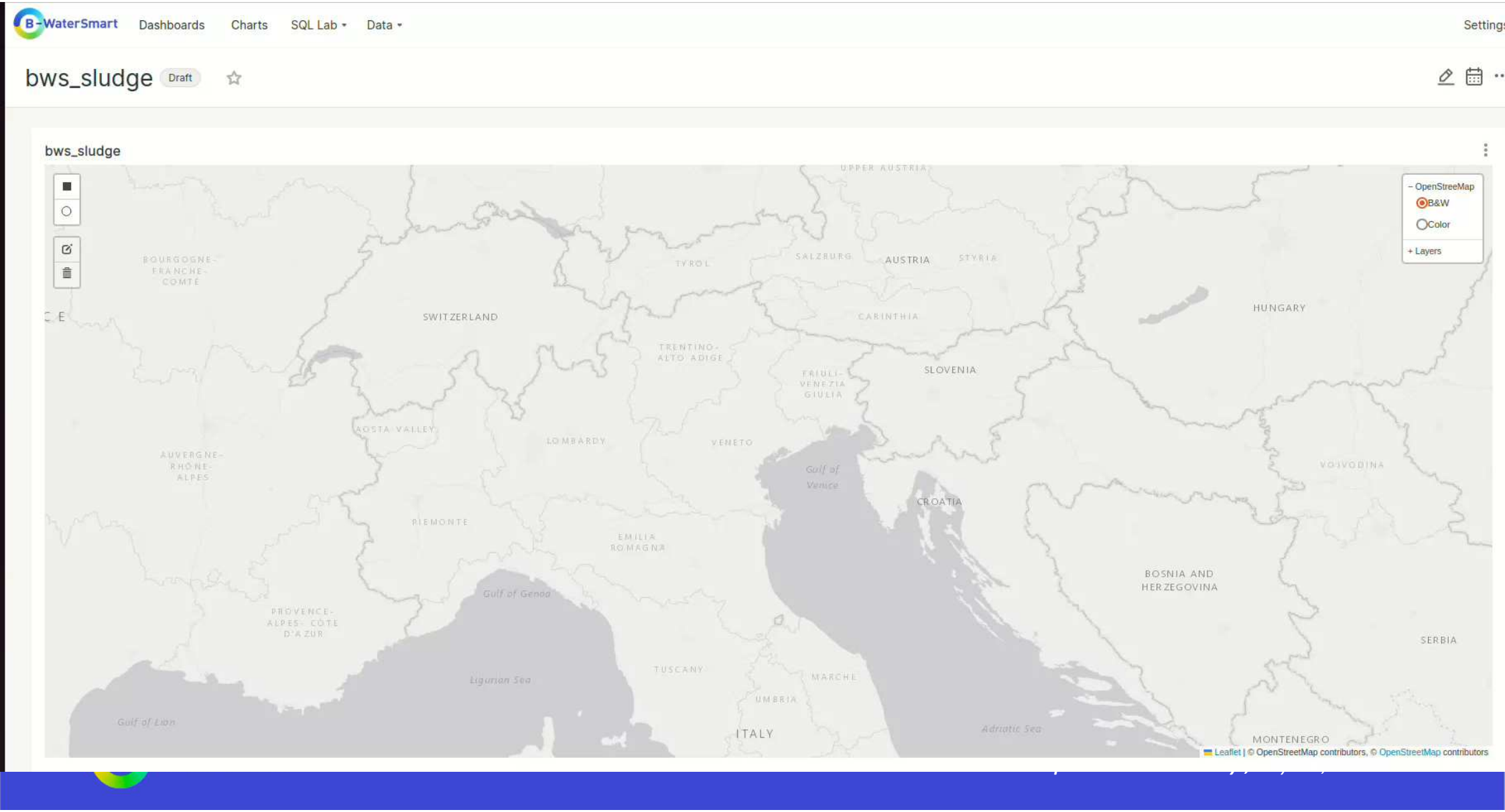
Average Value + Range of Variation for each Utility

TRACEABILITY about the reliability of the values

1st Filter - on Numerousness -critical if LOW

2nd Filter - on proximity to LL - critical - the error of measurement to be highlighted

3rd Filter - on results follen below the DL of method (the calculation of average to be standardized)


B-WaterSmart
Dashboards
Charts
SQL Lab
Data
Settings
bws_sludge
Draft
bws_sludge
OpenStreeMap
B&W
Color
+ Layers
UPPER AUSTRIA
BOURGOGNE-FRANCHE-COMTÉ
TYROL
SALZBURG
AUSTRIA
STYRIA
HUNGARY
SWITZERLAND
CARINTHIA
TRENTINO-ALTO ADIGE
FRIULI-VENEZIA GIULIA
SLOVENIA
AOSTA VALLEY
LOMBARDY
VENETO
AUVERGNE-RHÔNE-ALPES
Gulf of Venice
VOJVODINA
CROATIA
PIEMONTE
EMILIA ROMAGNA
BOSNIA AND HERZEGOVINA
Gulf of Genoa
PROVENCE-ALPES-CÔTE D'AZUR
SERBIA
Ligurian Sea
TUSCANY
MARCHE
UMBRIA
Gulf of Lion
ITALY
Adriatic Sea
MONTENEGRO
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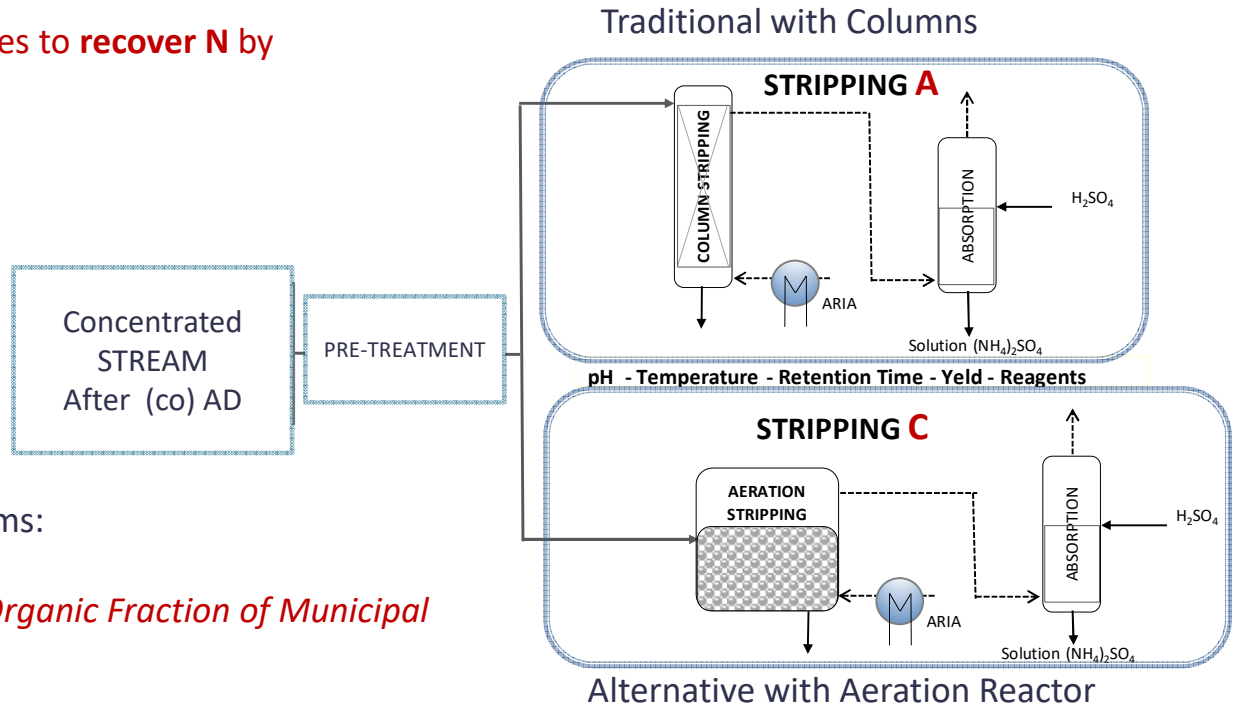
STRIPPING for nutrient recovery – DEPURACQUE & ETRA

2) ASSESSING the **SUSTAINABILITY** and opportunities to **recover N** by **AMMONIA** to produce the *$(N\text{-}NH_4)_2SO_4$ salt*



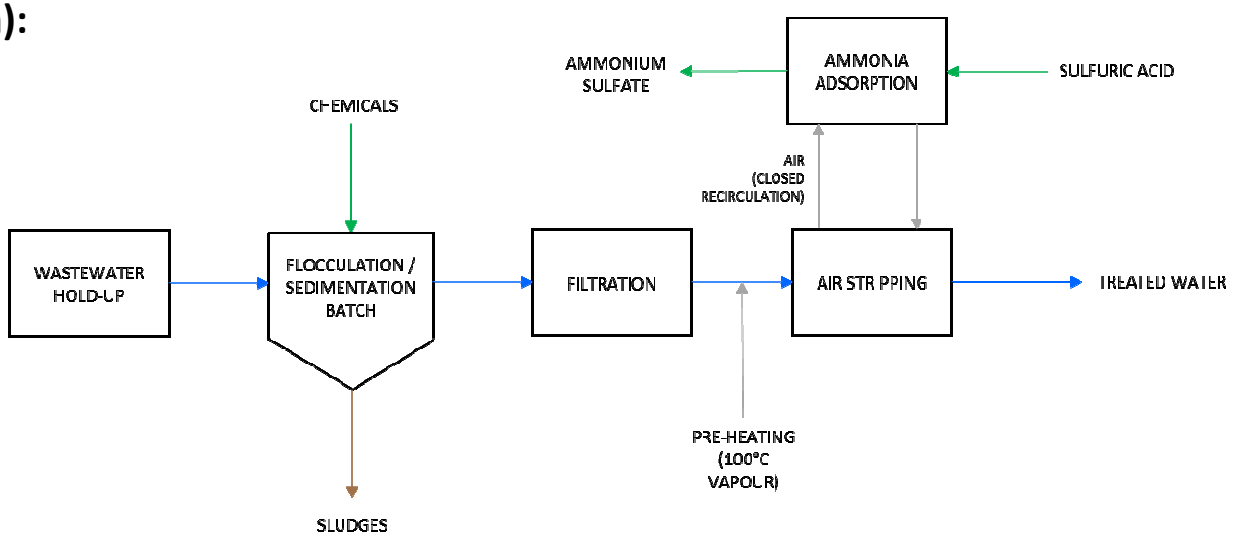
Using **two SUBSTRATES** - Concentrated Liquid Streams:
S-SLUDGE ANAEROBIC DIGESTION
S-OFMSW ANAEROBIC CO-DIGESTION (OFMSW= *Organic Fraction of Municipal Solid Waste*)

averages	S	S-OFMSW	
pH	7,8	8	
TS	0,15	0,6	%
TSS	1,000	2,200	mg/l
N-NH4+	700	1,000	mg/l
ALK	3,000	7,000	mgCaCO3/l

Column STRIPPING for nutrient recovery – DEPURACQUE

PILOT PLANT FINAL DESIGN (400 l/h):

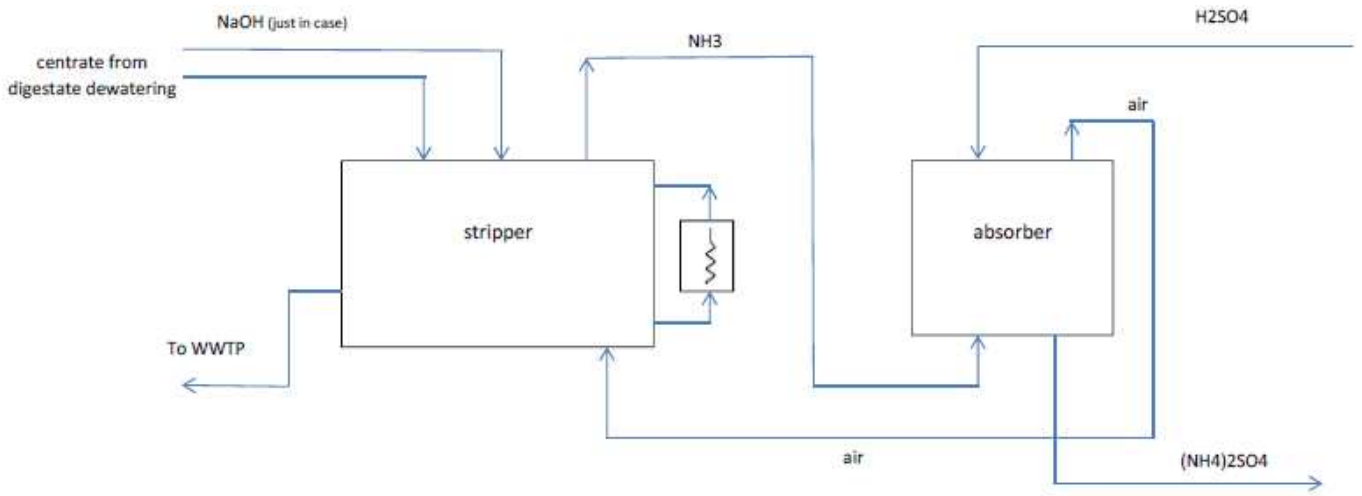




ADVANTAGES	DISADVANTAGES
- Higher removal efficiencies	- Pre-conditioning of the matrix required: - Heating up to 60°C and pH=11 - Chemical addition to avoid cloggings and scaling and to increase PH
- Short retention time	- Sludge production
	- Minimum flowrate required for a representative scale-up (400-500 l/h)

AERATION STRIPPING for nutrient recovery – ETRA

PILOT PLANT FINAL DESIGN (100 l/h):

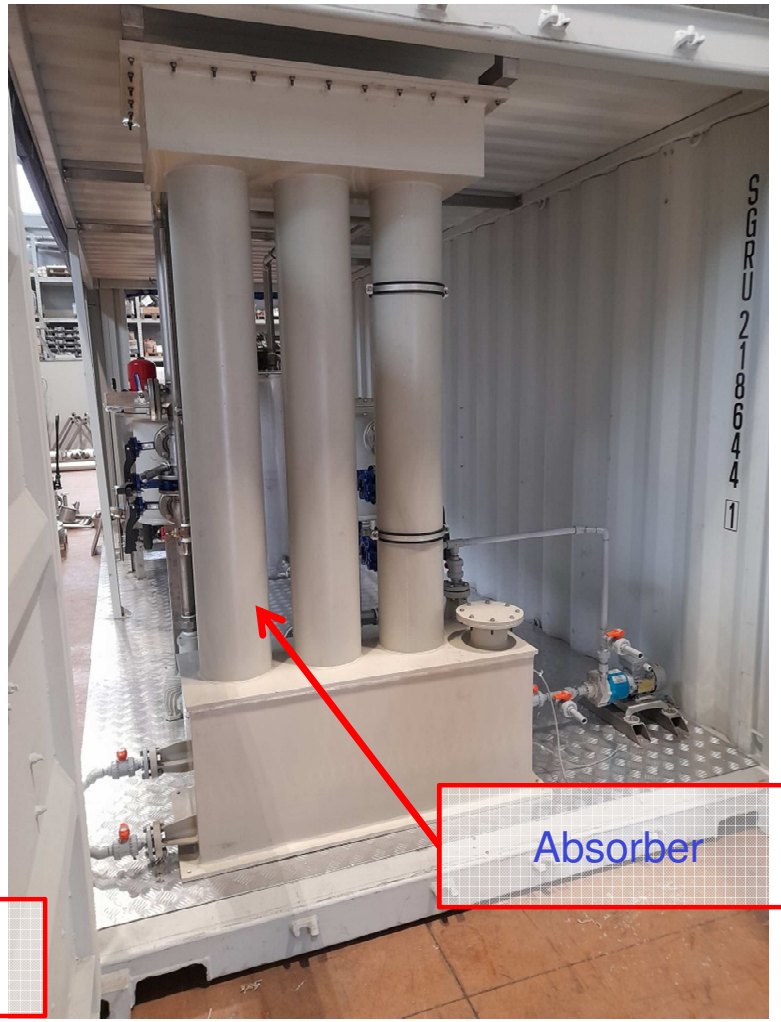


Simpler:
- No pretreatment
- Normal tank instead of a packing column
- No sludge production

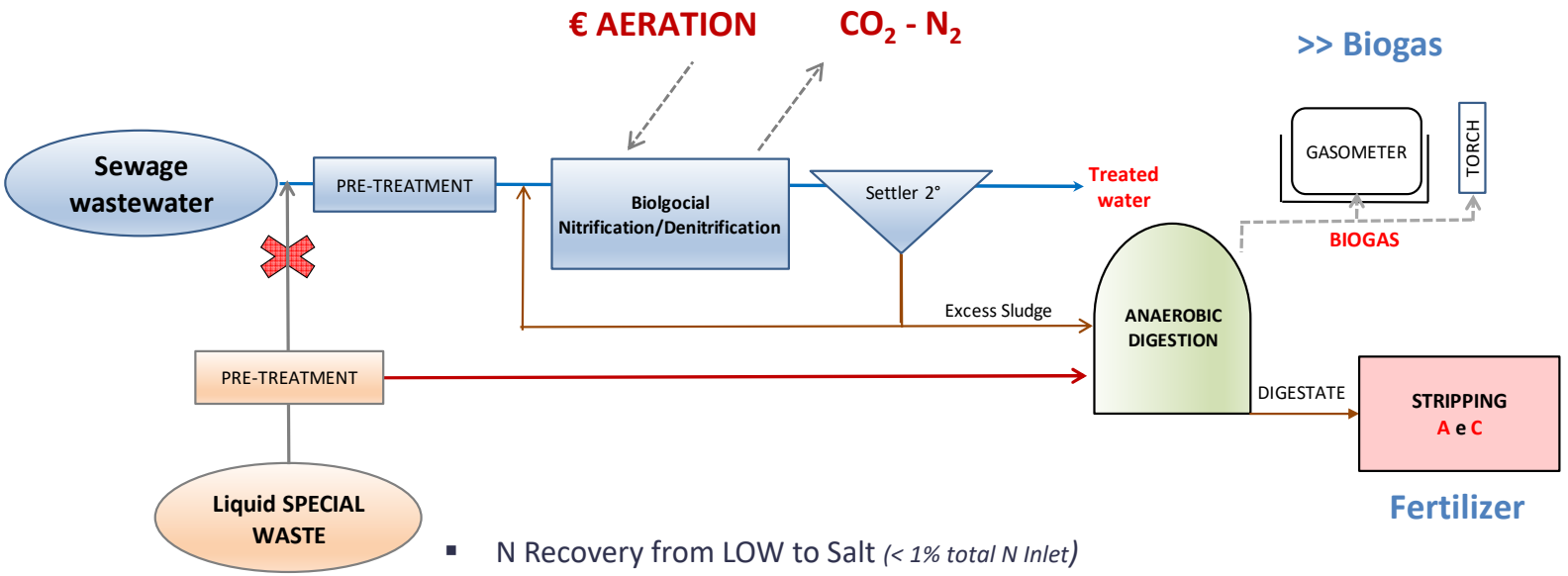
Expected to need:
- Less attention to scale
- Less or no chemicals in the influent
- Lower process temperature

But
- Lower yield
- Longer retention time


Stripper


SGRU 2186644 1
Absorber

CO-DIGESTION – LOW and SLUDGE



- N Recovery from LOW to Salt *(< 1% total N Inlet)*
- Decreasing *CO2e-Cfp* due to EE consumption (*N oxidation*) – N_2O emission (*1% of N Inlet*)
- Decreasing in Sludge production (*depending on N and COD removed*)
- Increasing of BIOGAS Production (*0,5 Nm3/Kg COD Sub; 0,6-0,8 Nm3/Kg SSV Sub*)

In terms of NITROGEN RECOVERY

All the solutions in studying some way (directly or indirectly) condition the Nitrogen use and recovery

1) EFFLUENTS	Total N (*especially* NO3) discharged- lotic receiving body - **biodiversity** - agricultural withdrawal downstream - agricultural uses **ferti-irrigation** *(~ 500 M m3)*	***4,000-5,000*** *ton/year* ***N***	*3-4%*
2) N recovered by **STRIPPING**	FRACTION in the LIQUID AN digestate - usually sent to the main WWTP and **lost** with the effluent *(26% sludge undergos ANAD)*	***300*** *ton/year* ***N*** *(1,300 if all sludge underwent AD)*	*0,20%*
3) The potential **Co-DIGESTED LOW**	Enrich both LIQUID and SOLID digestate coming out from the AD *(From Concession at RS)*	***50*** *ton/year* ***N***	*0,04%*
4) SLUDGE VALORIZATION	Rreservoir for **RECOVERY** of **nutrients** we need (5%N-2/3%P -30-35% C), currently not well exploited *(70% Low Risk for INDUSTRY)*	***2,000*** *ton/year* ***N*** *(3,000 if all sludge was of good QL)*	*2%*

TOTAL *NITROGEN APPLIED a REGIONAL SCALE*
130,000 tons

Fertilizers	2018	**92.000**
	2015	97.600
	2013	87.000
From manure	2019	**38.000**
	2013	50.240

70-80% Inorganic

Rif - *ISTAT 2018 - IVPianoNO3-all.B; Veneto Agricoltura; ARPAV 2019 IVPianoNO3; ARPAV;*

In terms of CFP for N2O emission avoided by STRIPPING

2021_Marinelli et al., Water Research 2021
US EPA, 2021
Saurajyroti Kar et al, Science of the Total Environment, 2023

ESTIMATIONS by using some literature

		Today	Potential Projaction
SLUDGE UNDERGONE to ANA.D.	ton/year	13.716	63.655
N RECOVERED by STRIPPING	ton/year	288	1.359
CFP AVOIDED for N2O Emiss.Reduc.		> 15.000 PE	
Emission-factors from WWTP (N_2O)	kgN2O/kg N $_{removed}$	0,00066	0,00066
N_2O Emission Avoided (	tonN2O/year	0,19	0,90
CO2eq/N2O ratio	CO2eq g/gN2O	298	
CFP AVOIDED *(for N_2O Emiss.Reduc)*	CO2 eq ton/year	57	267
Emission Ratio for Stripping	kg CO2e/kg N	0.94-2.36	
CFP ADDED for **STRIPPING**	CO2eq ton/year	1,281-3,203	
Total Potential Recovery		1.359	
CO2eq Emission Avoided		267	
Minumum - Maximum CFP PRODUCED vs AVOIDED		5	12
Emission Ratio- HUBER-BOSCH *(N-Prod.)*	kg CO2e/kg N	11,8	
N RECOVERED by STRIPPING	ton/year	288	1.359
CFP- HABER BOSCH AVOIDED	CO2eq ton/year	3.403	16.036

WWTPs	< 15.000	140	18.500	9%	6.284	10%
WWTPs	> 15.001		235.372	24%	56.489	90%
***Note** : Approximative but macroscopically reliable calculation*					62.773	

Without considering EE reducing

A large fraction of AS and AN production occur as co-products in nylon, nickelmining, and nickel smelting and refining processess.
The current market of AS production from HUBER-BOSCH sourced ammonia is 7,2%
(Saurajyroti et al, 2023)



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 869171. The publication reflects only the authors' views and the European Union is not liable for any use that may be made of the information contained therein.

REwaise
REsilient WAter Innovation for Smart Economy

aqualia

http://rewaise.eu/

Nutrient recovery in H2020 Rewaise

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jvazquep@fcc.es
Innovation & Technology

Resource Recovery in the (waste)water field

The paradigm shift needed

Aqualia treats 500 000 000 m^3/year of urban WW

Electric consumption associated:

0,5 kWh_{el} /m^3 = 250 M kWh

The energy content of urban WW is tipically ~2 kWh_{th}/m^3

Wastewater is Bioenergy!

N fixation Haber-Bosch Process 10 kWh/kg N

Wastewater is a nutrient source!



Phosphate rock depletion

Wastewater is a nutrient source!

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 869496

REwaise REsilient WAter Innovation for Smart Economy

Extracting value in/through/from water

H2020 Rewaise

http://rewaise.eu/



WATER FULL VALUE

REWAISE reveals the full Value of Water for Europe, considering three key technical, economic and societal factors:

value in water, by extracting minerals from seawater brine, recovering nutrients from wastewater, and converting all organic matter and biomass into energy

value through water, generating wellbeing in society through stakeholder participation and new governance methods to maximize the positive effects of innovation for the users and the environment.

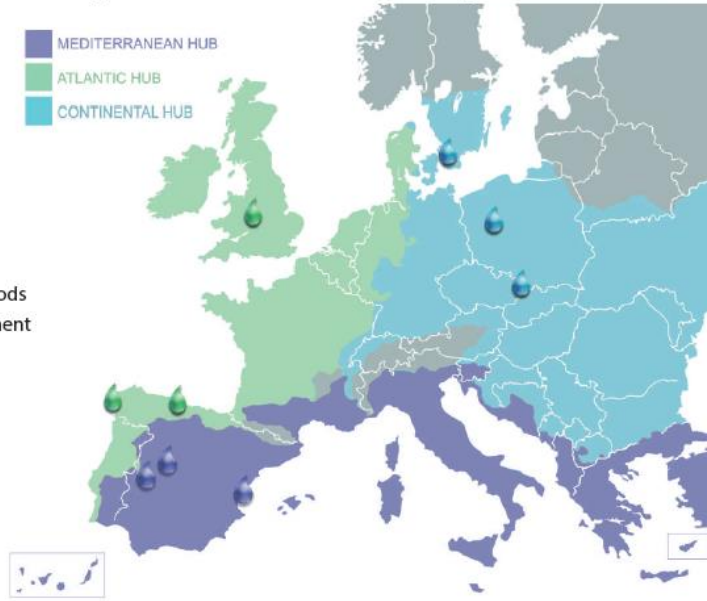
value from water, developing the business of sustainable services and innovative products all along the water cycle, working with start-ups and SMEs to give them privileged access to the large utility users

CONSORTIUM

REWAISE comprises 25 entities from 11 European countries: Belgium, Croatia, Czech Republic, Denmark, France, Italy, Ireland, Poland, Spain, Sweden and the United Kingdom. These entities are experts in the different areas involved in the project: water, energy, local governance, venture capitals and business experts, research and also ancillary services.

LIVING LABS

REWAISE will recover energy, nutrients, and materials from water in real operational environments, implementing technological innovations and new water governance models with **a network of living labs in five countries.**



CONTRIBUTIONS

- Social engagement
- Redefine governance methods
- Alternative water management
- New business models

WINcubator

To trigger new entrepreneurs, REWAISE launches the business accelerator WINcubator, that connects large utility users with creative product suppliers. Based on the Swedish Water Innovation Network-WIN model, it will support a market arena using open innovation.

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 869496

REwaise
REsilient WAter Innovation for Smart Economy

1. Anaerobic Membrane Bioreactor

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 869496

Resource Recovery in the (waste)water field

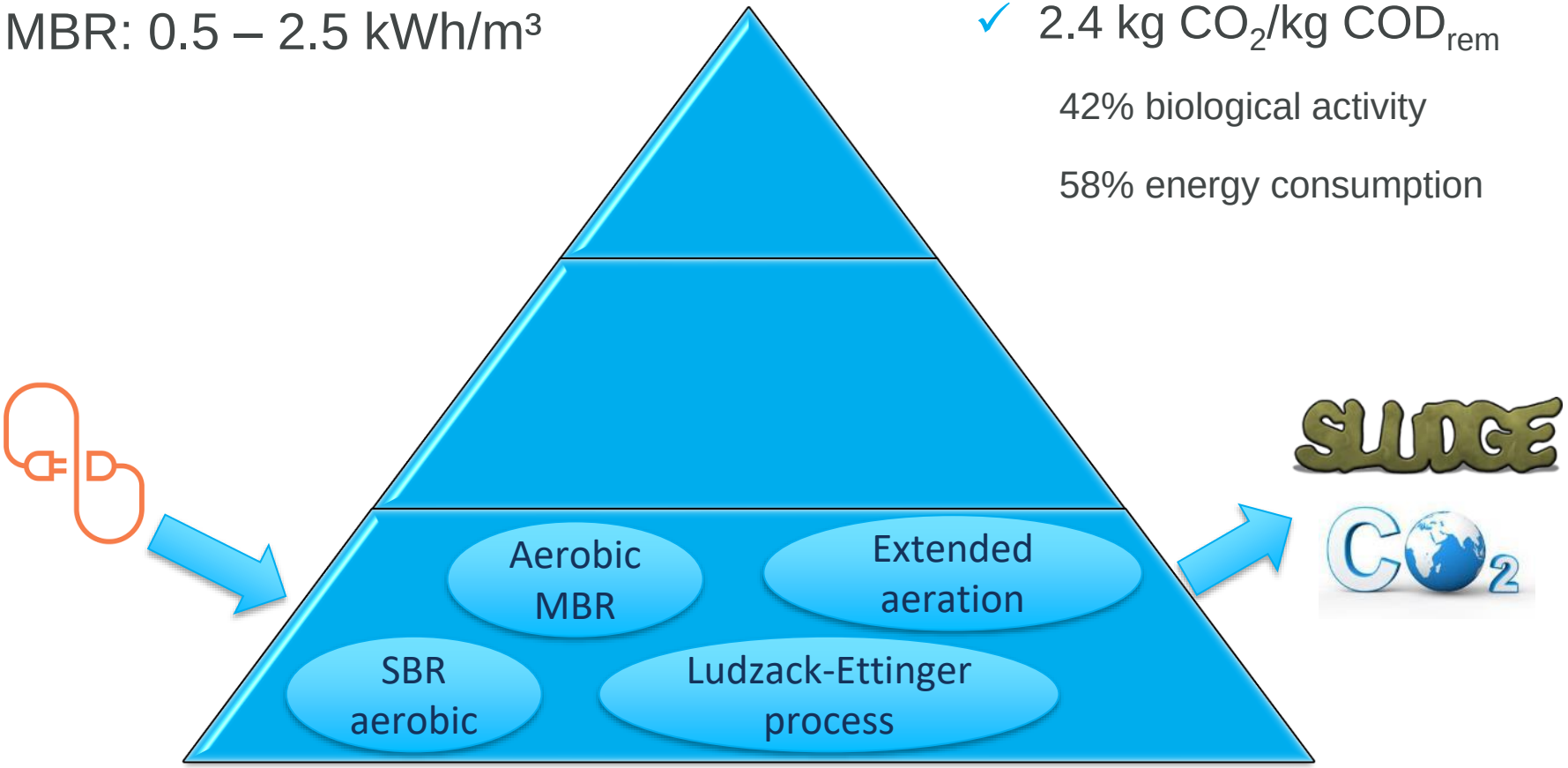
The paradigm shift needed

- ✓ AS: 0.25 – 0.6 kWh/m³
- ✓ MBR: 0.5 – 2.5 kWh/m³

- ✓ 0.4 kg VSS/kg COD
- ✓ 2.4 kg CO_2/kg COD_{rem}

  42% biological activity

  58% energy consumption

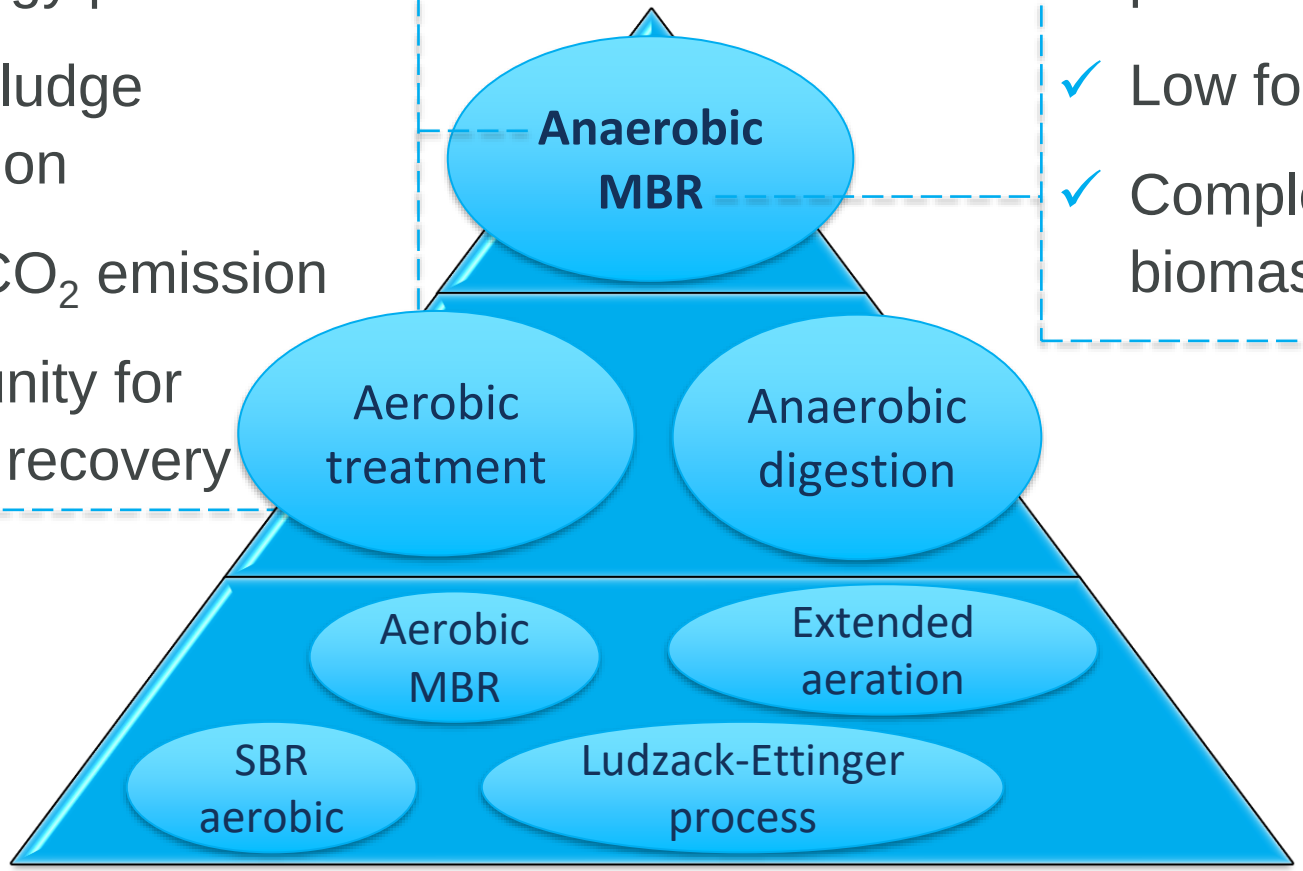


Resource Recovery in the (waste)water field

The paradigm shift needed

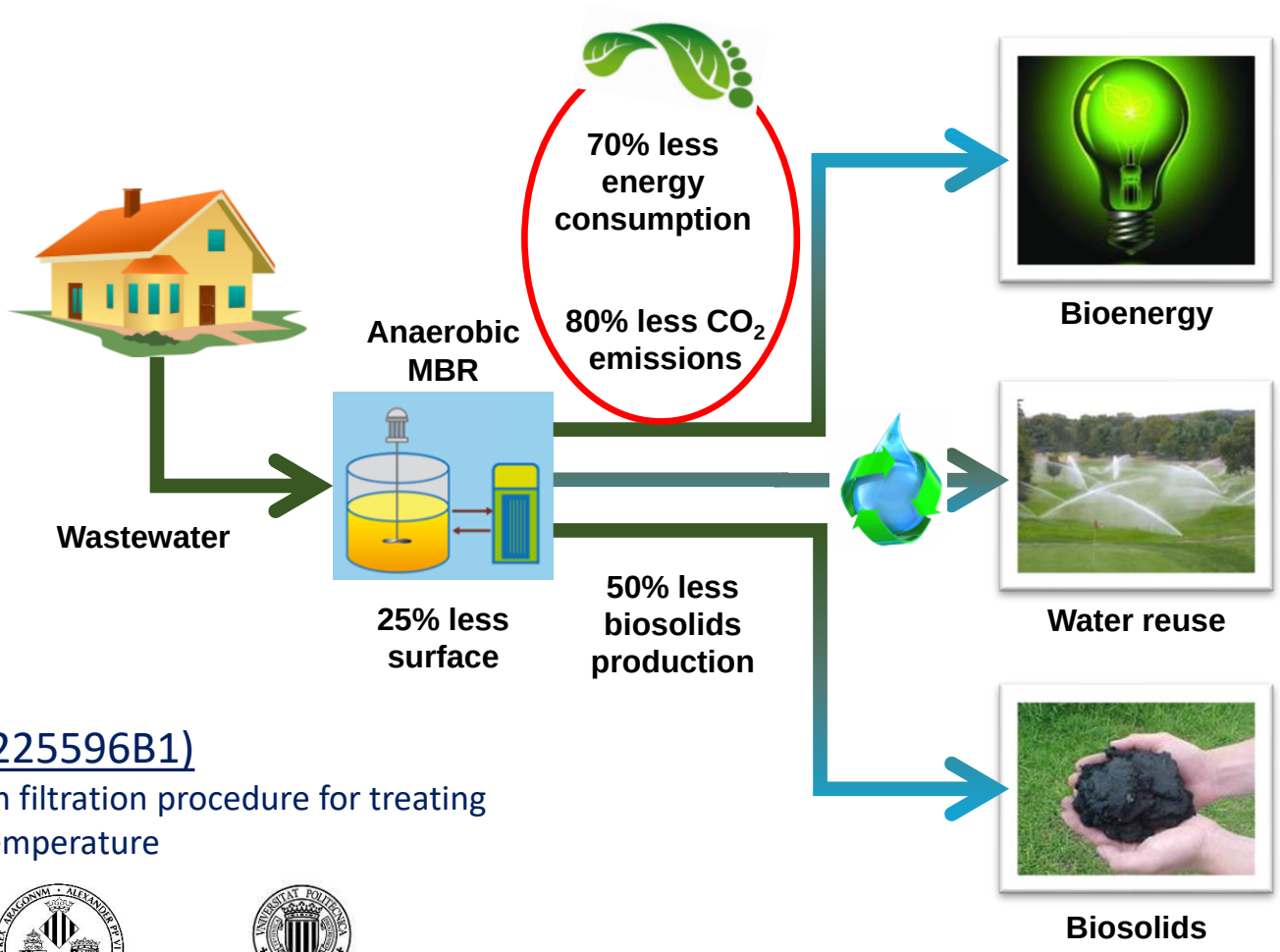
- ✓ Lower energy demand / net energy production
- ✓ Lower sludge production
- ✓ Lower CO_2 emission
- ✓ Opportunity for nutrient recovery

- ✓ High-quality permeate
- ✓ Low footprint
- ✓ Complete biomass retention



Anaerobic Membrane BioReactor (AnMBR)

The paradigm shift needed

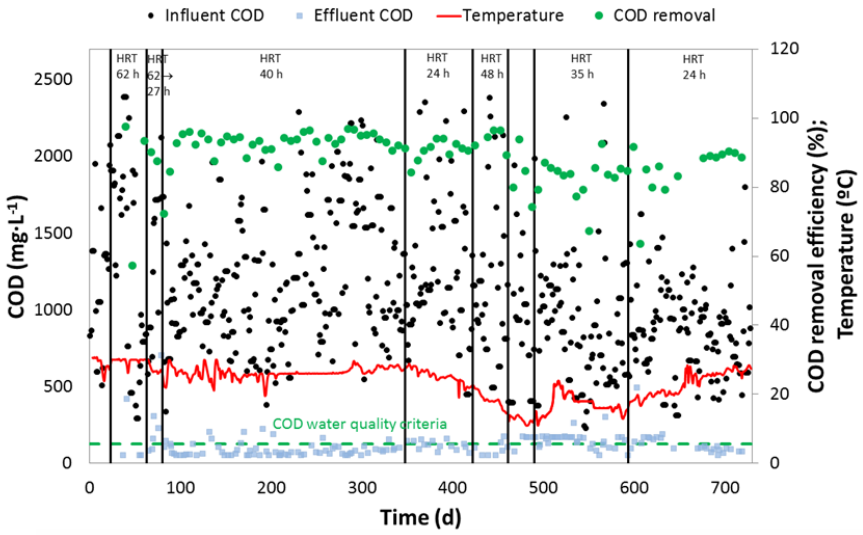


Joint patent (EP3225596B1)

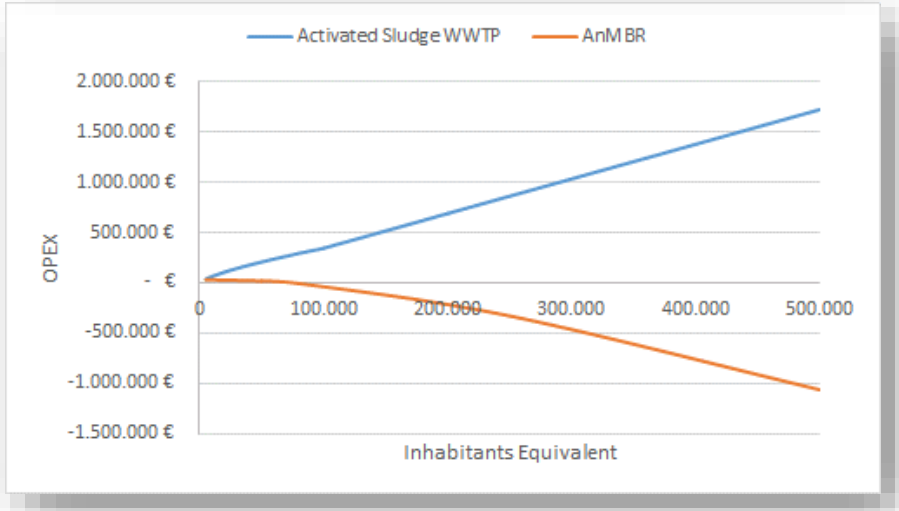
Anaerobic process with filtration procedure for treating wastewater at room temperature

Anaerobic Membrane BioReactor (AnMBR)

LIFE MEMORY (2014-2018)







ELSEVIER

Current Developments in Biotechnology and Bioengineering

Advanced Membrane Separation Processes for Sustainable Water and Wastewater Management - Case Studies and Sustainability Analysis

2020, Pages 289-310

12 - Energy and environmental impact of an anaerobic membrane bioreactor (AnMBR) demonstration plant treating urban wastewater

Antonio Jiménez-Benítez [a, b], José Ferrer [a], Frank Rogalla [c], José Ramón Vázquez [c], Aurora Seco [b], Ángel Robles [b]

10.1016/B978-0-12-819854-4.00012-5

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Anaerobic Membrane BioReactor (AnMBR)

LIFE MEMORY (2014-2018)

- From an environmental, economic and social point of view, AnMBR for urban wastewater treatment is a promising technology:
  - Suitable **COD removal (> 90%)** and **methane production (70% in biogas)**
  - The AnMBR system can be operated with **transmembrane fluxes around 20 LMH** (competitive)
  - **Low biosolids production** can be achieved, far below the reported values in aerobic processes
  - AnMBR can be a **net energy producer**, but recovering methane from effluent is a crucial step for the favorable energy balance of the process
  - **High quality treated water** is obtained, which is rich-nutrient water → Identify value of nutrient rich irrigation reuse



This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 869496

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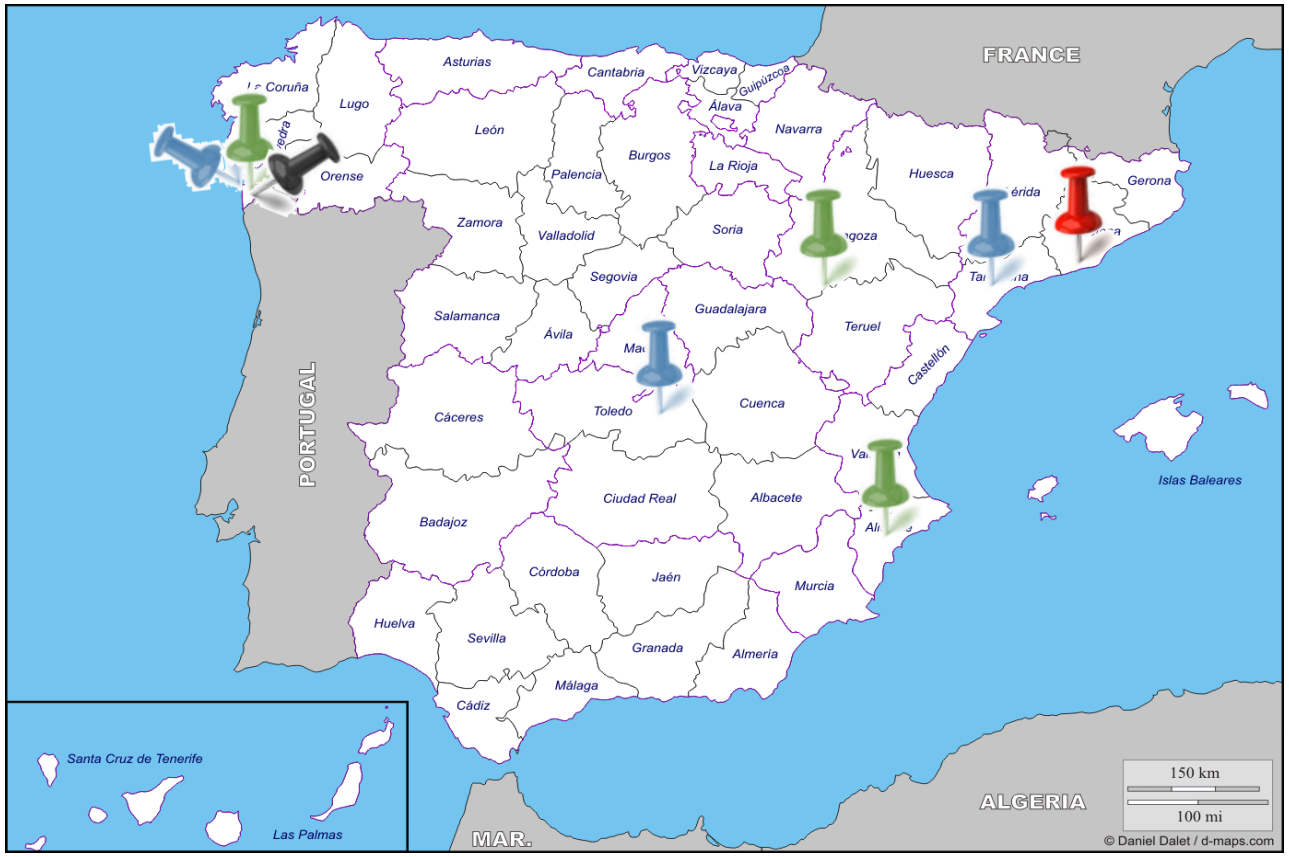
Anaerobic Membrane BioReactor (AnMBR)

Applied to a broad range of WW



Urban WW **Black Water** **Industrial** **OFMSW**

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 869496

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2. AnMBR Decentralized WWTP

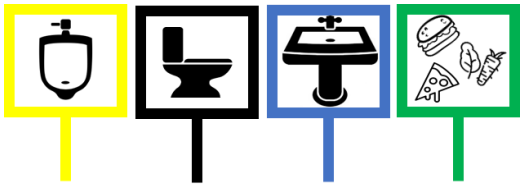
This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 869496

H2020 Run4Life: decentralised resource recovery at 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





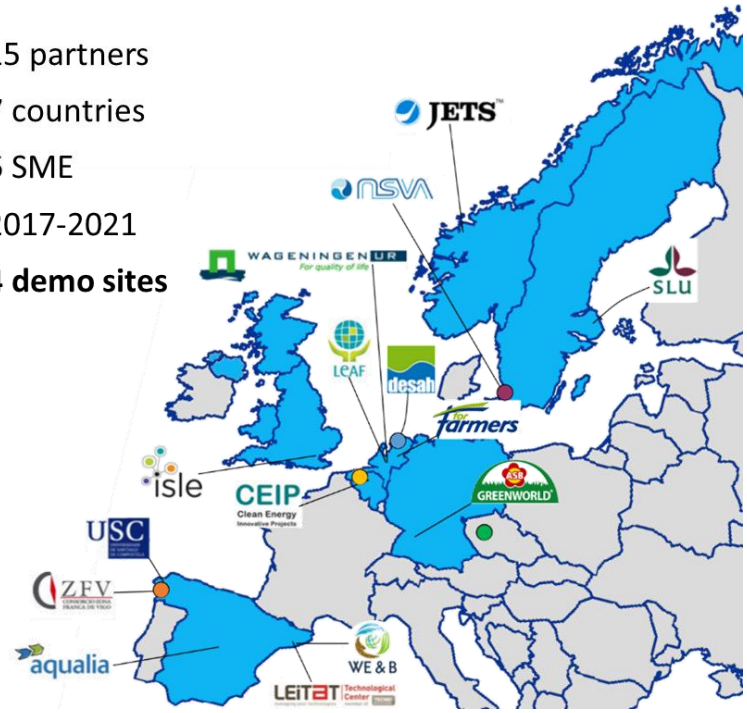


This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 869496

Resource Recovery in the (waste)water field

The paradigm shift needed

- 15 partners
- 7 countries
- 6 SME
- 2017-2021
- **4 demo sites**





Horizon 2020, GA 730285.

Anaerobic Membrane BioReactor (AnMBR)

Wide Experience

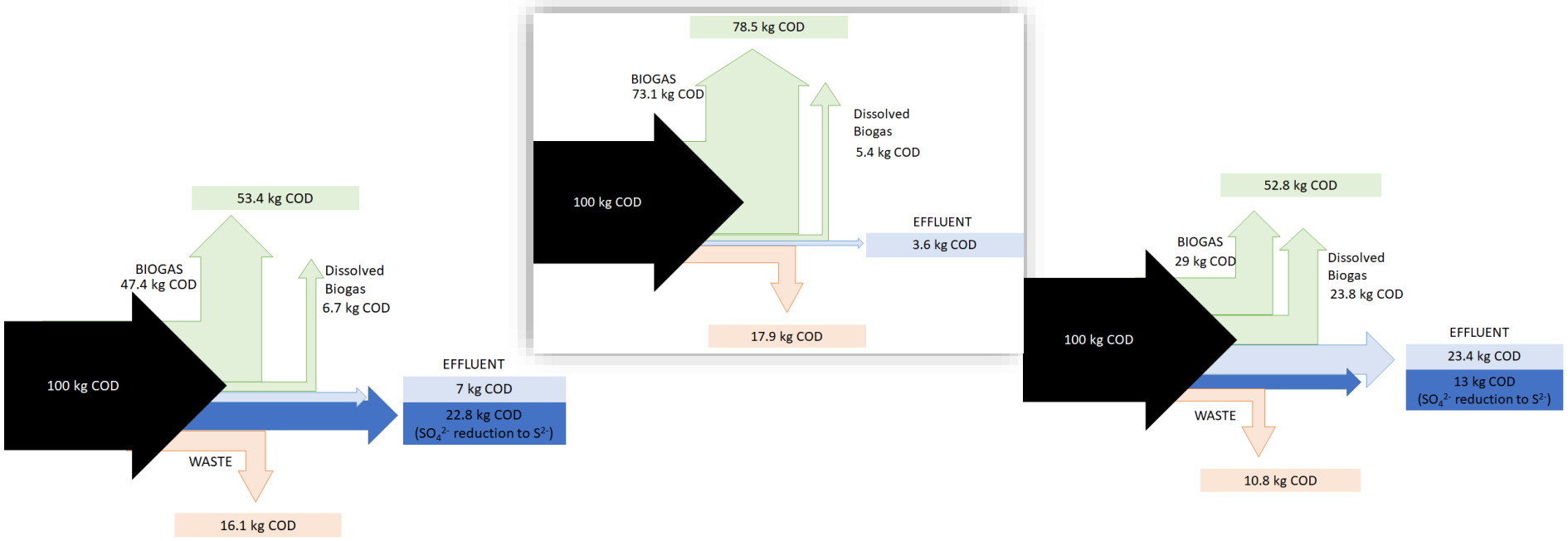
PROJECT	LIFE Memory	H2020 Run4Life / REWAISE	BESTF2 Biowamet
Location	Alcazar de San Juan WWTP (Spain)	Business center Porto do Molle, Nigrán (Spain)	Bítem WWTP, Tortosa, (Spain)
Running time (d)	>365 d	>700 d	>365 d
WW type	Municipal and industrial WW	Municipal Blackwater	Municipal WW
COD inlet [g/L]	1.17 ± 0.54	1.49 ± 0.80	0.77 ± 0.97
Temperature (ºC)	11 … 30	18 … 27	10 … 29
Membrane configuration	Submerged Hollow fiber	Submerged Flat sheet	Submerged Hollow fiber
Reaction volume (m^3) (Anaerobic reactor + membrane chamber)	36.8= [34.4 + (3 x 0.8)]	2.8= (1.8 + 1)	23= (15 + 8)
Filtration area (m^2)	3 x 41	1 x 6.25	2 x 31.5
Treated flow (m^3/d)	20-22	0.80 – 1.44	12-20
More info…	life-memory.eu	run4life-project.eu	Bitem WWTP

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 869496

Anaerobic Membrane BioReactor (AnMBR)

Wide Experience

		Summer operating conditions			Winter operating conditions		
	Parameters	Alcázar de San Juan WWTP	Porto do Molle B.C	Santa Rosa WWTP	Alcázar de San Juan WWT	Porto do Molle B.C	Santa Rosa WWTP
PERMEATE	tCOD(mg/L)	91±29	70±13	87±9	79±18	66±7	66±18
	COD removal (%)	93±2	96±1	77±2	90±1	92±4	87±1
	TN (mg/L)	48±6	88±33	86±8	34±6	121±21	84±11
	TP (mg/L)	9±2	10±1	9±1	6±1	12±1	9±1



This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 869496

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3. MEMB-RANER

Sewer mining

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 869496

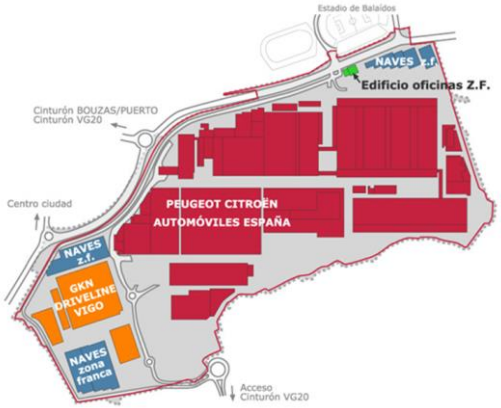
MEMB-RANER in Rewaise – Sewer Mining

- Sewer Mining in Balaídos Car Factory Site
- Treating urban WW from the industry
- Pilot in a container









This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 869496

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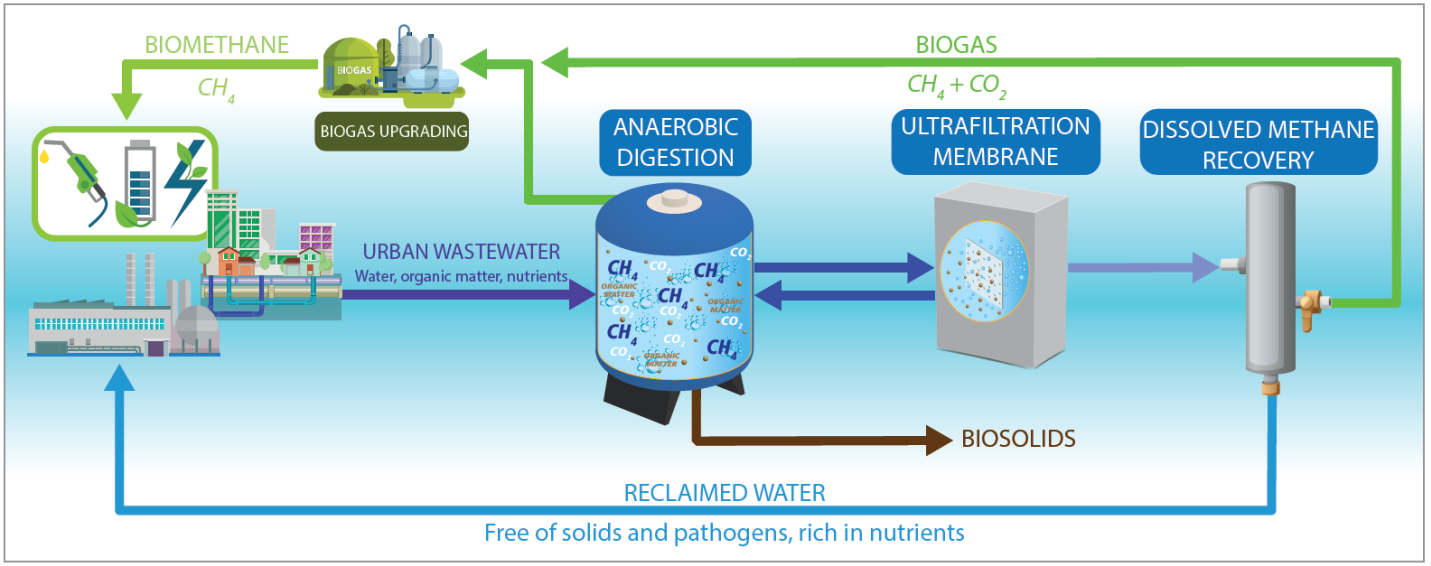
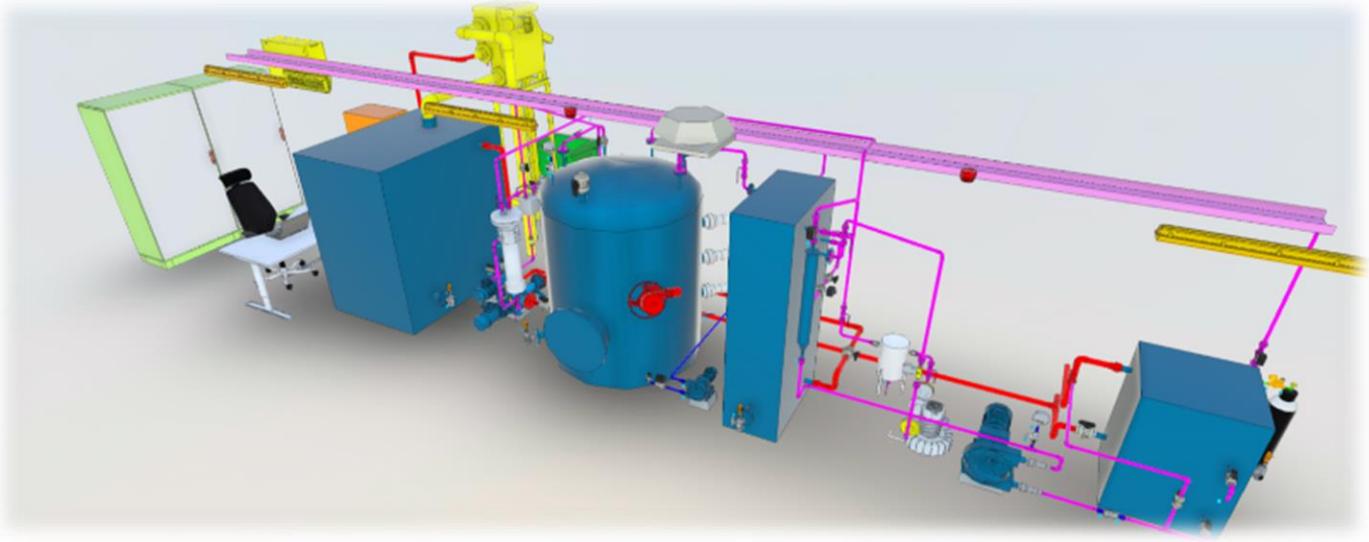
MEMB-RANER in Rewaise – Sewer Mining

AnMBR (10 m^3/d)





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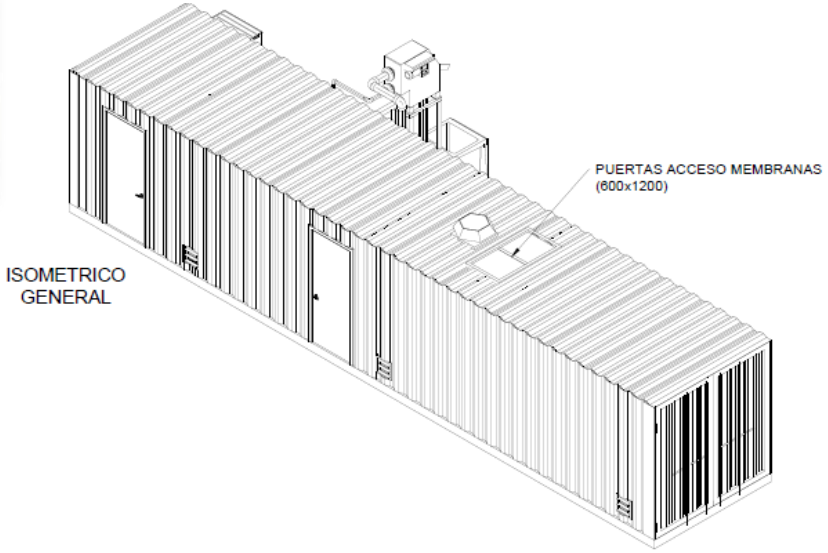
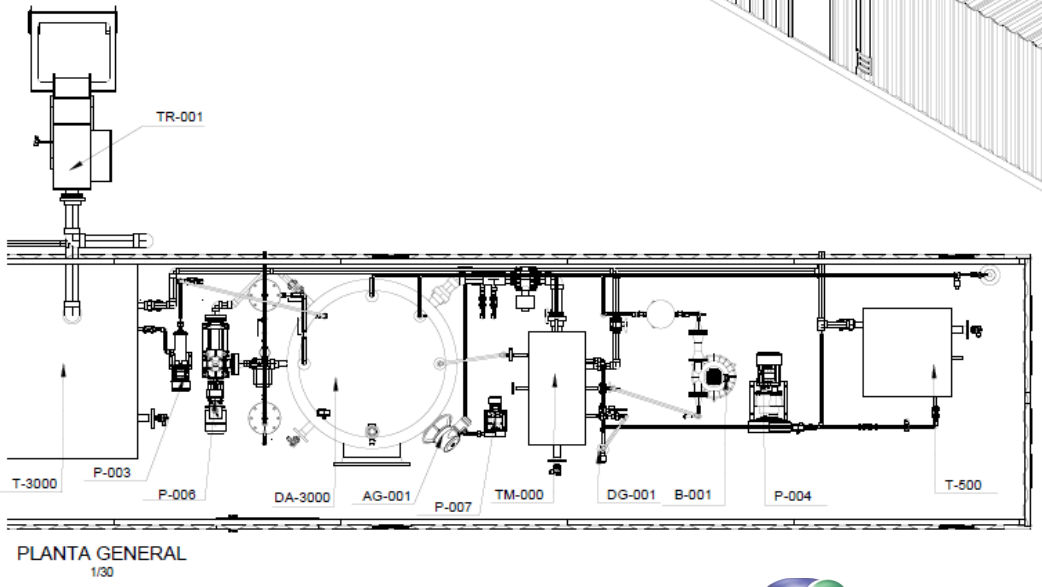
MEMB-RANER in Rewaise – Sewer Mining

AnMBR (10 m^3/d)



40 feet HighCube container





This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 869496

REwaise
REsilient WAter Innovation for Smart Economy

MEMB-RANER in Rewaise – Sewer Mining

aqualia

AnMBR (10 m^3/d)



$V_t \approx 3\ m^3$

$V_t \approx 4\ m^3$
$V_L \approx 3\ m^3$
$V_G \approx 1\ m^3$





$V_t \approx 1\ m^3$
$V_L \approx 0.75\ m^3$
$V_G \approx 0.25\ m^3$
Hollow fiber outside-in
PVDF
2 x 14 m^2
Pore size: 20 nm (UF)



$V_t \approx 0.5\ m^3$

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 869496

REwaise
REsilient WAter Innovation for Smart Economy

MEMB-RANER in Rewaise – Sewer Mining

AnMBR (10 m^3/d)

Container installed in April 22

- Electrical installation
- Sewer connections
- Configuration of automatic control
- Hydraulic tests

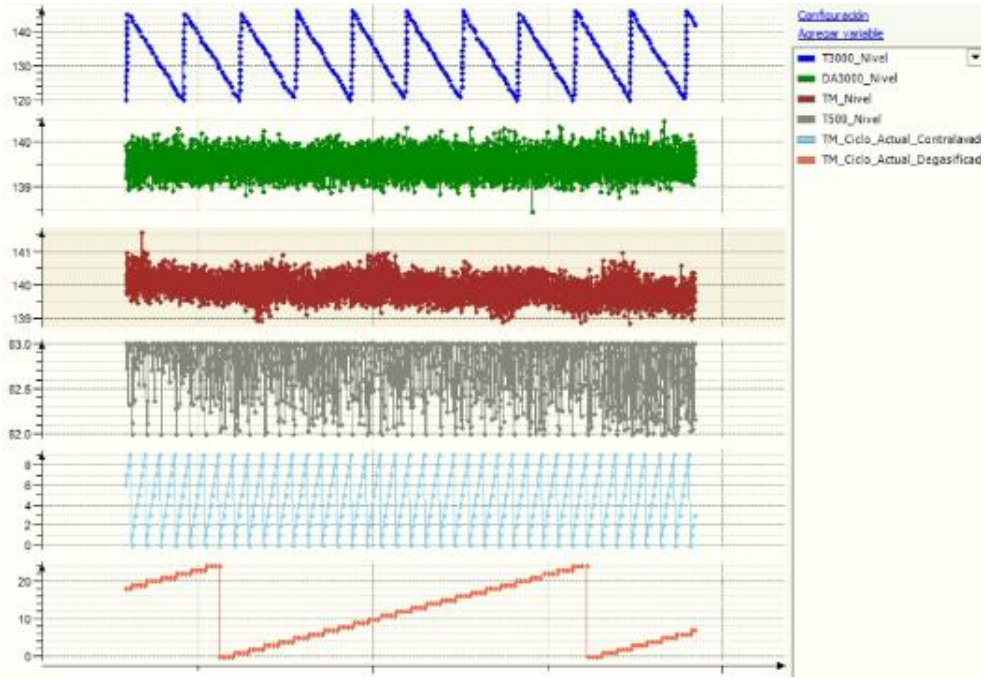
Inoculation performed in Nov 22



This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 869496

MEMB-RANER in Rewaise – Sewer Mining

Methane recovery in permeate





Start – Up in March 2023

Permeate: 4 m^3/d

Influent COD ≈ 1000 mg/L

Effluent COD ≈ 150 mg/L

Influent NT ≈ 150 mg N/L

Influent PT ≈ 15 mg P/L

REwaise
Resilient Water Innovation for Smart Economy

Project has received funding from the European Union's Horizon 2020 research and innovation program under Grant Agreement No 869496

VNIVERSITAT DE VALÈNCIA

CONSORCIO ZONA FRANCA VIGO

aqualia

FARO DE VIGO

Publicación	Faro de Vigo. General, 9	Fecha	10/09/2022
Soporte	Prensa Escrita	País	España
Circulación	33 149	V. Comunicación	14 700 EUR (14.833 USD)
Difusión	28 511	Tamaño	526,20 cm² (84,4%)
Audiencia	120 000	V.Publicitario	4576 EUR (4617 USD)

ECONOMÍA CIRCULAR

B.C

Zona Franca ya transforma aguas residuales en biogás en sus polígonos industriales de Vigo

» Tras el éxito de Porto do Molle como centro piloto del macroproyecto europeo "Run4life", el Consorcio suma su segunda instalación

Zona Franca de Vigo ya cuenta con dos centros piloto del macroproyecto medioambiental europeo "Run4life" para transformar las aguas negras (aguas de las cisternas de los inodoros y orinales que previamente han sido reutilizadas de las aguas grises procedentes de los lavabos) en fertilizantes y biogás. El primero fue en el parque de Porto do Molle y el éxito de los resultados ha llevado a instalar una segunda planta piloto en el polígono vigués de Balaídos.

David Regades se muestra "orgulloso de que dos parques empresariales de Zona Franca sean Centro Piloto, porque hemos puesto aquí muchos esfuerzos para que sea un ejemplo de sostenibilidad y economía circular" y destaca la "estrategia de apuesta por energías renovables y el medioambiente" de la entidad.

La de Balaídos es una planta piloto AnMBR (biorreactor anaerobio de membranas) para el estudio y tratamiento descentralizado de las aguas residuales generadas por las empresas del polígono, que estará próxima a una arqueta de residuales en las inmediaciones de la Portería San Andrés.

DAVID REGADES: "HEMOS HECHO UN GRAN ESFUERZO PARA QUE SEA UN EJEMPLO DE SOSTENIBILIDAD Y ECONOMÍA CIRCULAR"

En Balaídos, además de la obtención de fertilizantes, el proceso permitirá obtener biogás para el abastecimiento de las calderas de algunas naves del polígono,

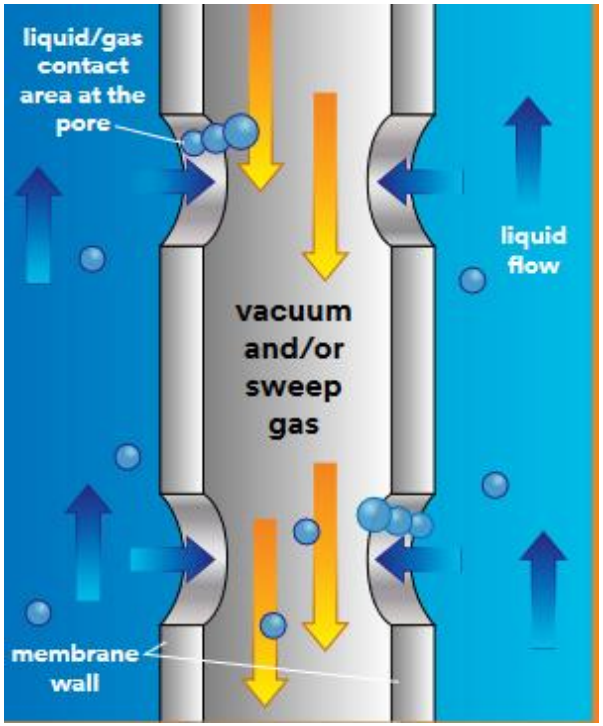


David Regades, delegado del Estado en el Consorcio de la Zona Franca de Vigo, visitó la instalación de Run4Life en Balaídos con Javier García Linares, director de la delegación de Galicia de Aqualia, y técnicos de la empresa que participan en el proyecto. // Gallica

Methane in the permeate

- Liquid effluent (permeate) is saturated with CH_4
- Potential loss of energy
- Greenhouse gasses (GHG) emissions

→ In REWAISE, a degassing system based on a membrane contactor was designed and connected to the pilot-scale AnMBR plant, in order to recover the dissolved methane in the permeate.

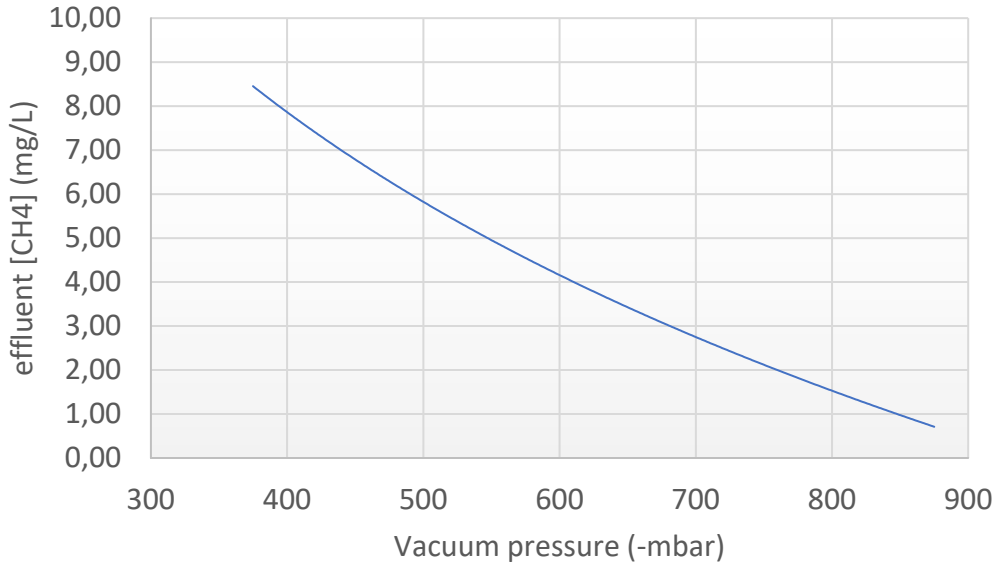


3MEXF Series 2.5 x 8 Polypropylene
Water flow: 0.1 - 0.7 m^3/h
0.4 L in Shellside
0.15 L in Lumenside

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 869496

MEMB-RANER in Rewaise – Sewer Mining

Methane recovery in permeate





≈80% methane was recovered at -625 mbar

≈90% methane was recovered at -760 mbar

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 869496

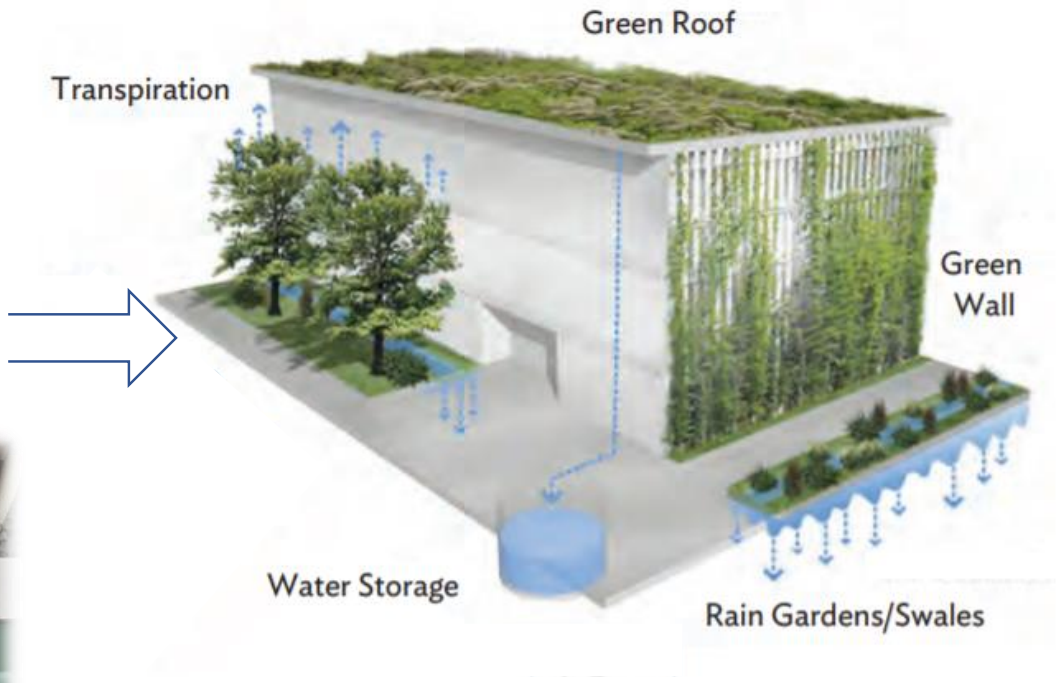
REwaise
REsilient WAter Innovation for Smart Economy

MEMB-RANER in Rewaise – Sewer Mining

Permeate potential reuse – Green wall fertigation







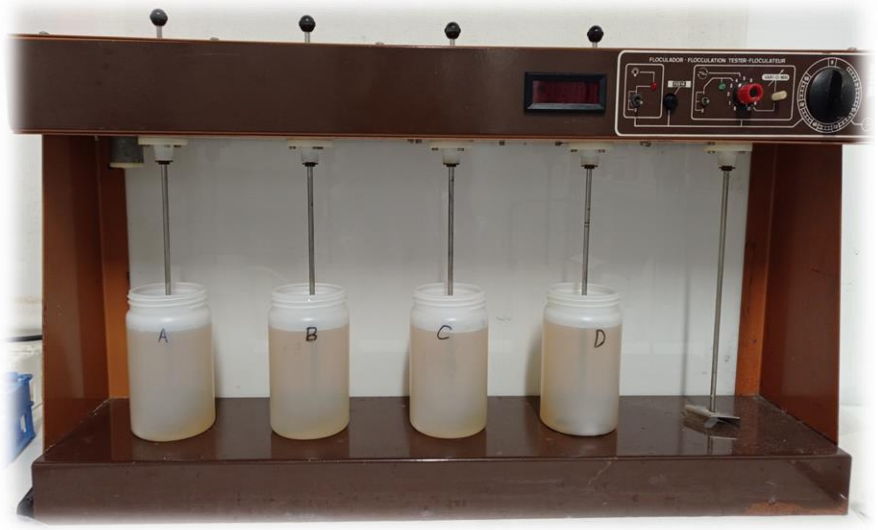
This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 869496

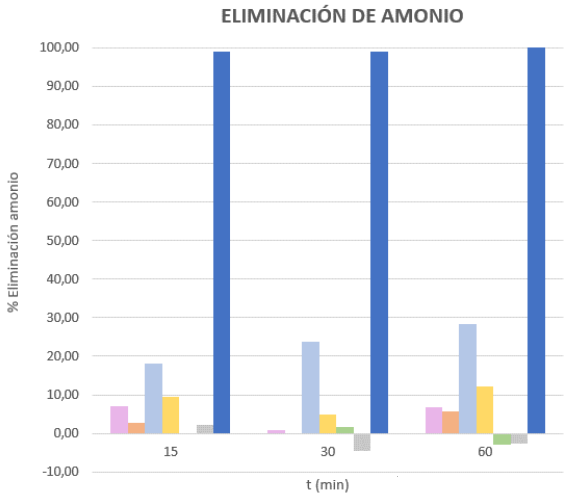
REwaise
REsilient WAter Innovation for Smart Economy

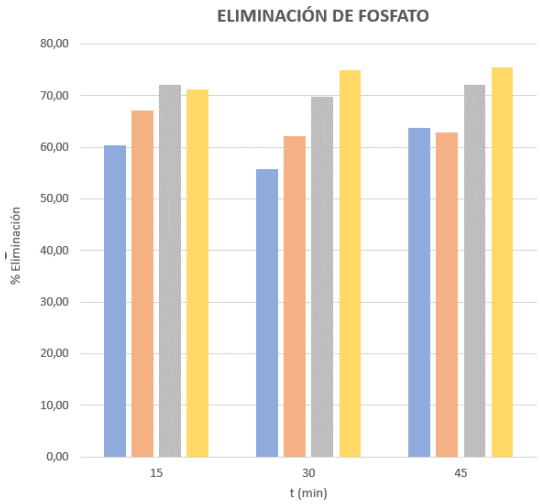
MEMB-RANER in Rewaise – Sewer Mining

Permeate nutrients recovery

pH i	Conductividad (µS/cm)	NH_4^+ i (mg/L)	PO_4^{-3} i (mg/L)	Adsorbente (g/L)
6,50	1489	95	14,3	10







- Solid adsorbents, some examples:
  - Clinoptinolite
  - Zeolite
  - Magnesium oxide
  - Activated carbon
- Organic coagulants

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 869496

REwaise
REsilient WAter Innovation for Smart Economy

4. Urban WWTP – New concept

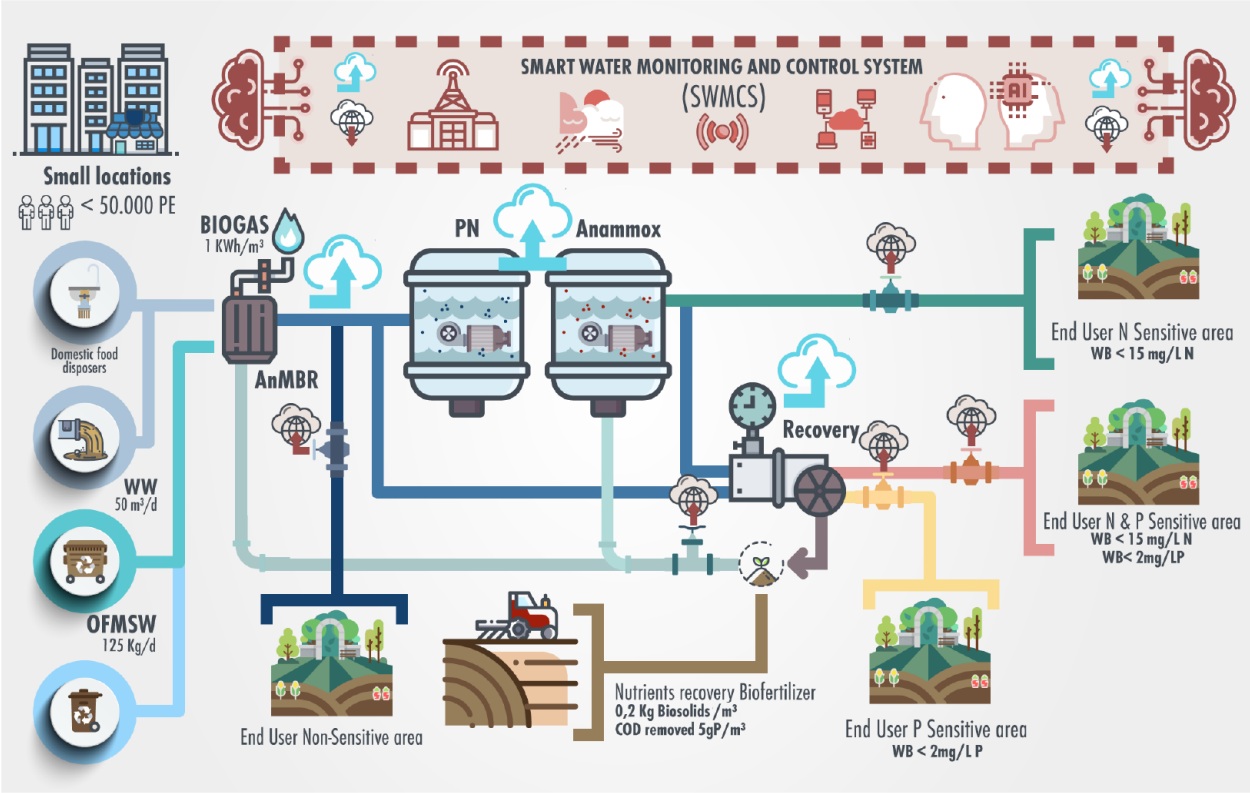
This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 869496

Anaerobic Membrane BioReactor (AnMBR)

Challenges ahead

Positive energy WWTP for combined treatment of wastewater and biowaste in small populations

Legislation on effluent quality requirements for the application of AnMBR effluent in irrigation (High N and P content)

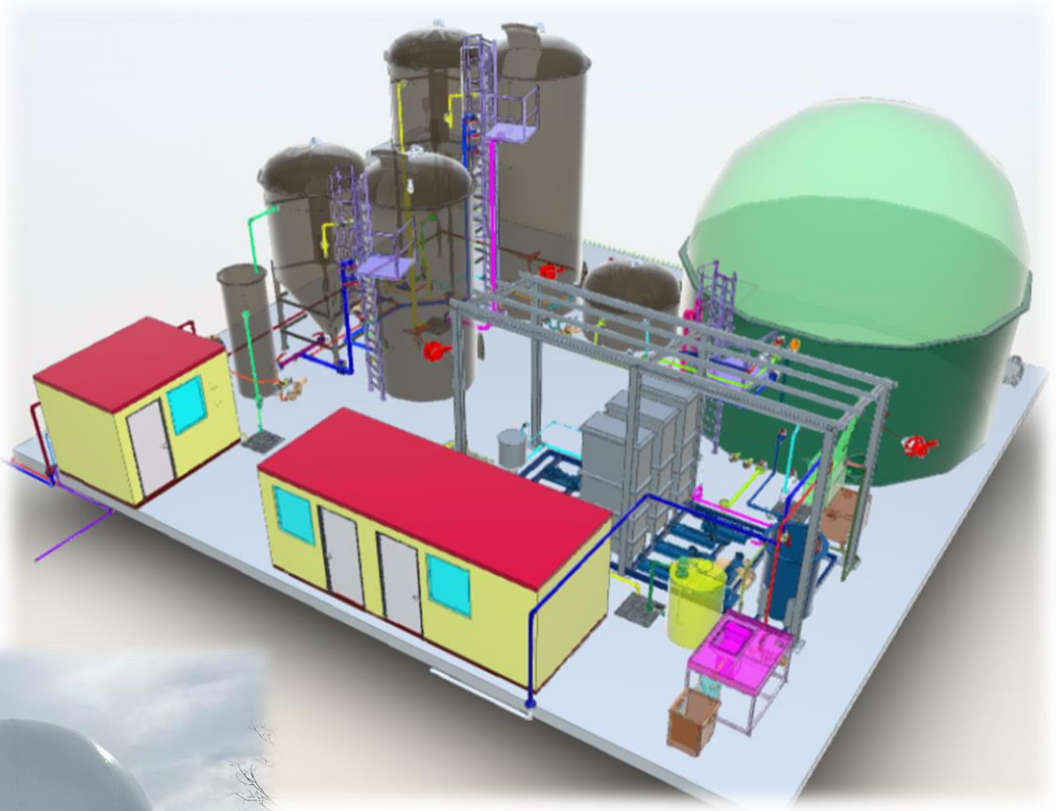


DURATION:
Start: 1/09/20
End: 31/08/24

LIFE ZERO WASTE WATER

AnMBR + water reuse and/or AQUELAN (autotrophic N removal) + P adsorption





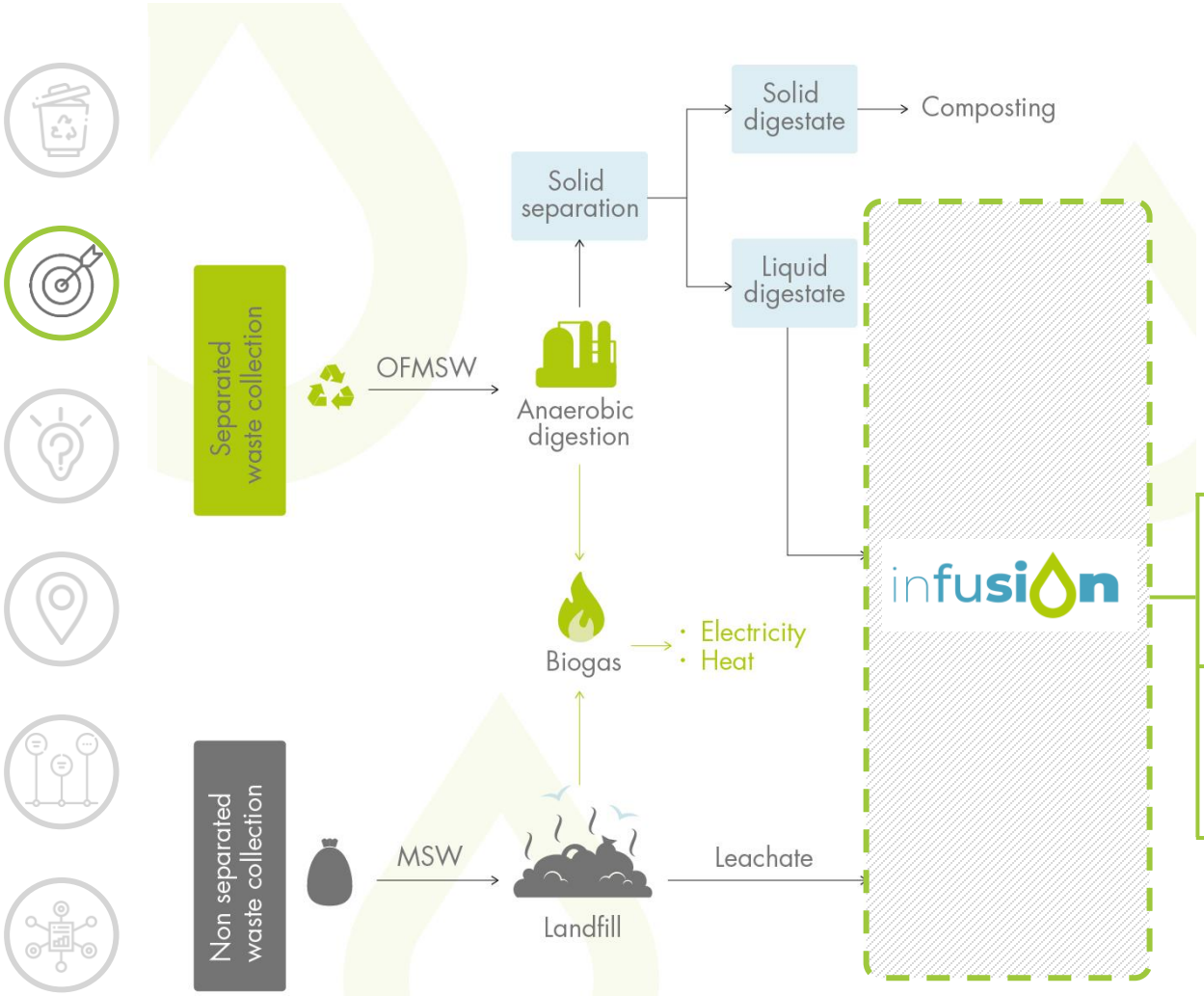




https://lifezerowastewater.com/

5. OFMSW leachate treatment

Life Infusion - Objectives



New sustainable and circular economy-oriented treatment proposed to deal with this wastewater challenge and recover resources



Biogas & biomethane



Sanitizes & stabilized solid (bio-fertilizers)



Reclaimed water

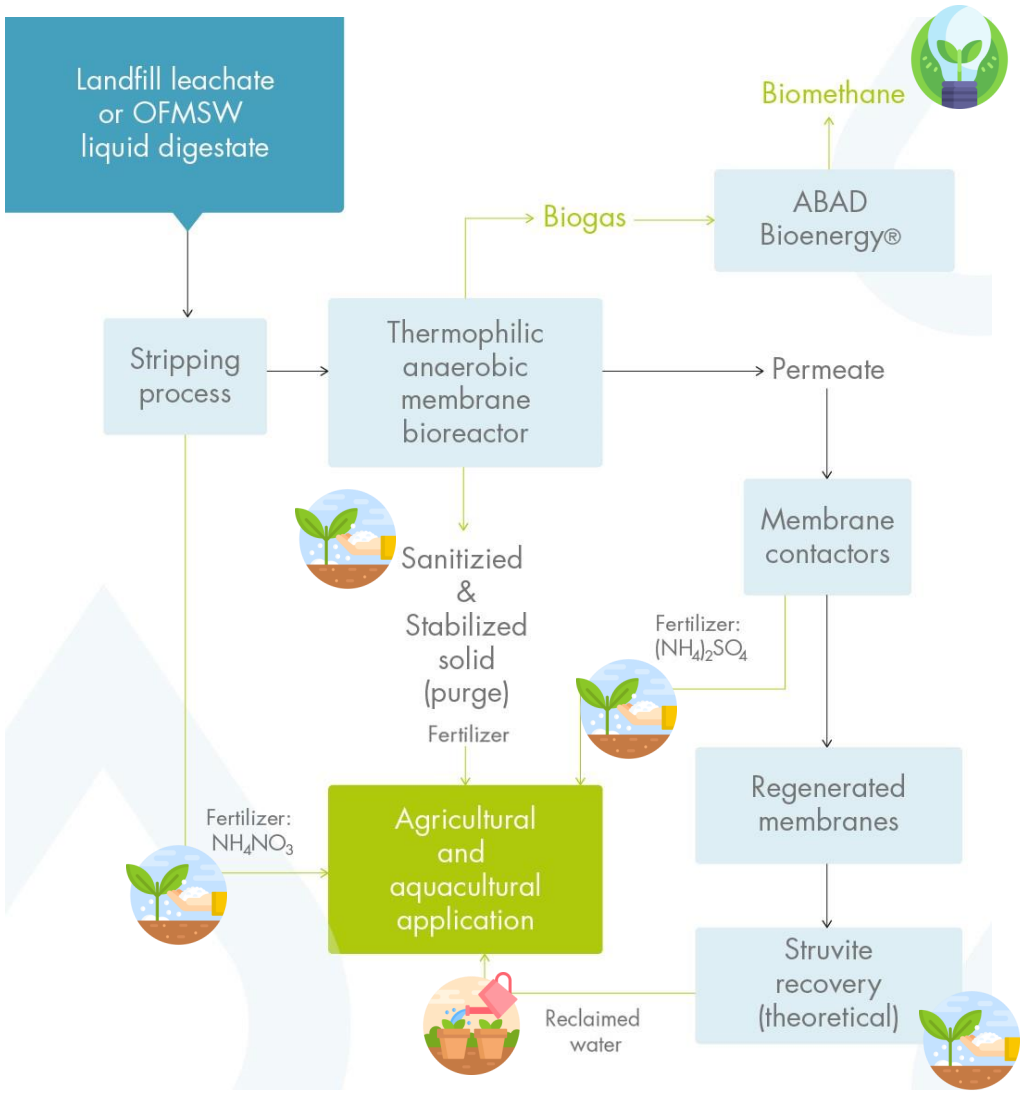
Project funded by the European Commission under the Life programme
LIFE19 ENV/ES/000283

infusion

https://lifeinfusion.eu/

Life Infusion - Solution

https://lifeinfusion.eu/



New resources



Energy

tAnMBR to convert organic matter into biogas (cogeneration motors - electricity)

Nutrients

Stripping to recover ammonium in the form of biofertilizers

Thermophilic AnMBR (55°C) the purge as organic fertilizer

Membrane contactors to recover ammonium in the form of biofertilizers

Water

Regenerated membranes to obtain regenerated water

Project funded by the European Commission under the Life programme
LIFE19 ENV/ES/000283

infusion

Life Infusion – Demo-site of Barcelona



Project funded by the European Commission under the Life programme
LIFE19 ENV/ES/000283

infusion

10.3389/fbioe.2021.642747

Case: LIFE Infusion



Input:	Liquid fraction organic waste (pH=8,2)
Reason:	- Prevent ammonia toxicity - Demand for renewable fertilisers
Influent:	ca. 4.300 mg NH4-N/L
Effluent:	ca. 1.330 mg NH4-N/L
Efficiency:	69%
Remark:	No caustic dosing, 55°C
End product:	Ammonium nitrate and ammonium sulphate

https://lifeinfusion.eu/



Project funded by the European Commission under the Life programme
LIFE19 ENV/ES/000283

infusion

REwaise
REsilient WAter Innovation for Smart Economy

aqualia

http://rewaise.eu/

Nutrient recovery in H2020 Rewaise

Jose R. Vázquez-Padín
jvazquep@fcc.es
Innovation & Technology

wetsus
european centre of **excellence**
for sustainable **water technology**



“Future scheme of aerobic granular sludge WWTPs”

Presenter: Nouran Bahgat
Email: NBAH@wetsus.nl,
T.M.S.M.Bahgat@tudelft.nl
Supervisors: Leon Korving, Philipp Wilfert, Yuemei Lin, Mark van Loosdrecht

water mining

TU Delft

combining scientific excellence with commercial relevance

Water Mining Project



- Demonstrate new and efficient ways to reclaim nutrients, minerals, biopolymers, energy, and freshwater from desalination, and industrial and urban wastewater.

- Produce science-based, market-oriented policy recommendations, design circular business models, and engage stakeholders, leading to sustainable management of water resources.

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Water Mining Project

Desalination / Sea-Mining



CS1 Lampedusa

CS2 Almeria

Urban Mining



CS3 Faro

CS4 Larnaca

CS5 La Llagosta

Industrial Mining



CS6 Port of Rotterdam

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for sustainable **water technology**

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Water Mining Project




Wokke Wijdeveld Leon Korving

CS4: P-removal to ultra-low levels and P-recovery






Nouran Bahgat Philipp Wilfert Leon Korving Mark van Loosdrecht

CS3: EPS (Kaumera) Valorization

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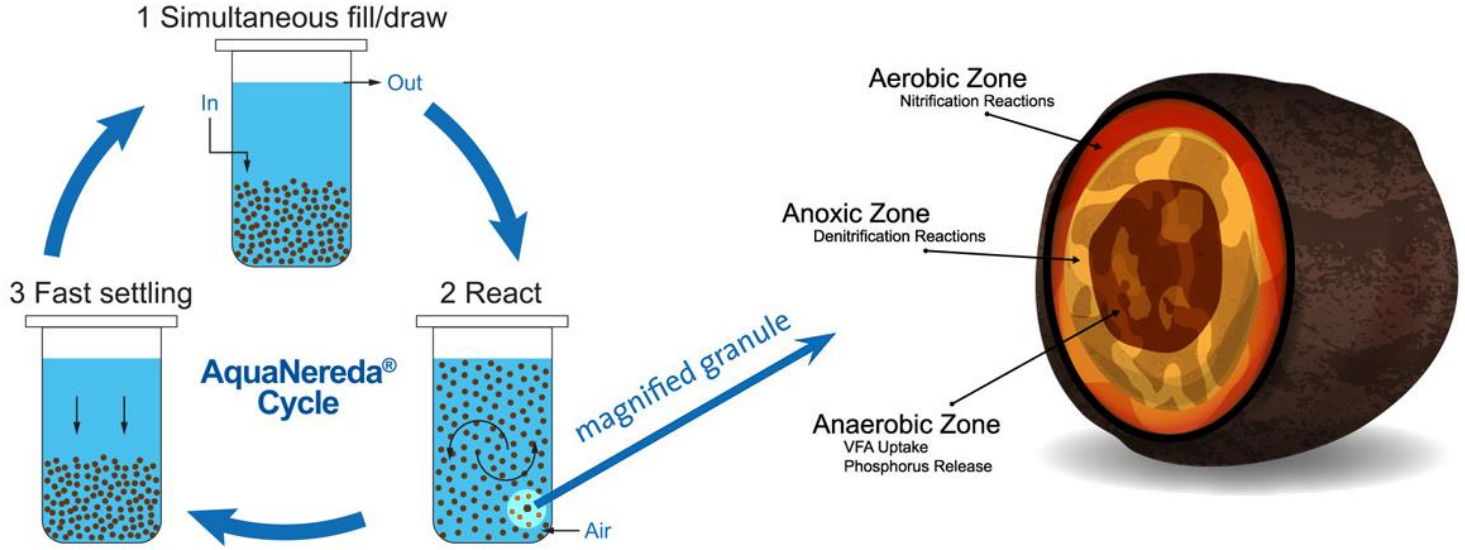
Aerobic Granular Sludge (AGS) WWTP



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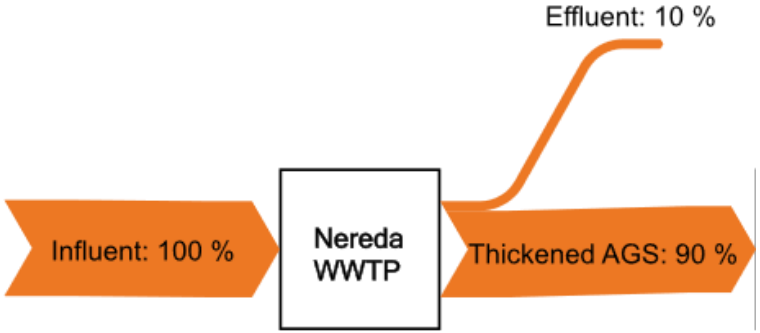
AGS WWTP- Effluent stream





Wokke Wijdeveld **Leon Korving**



P-removal to ultra-low levels and P-recovery (BioPhree)

*Biophree is tested on a different stream in WM but would also work here

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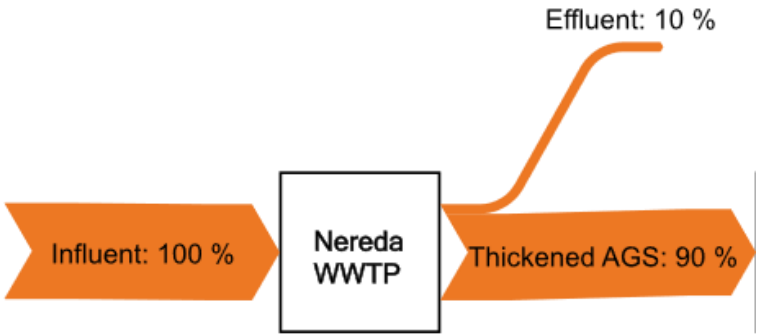
AGS WWTP- Effluent stream

P-removal to ultra-low levels and P-recovery (BioPhree)





Prevent Eutrophication

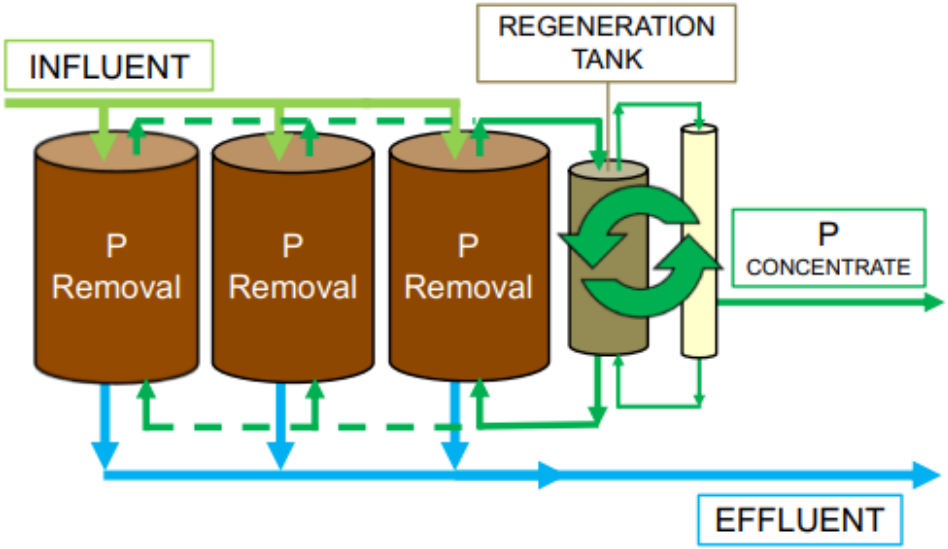


Water Reuse



Recovery

BioPhree concept





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Iron oxide based adsorbents



- Goethite based
- Porous granules
- Cheap
- Naturally abundant
- Good affinity for phosphate
- Allow regeneration

Highlight: Effluent concentration < 50ppb, regeneration is successful

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AGS WWTP- Excess Sludge stream



Nouran Bahgat **Philipp Wilfert** **Leon Korving** **Mark van Loosdrecht**

EPS (Kaumera) Valorization

*Nouran T. Bahgat, Philipp Wilfert, Leon Korving, Mark van Loosdrecht, Integrated resource recovery from aerobic granular sludge plants, Water Research,Volume 234, 2023, https://doi.org/10.1016/j.watres.2023.119819.

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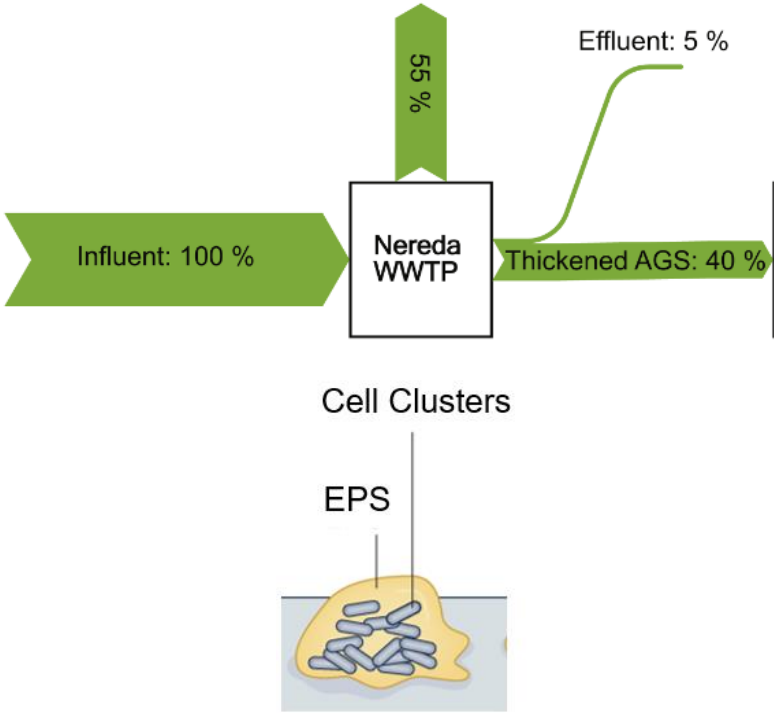
AGS WWTP- C mass balance



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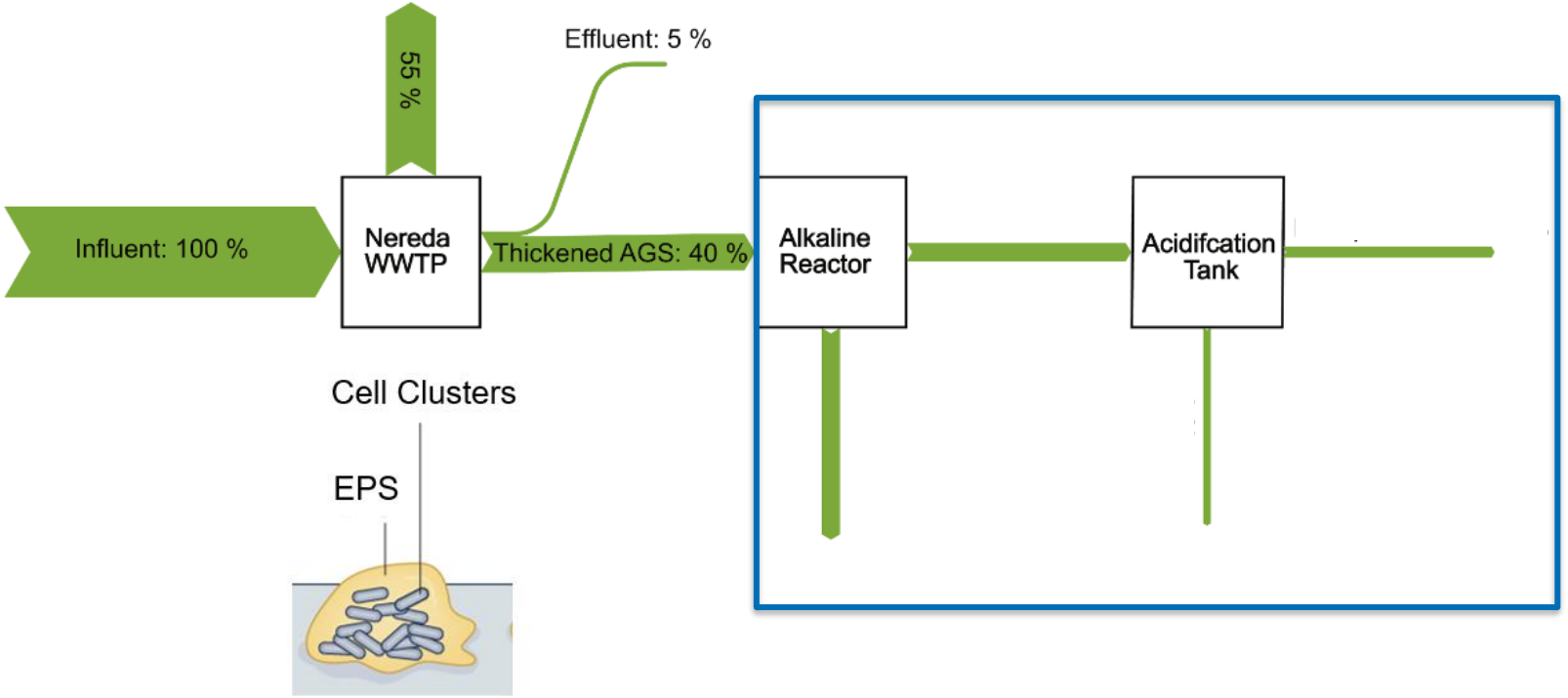
AGS WWTP- C mass balance



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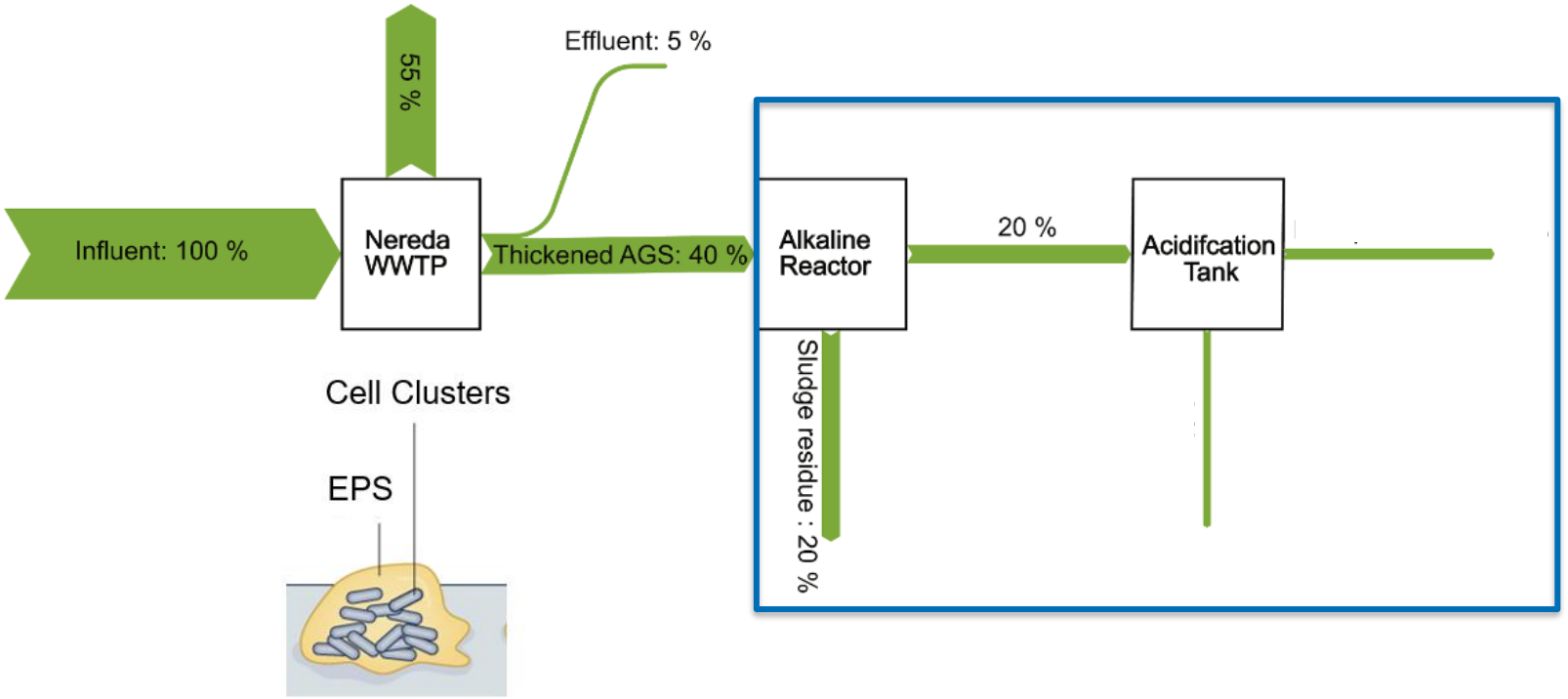
AGS WWTP- C mass balance



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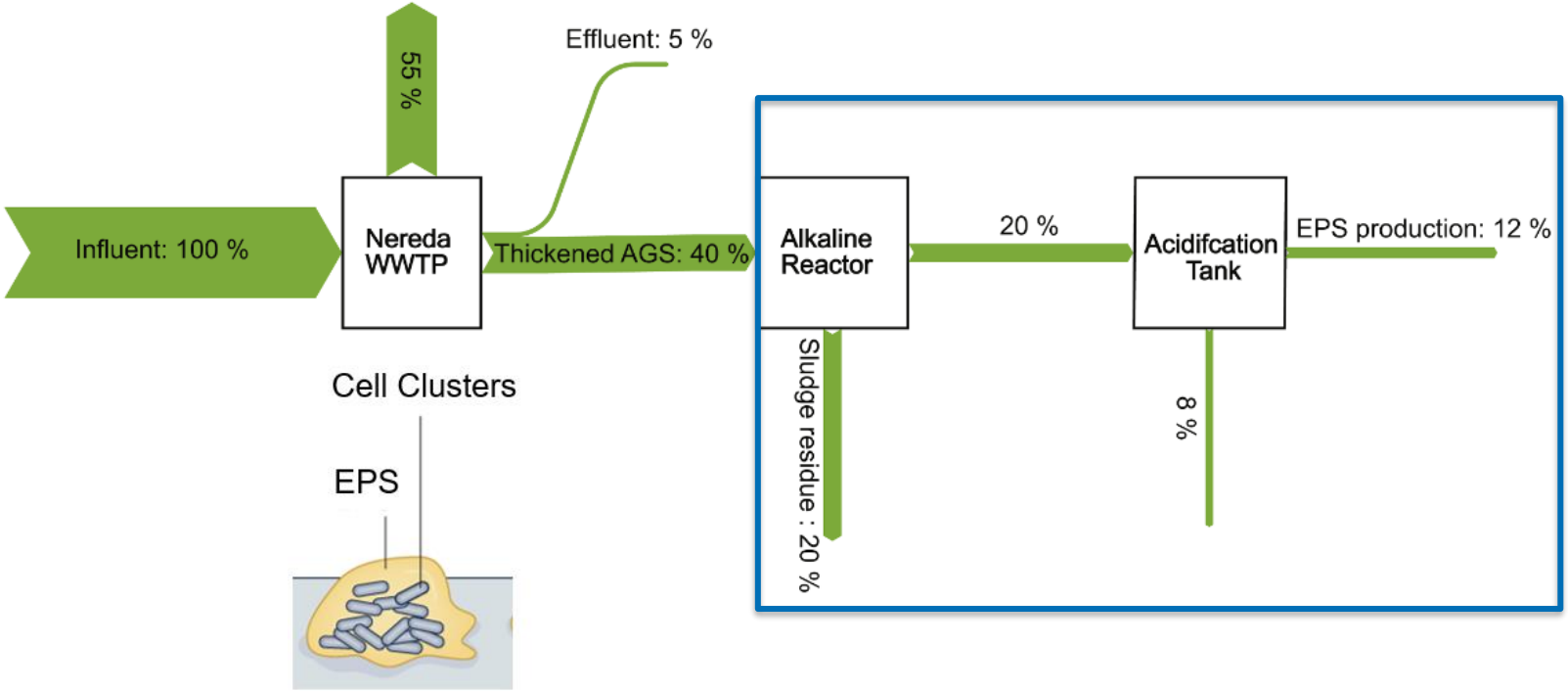
AGS WWTP- C mass balance



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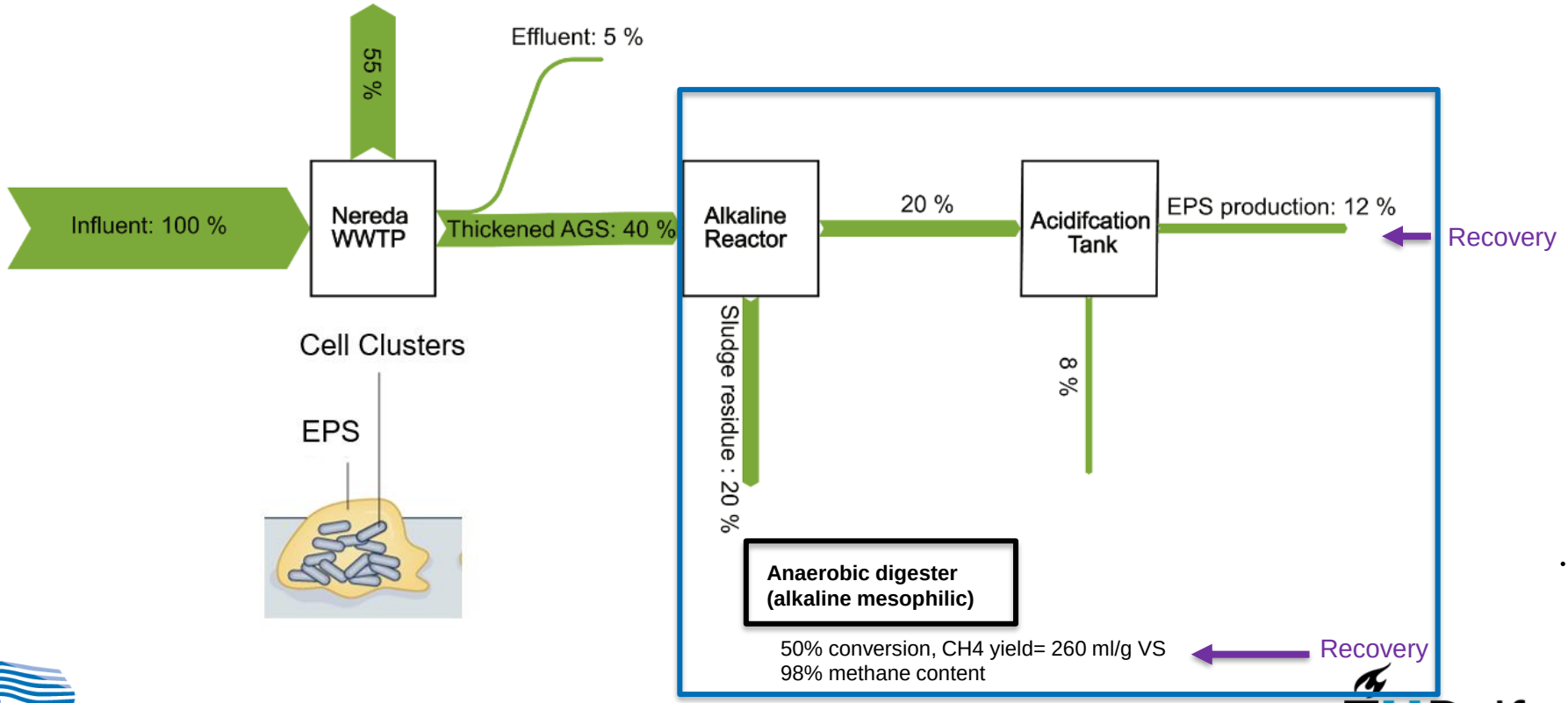
AGS WWTP- C mass balance



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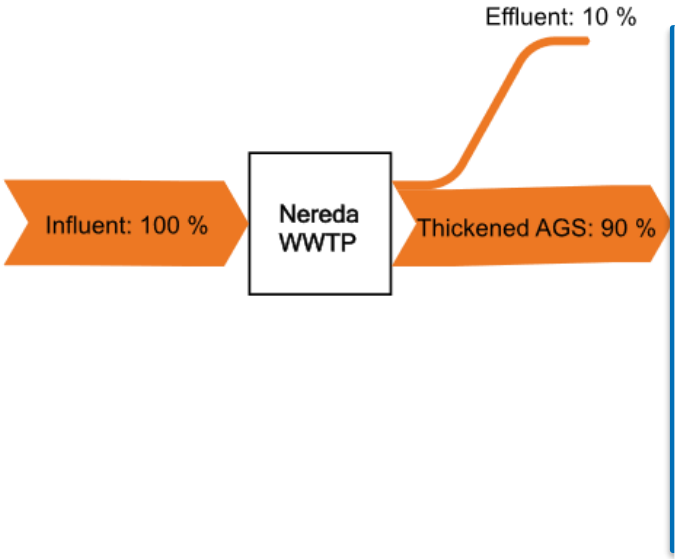
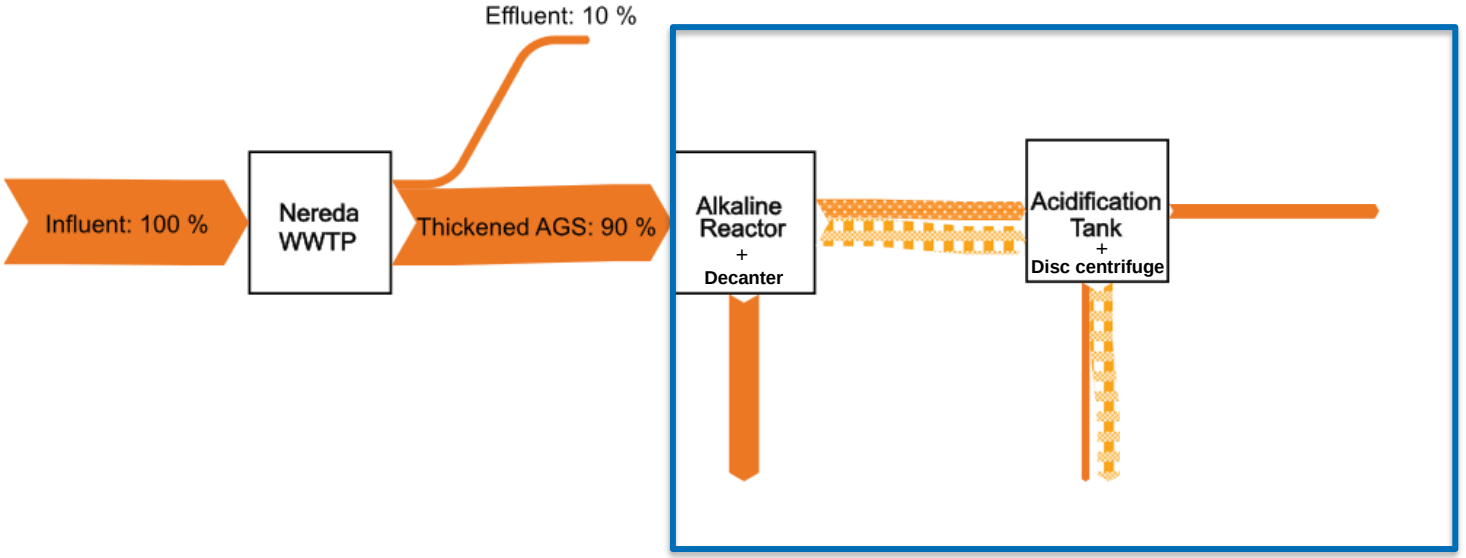
AGS WWTP- P mass balance



AGS WWTP- P mass balance



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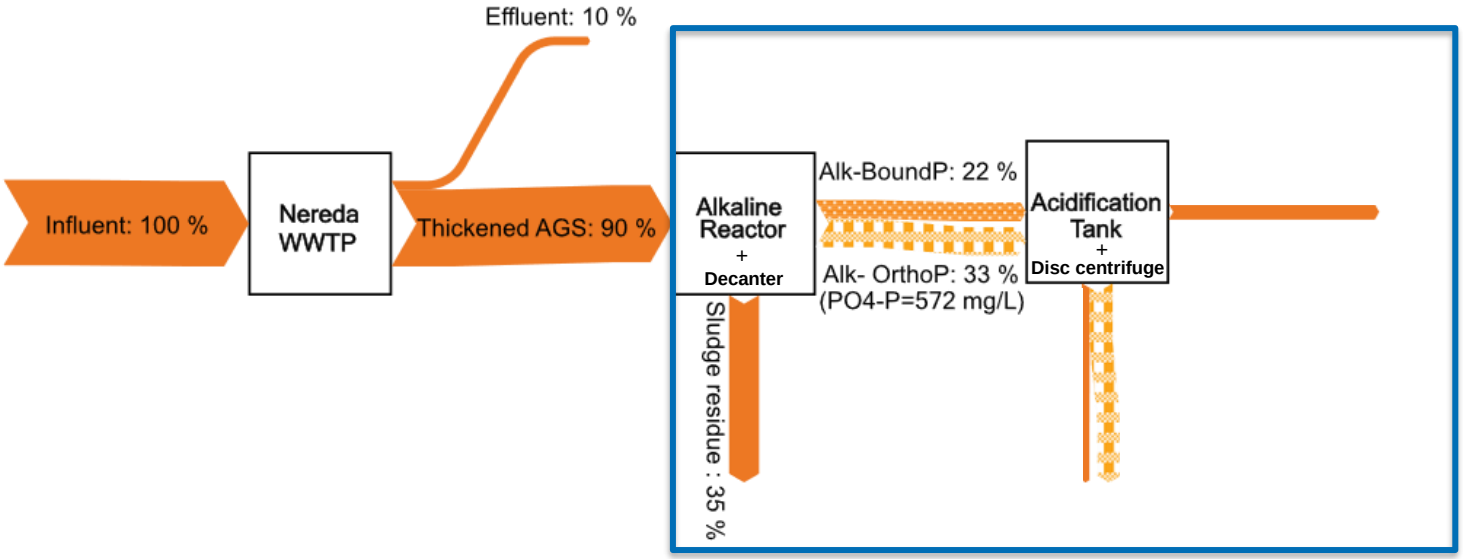

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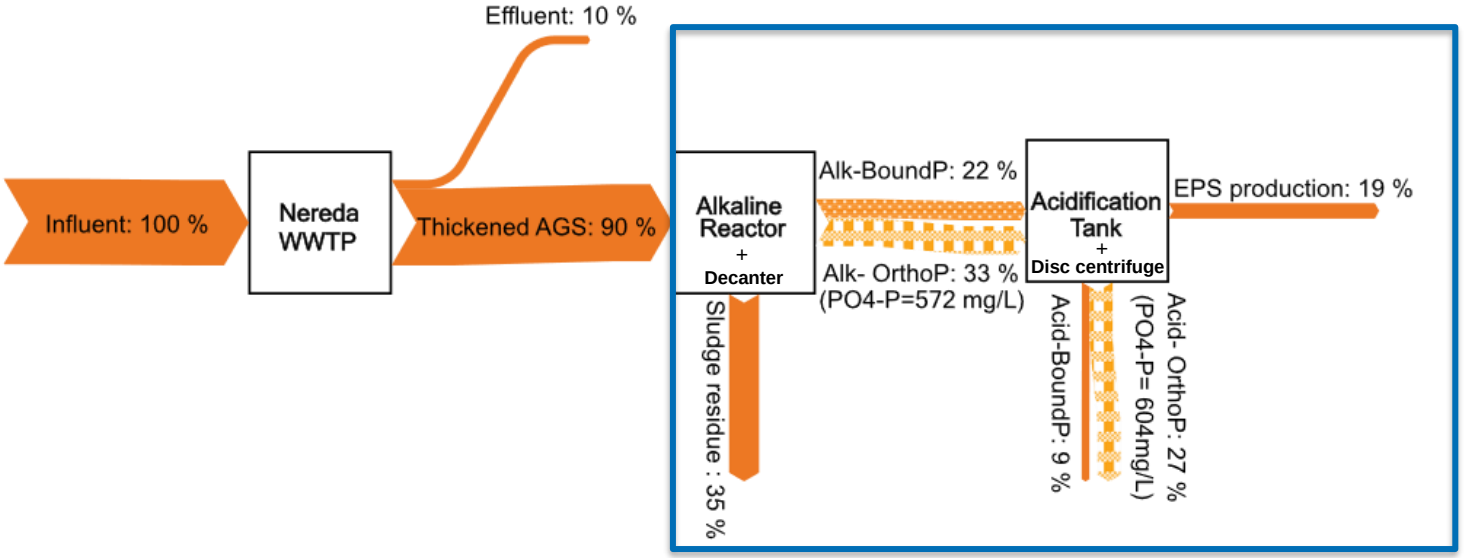

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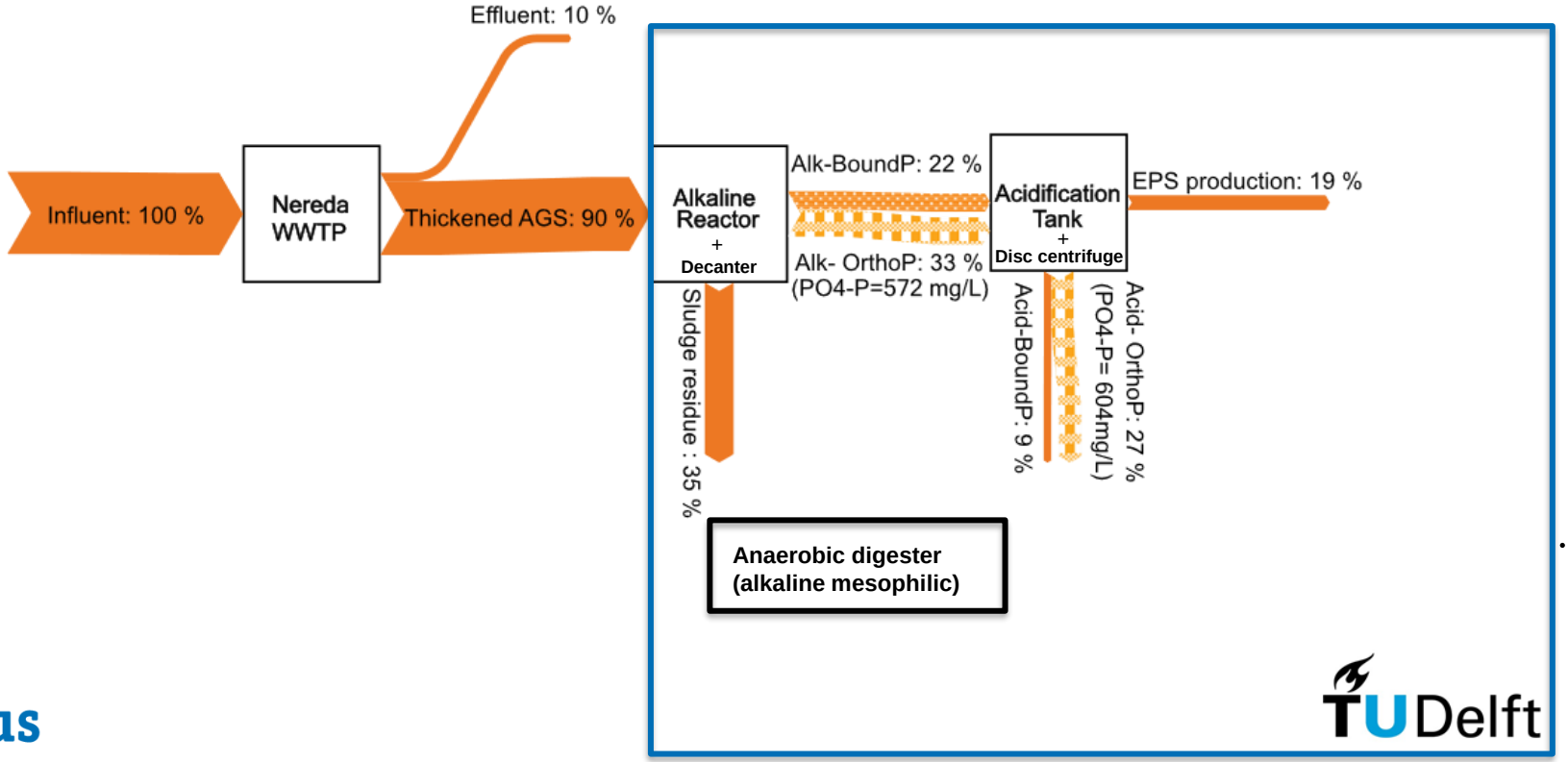

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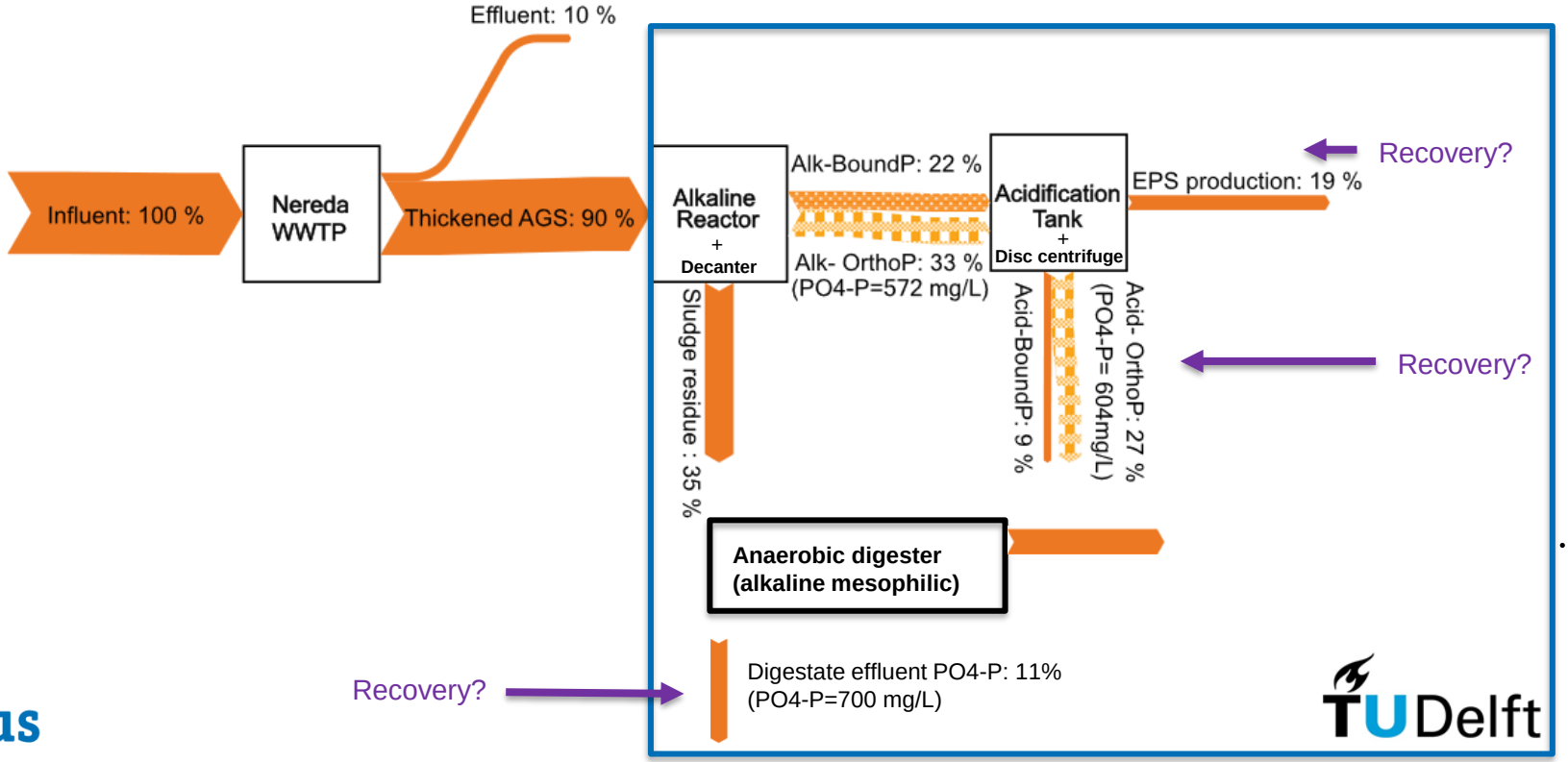
AGS WWTP- P mass balance



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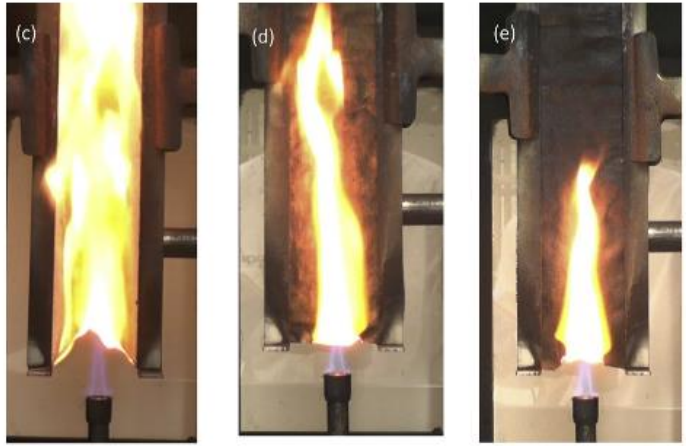
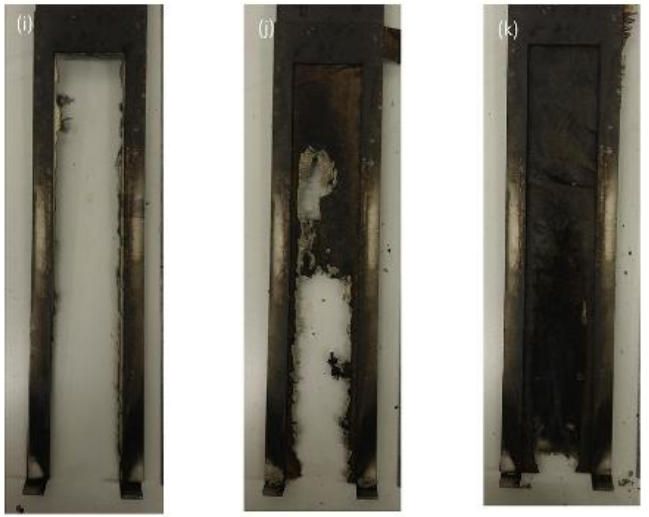
Phosphorus in Kaumera



uncoated flax fabric | EPS_{flocs} coated flax fabric | $EPS_{granules}$ coated flax fabric



uncoated flax fabric | EPS_{flocs} coated flax fabric | $EPS_{granules}$ coated flax fabric

- Upcycling P-recovery products with higher value and quality than fertilizer phosphates is a way to accelerate the P- recovery market

Highlight: Phosphorus effect on Kaumera properties & potential applications (ex: flame retardants)

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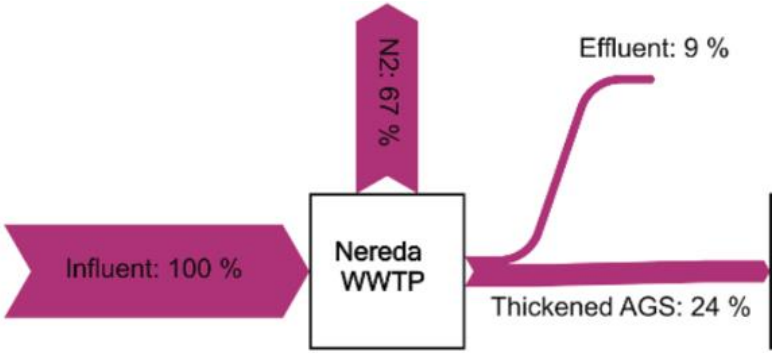
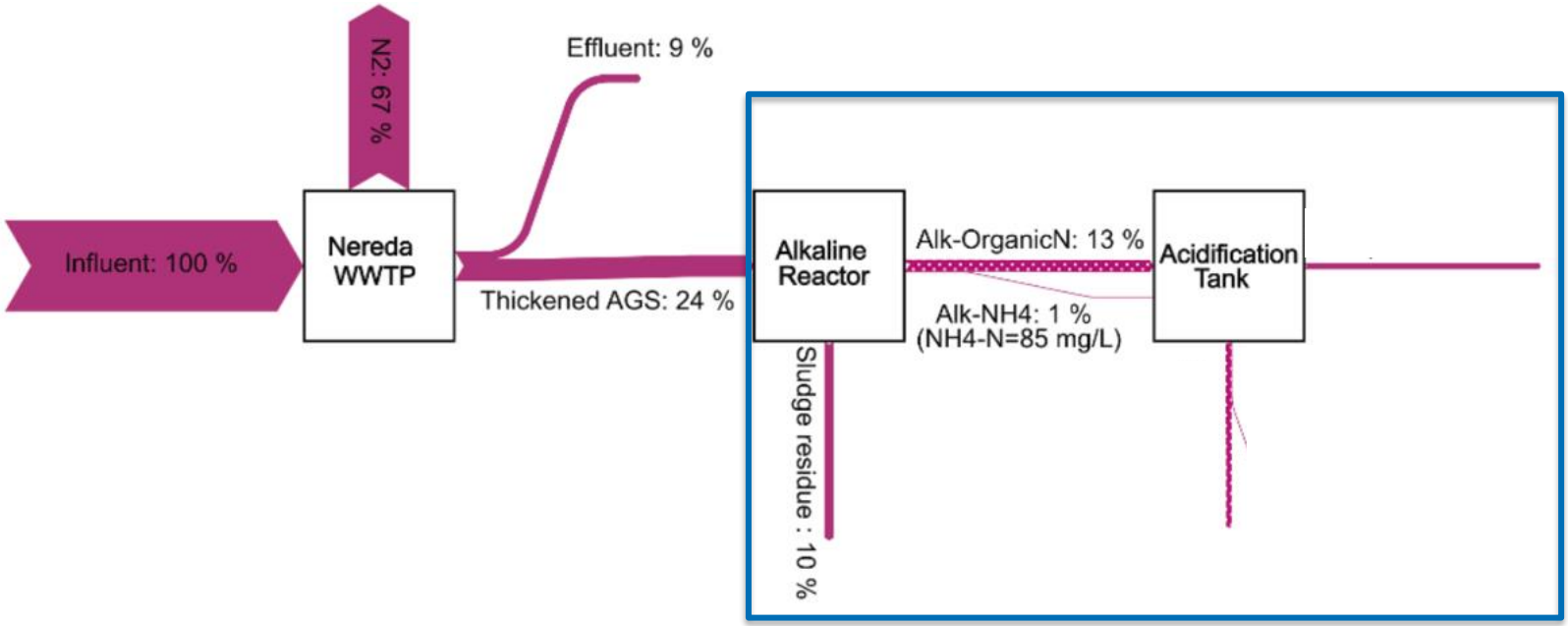
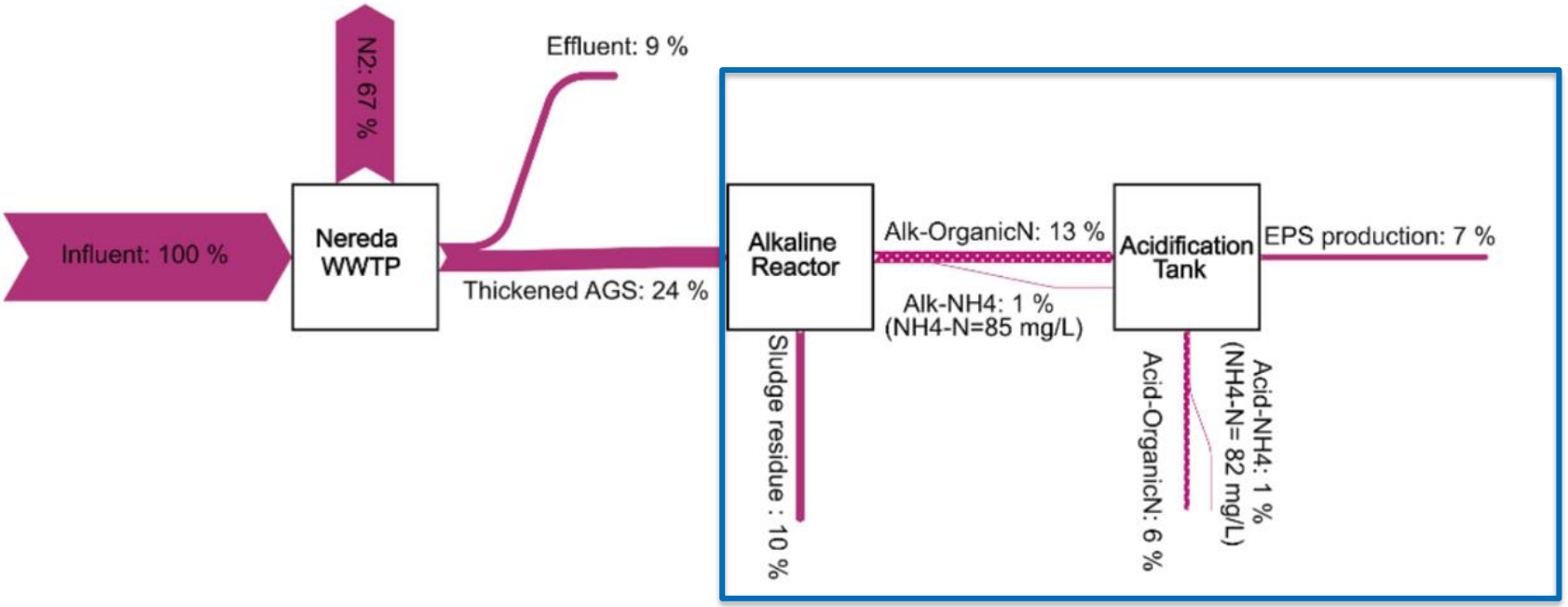
AGS WWTP- N mass balance



AGS WWTP- N mass balance



AGS WWTP- N mass balance



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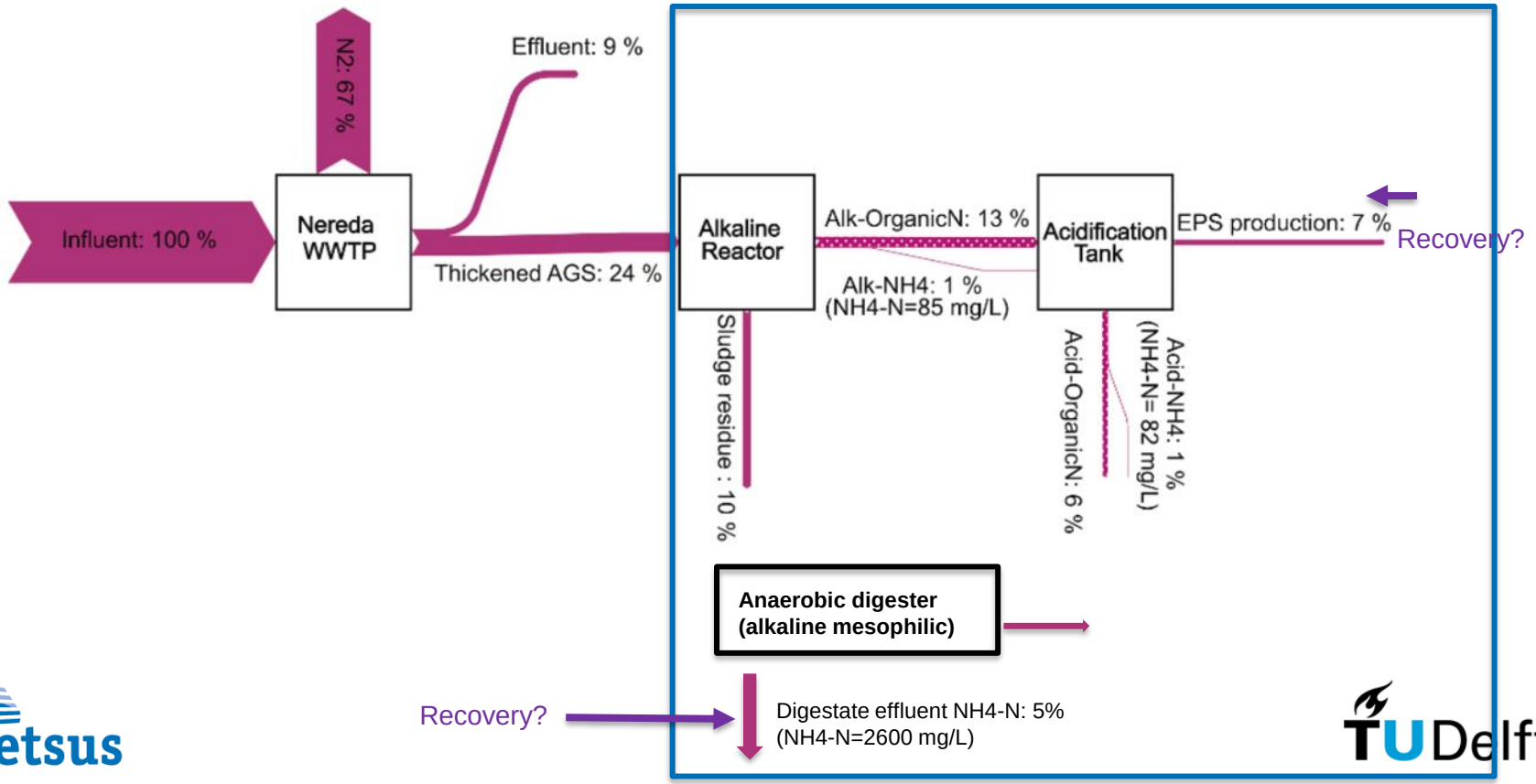
AGS WWTP- N mass balance



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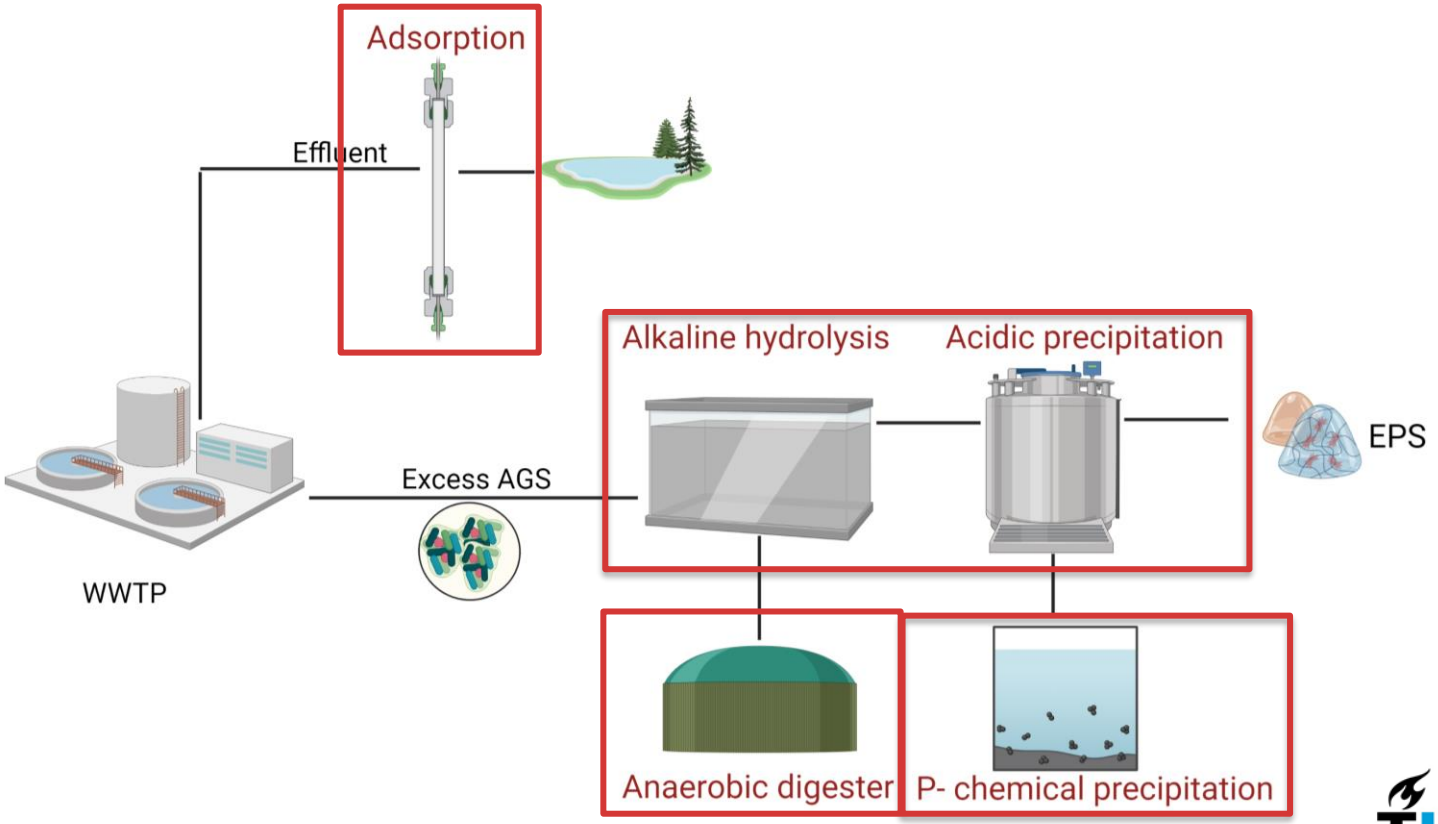
Conclusion: Future Scheme of AGS WWTPs



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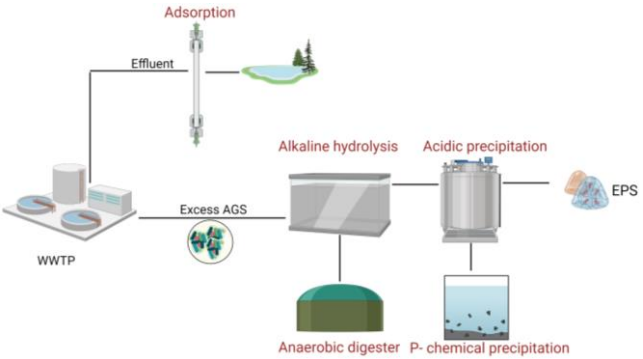
Conclusion: Future Scheme of AGS WWTPs



100% Excess AGS

C
- **30%** EPS
- **25%** Methane (260 ml/ gVS)

N
- **30%** EPS
- **20%** AD digestate

P
- **20%** EPS
- **30%** acidic by-product
- **13%** AD digestate

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Acknowledgments





















Thank you, Questions?

Email: NBAH@wetsus.nl
T.M.S.M.Bahgat@tudelft.nl

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LinkedIn:

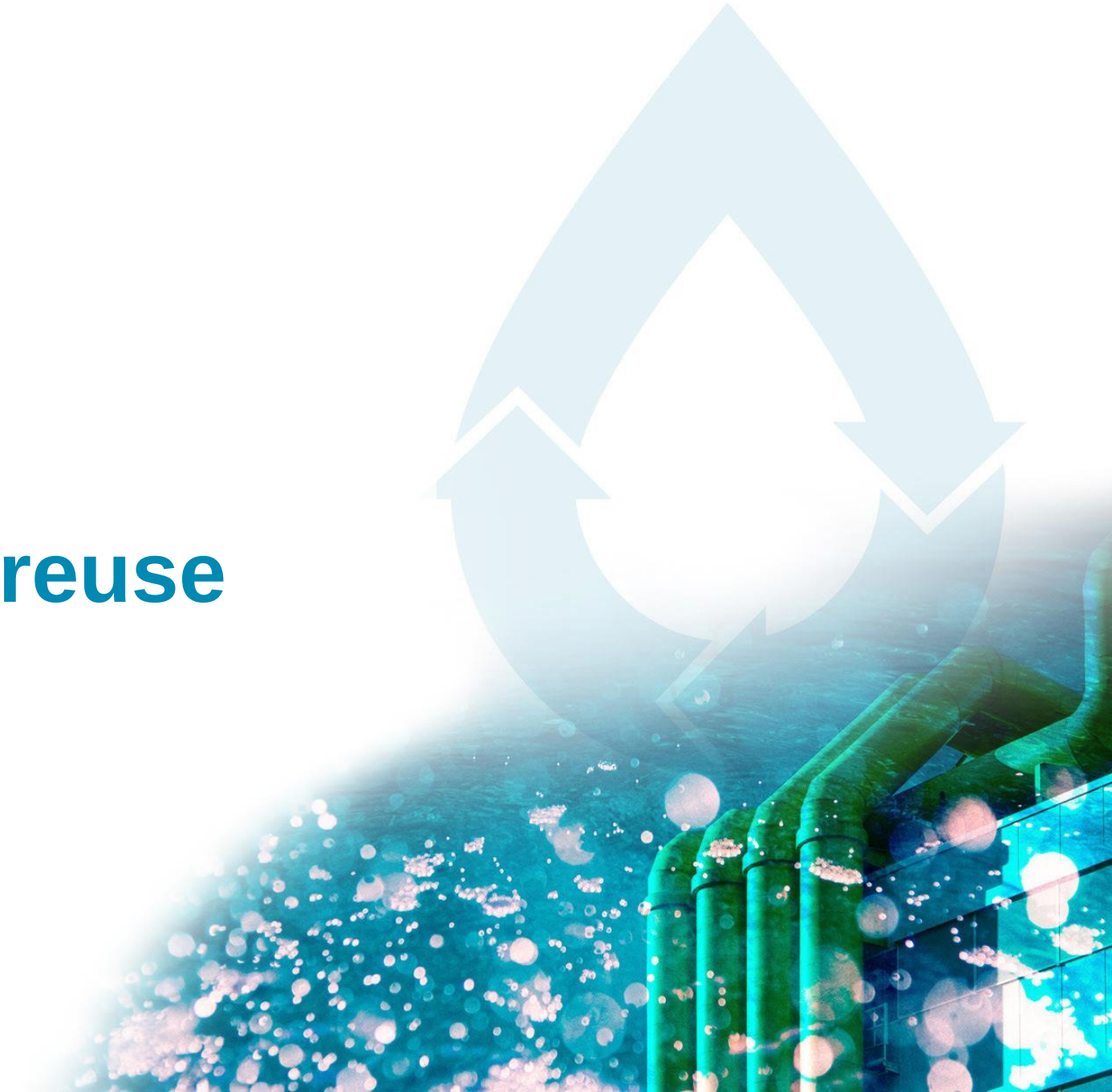
ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

Online seminar
Material recovery & reuse

F. Fatone, J. González Camejo

May, 2nd 2023.



Key ULTIMATE Information

Call	2017 - H2020 – Greening the economy in line with the Sustainable Development Goals (SDGS) - H2020-SC5-2018-2019-2020
Topic	CE-SC5-04-2019 - Building a water-smart economy and society
Budget	**TOTAL:** Budget 16.614.814€
Duration	48 months (01/06/2020 – 31/05/2024)
Partners	27 (12 private companies; 8 non-profit/private centers; 7 public centers) from 11 countries
Coordinator	KWR WATER (NL)

Website: https://ultimatewater.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



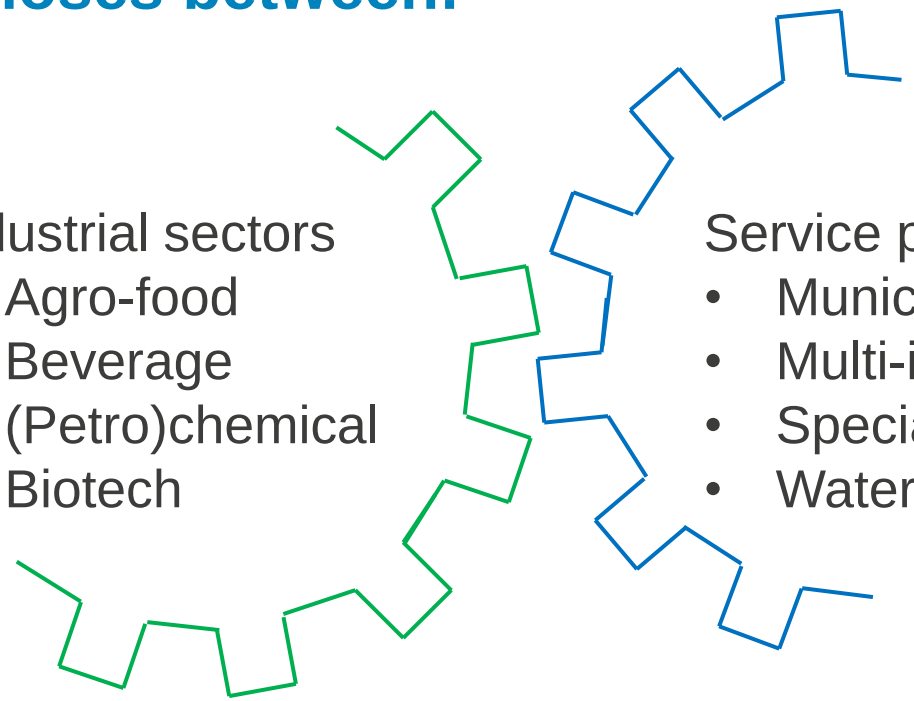
The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

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

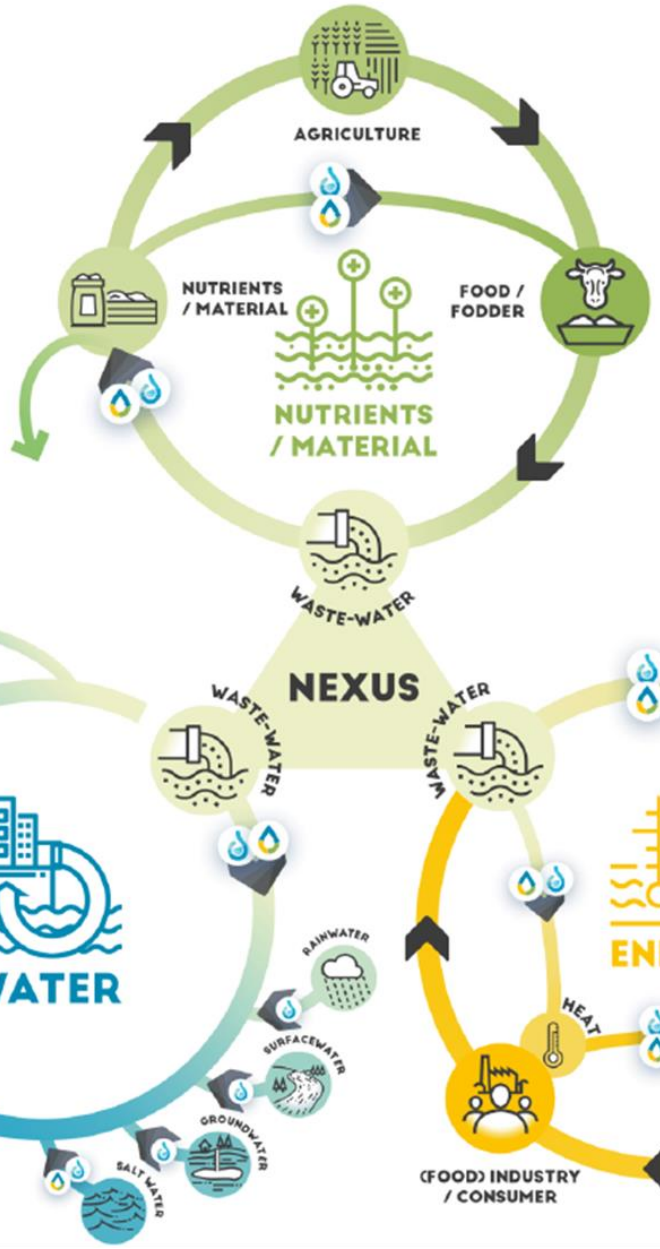
27 Partners

37 Technologies



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: 7 Topics



UNIVERSITÀ POLITECNICA DELLE MARCHE



F. Fatone

- Nutrient recovery
- Material recovery & reuse

eurecat
Centre Tecnològic de Catalunya



A. Naves



S. Casas

- Membrane technologies
- Adsorption and AOP technologies

KOMPETENZZENTRUM Wasser Berlin



A. Kleyböcker

- Biogas technologies
- Heat Recovery
- Digitalization

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

Coordinator: KWR

9 Case Studies

27 Partners

37 Technologies



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Agenda

CS meeting on "Material recovery & reuse" on Nov 22nd, 2023

Microsoft Teams link:

Click here to join the meeting

16:00	**Introduction** *Francesco Fatone (UNIVPM)*
16:10	**Material recovery & reuse in H2020 ULTIMATE Case Study 3** *Massimiliano Sgroi (UNIVPM)*
16:25	**Material recovery & reuse in H2020 ULTIMATE Case Study 6** *Dimitri Iossifidis (GTG) (tbd)*
16:40	**Material recovery & reuse in H2020 ULTIMATE Case Study 8** *Anne Reguer (SUEZ IWS) (tbd)*
16:55	*5 minutes break*
17:00	**Material recovery & reuse in H2020 WIDER-UPTAKE**: CS1 Netherlands case study *Peter van Gilst (NPSP)*
17:15	**Material recovery & reuse in H2020 WATER-MINING**: CS1 and CS2 Italy and Spain case studies *Dimitris Xevgenos (TUD)*
17:30	**Material recovery & reuse in H2020 WATER-MINING:** CS3 Portugal and Netherlands case study *Philipp Wilfert (TUD)*
17:45	**Final discussion**
18:00	**End**

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ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

CS3 – Material recovery & reuse in H2020 ULTIMATE Case Study 3

Massimiliano Sgroi (UNIVPM)

22nd November 2023



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H2020 ULTIMATE:
Industry water-utility symbiosis for a smarter water society

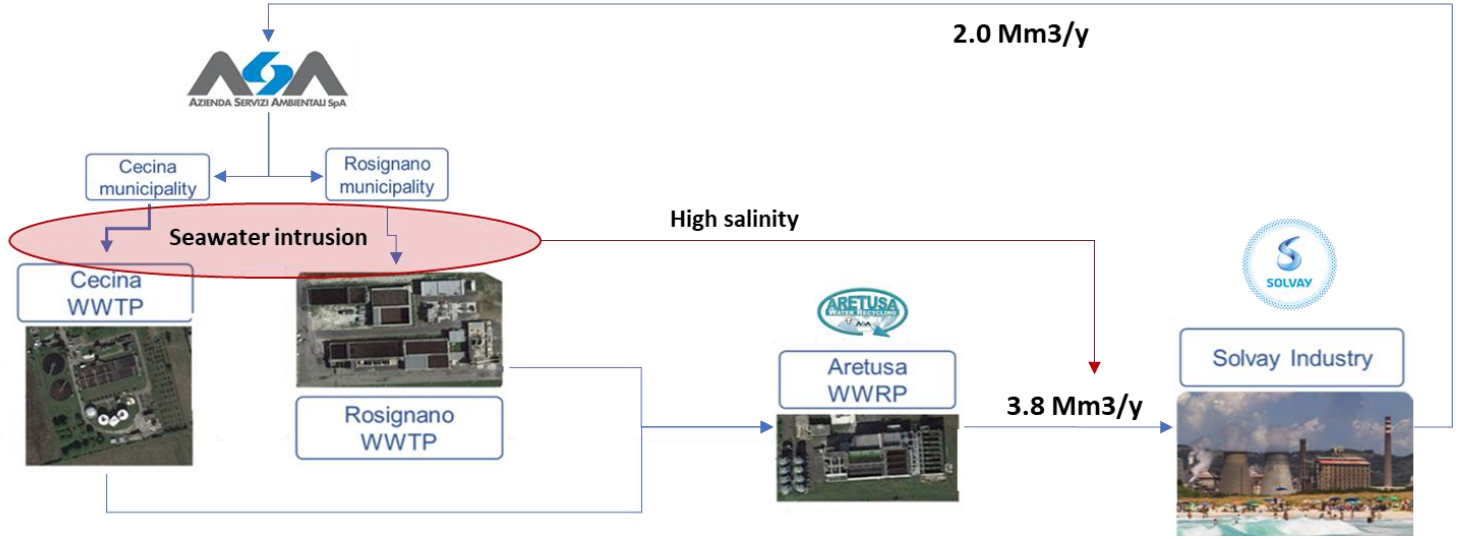
ULTIMATE
WATER SMART INDUSTRIAL SYMBIOSIS

Promote, establish and extend **water smart industrial symbiosis between service providers from the water sector and the industrial sector** by implementing circular economy **solutions for water, material and energy recovery**.

- 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



Rosignano case study



ARETUSA Water Recycling · WEST Systems · AZIENDA SERVIZI AMBIENTALI SpA · CPTM Consorzio Polo Tecnologico Magona · Termomeccanica Ecologia · Termomeccanica Group · SOLVAY

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Water and Waste Environmental Engineering LAB · ARETUSA Water Recycling · CPTM · WEST Systems

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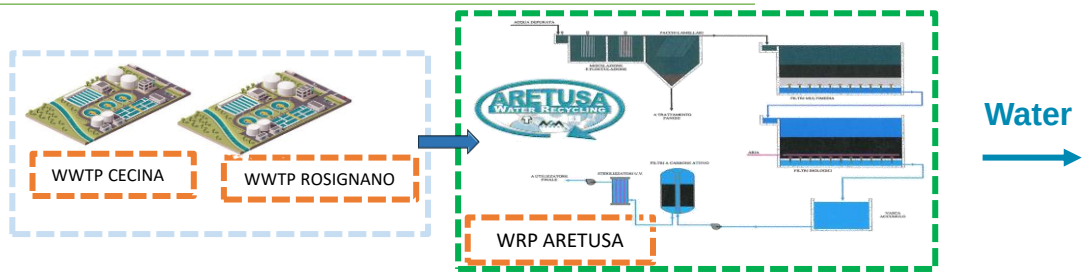
FRAMEWORK OF THE REGIONAL SYMBIOSIS SISTEM



Water

Water

By products for water treatments

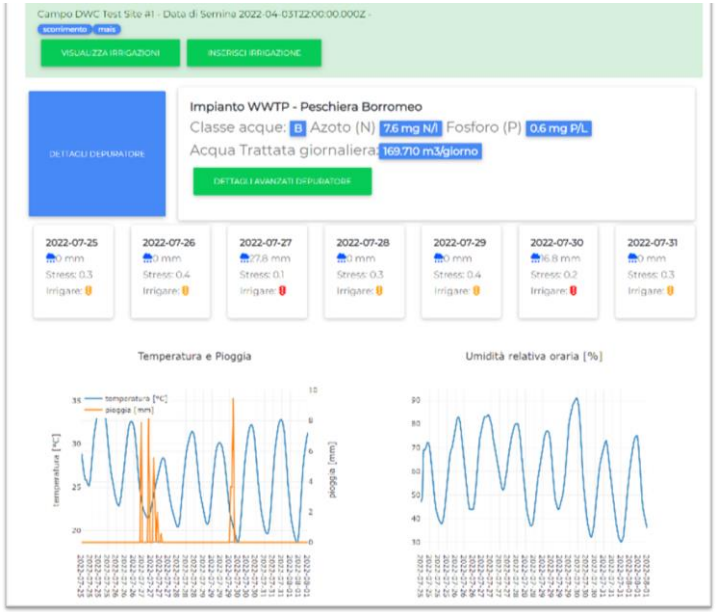
Industrial sites in the area



Freshwater



Match-Making TOOL for water reuse in the area (agricolture)



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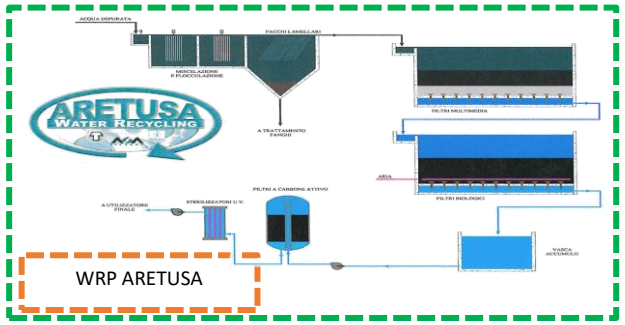

Water

Industrial sites in the area



Limits for industrial reuse – cooling water

N°	Description	Unit of measure	Specific	Maximum value
1	Cl-	ppm	≤ 500	500
2	NH4	ppm	≤ 8	8
3	Sospended solids	ppm	≤ 2	2
4	**Conducibility**	**microS.**	**≤1.030**	**1030**
5	Alkalinity	ppm CaCO3	≤ 340	340
6	**Ca**	**ppm Ca**	**≤ 160**	**160**
7	**Mg**	**ppm**	**≤ 45**	**45**
8	SO_4	ppm	≤ 140	140
9	Fe	ppm	≤ 0,1	0.1
10	Si	ppm SiO2	≤ 30	30
11	Mn	ppm	≤0,4	0.4
12	PO_4	ppm	≤ 3	3
13	Al	ppm	≤ 0,1	0.1
14	As	ppm	≤ 0,2	0.2
15	Ba	ppm	≤ 2,5	2.5
16	Fluorides	ppm F	≤ 0,1	0.1
17	Vegetable and animal oils	ppm	≤ 1	1
18	**COD**	**ppm O2**	**≤ 10**	**10**
19	Surfactants	ppm	≤ 0,5	0.5
20	BOD	ppm	≤10	10
21	**Esch. Coli**	**CFU/100ml**	**≤ 250**	**250**
22	Coli Tot.	CFU/100ml	≤ 250	250
23	Strep. Coli	CFU/100ml	≤ 20	20
24	Filamentous bacteria		absent	0

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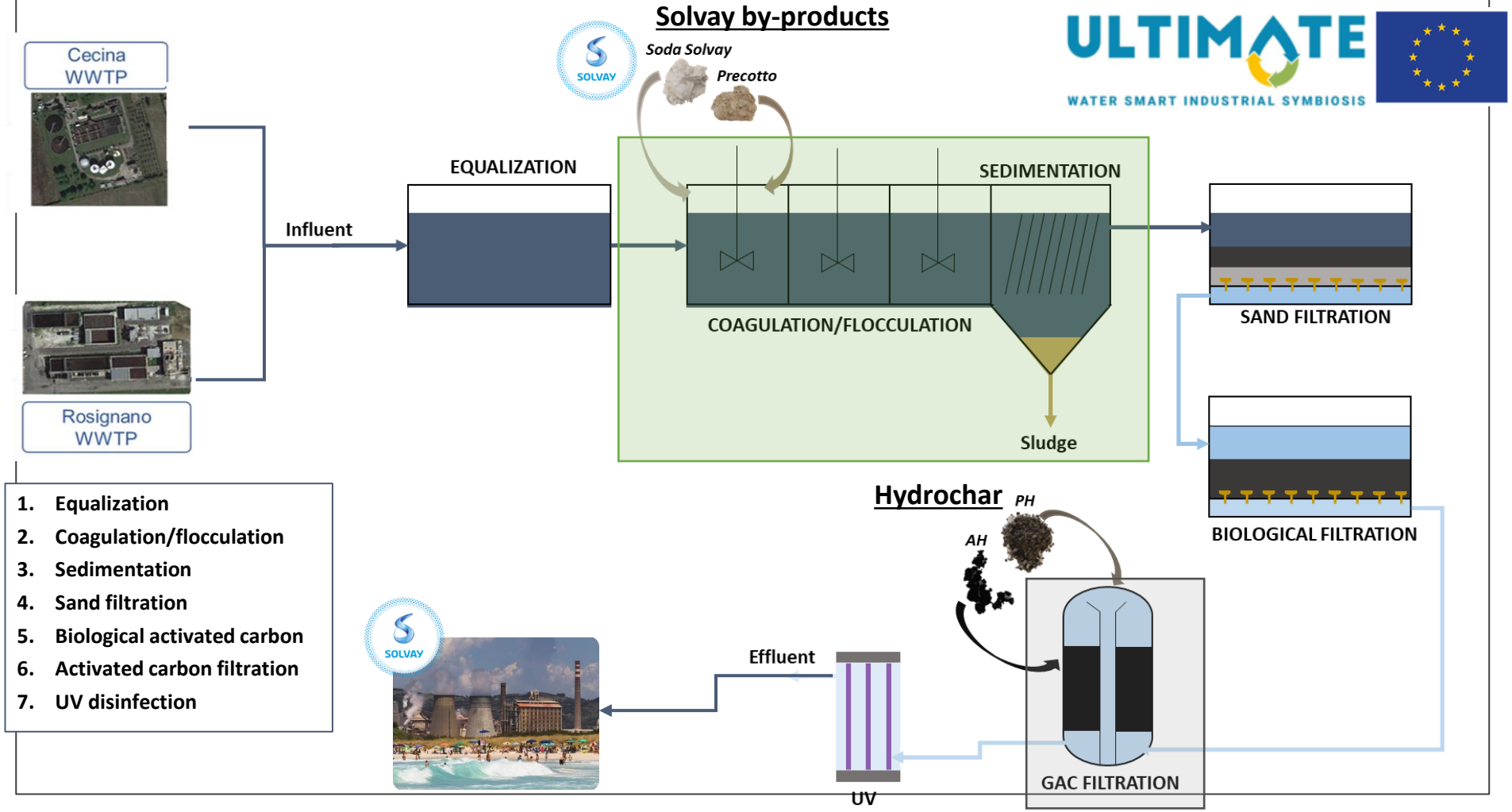
WATER SCARCITY and RESOURCE DEPLETION – WATER REUSE – INDUSTRIAL SYMBIOSIS

BY-PRODUCTS reuse in ADVANCED TREATMENT PROCESSES for water reuse in industries



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WATER SCARCITY and RESOURCE DEPLETION – WATER REUSE – INDUSTRIAL SYMBIOSIS

TESTED BY-PRODUCTS

GRANULATED LIMESTONE ROCKS ONLY PARTIALLY CALCINATED (PRECOTTO)



"PRECOTTO": GRANULATED LIMESTONE ROCKS ONLY PARTIALLY CALCINATED AND SLACKED, WITH A DECLARED CONTENT OF $Ca(OH)_2$ OF ABOUT 9%.

SOLVAY CHIMICA ITALIA SPA BY-PRODUCTS TESTED

SOLVAY

Na_2CO_3 "Soda Solvay® Light" OUT OF SPECIFICATION



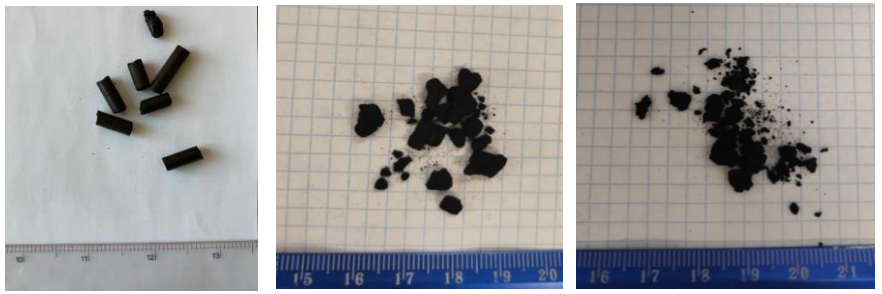
Na_2CO_3 "Soda Solvay® Light" PRODUCT THAT RESULTED TO BE OUT OF SPECIFICATION

SOLVAY CHIMICA ITALIA SPA BY-PRODUCTS TESTED

SOLVAY

HYDRO-CHAR FROM MUNICIPAL SEWAGE SLUDGE

HYDROCHAR ACTIVATED WITH DIFFERENT PROCESSES



BY-PRODUCT	PRODUCTION PROCESS	Description	POSSIBLE USES
Hydrochar	Hydrotermal Carbonization (HTC) of sewage sludge or biomass	Carbon-rich porous material	- Soil amendment - Energy production - Adsorbent
Soda Solvay out of specification	Soda production line (washing process)	Soda Solvay with "foreign bodies" (e.g. screws, pieces of wood), "pollutants" (e.g. oil stains), or dust.	- Chemical industrial process - Coagulant and Softening agent
Precotto	Soda production line	Partially cooked limestone	- Construction sector - Cement production - Concrete, brick - Ceramic production - Coagulant and softening agent

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WATER SCARCITY and RESOURCE DEPLETION – WATER REUSE – INDUSTRIAL SYMBIOSIS

BY-PRODUCTS reuse in ADVANCED TREATMENT PROCESSES for water reuse in industries

By-products for softening process

Materials characterization

Soda Solvay
Out of specification Na2CO3



Collected during the maintenance and cleaning operations of the Solvay plants which do not meet the required standard

Precotto
Granulated limestone rocks



Partially cooked limestone, residual from the production line of Soda in Solvay industry

SOFTENING TESTS to reduce hardness
Batch tests with pH of 8.5-9-9.5-10 at different dosages of the by-products (0.1-0.4 g).

Laboratory Tests



TREATMENT GOAL:

Concurent removal of COD and Hardness

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WATER SCARCITY and RESOURCE DEPLETION – WATER REUSE – INDUSTRIAL SYMBIOSIS

BY-PRODUCTS reuse in ADVANCED TREATMENT PROCESSES for water reuse in industries

By-products for softening process

Softening agent	PAC	Alluminium Sulphate	Flocculant	Target pH	Final pH	Conductivity	TSS	COD	Mg	Ca	COD Removal	Mg Removal	Ca Removal
-	ml	mg	ml	-	-	µS/cm	mg/l	mg/l	mg/l	mg/l	%	%	%
INFLUENT WASTEWATER - ARETUSA WWTP (By-products solution at 40 mg/l)					**8.6**	**1597**	**4.8**	**64.5**	**55.5**	**178**	-	-	-
-	-	-	1	-	8.5	1910	10	64.5	54.2	175	0.00	2.29	1.7
-	-	98	1	-	7.3	1844	5	25.8	52.6	165	60.00	5.16	7.6
Precotto	-	-	1	9	8.9	1895	8	34.4	49.2	168	46.67	11.38	5.7
Precotto	-	-	1	9.5	9.4	1849	4	60.2	50.3	162	6.67	9.32	9.1
OoS Soda Solvay	-	-	1	9	9.0	1934	13	34.4	50.8	162	46.67	8.42	9.0
OoS Soda Solvay	-	-	1	9.5	9.5	2000	19	17.2	55.3	135	73.33	0.27	23.9
Mix	-	-	1	9	9.0	1993	4	8.6	52	178	86.67	6.24	0.3
Mix	-	-	1	9.5	9.5	1998	15	12.9	53.3	135	80.00	3.86	24.3
INFLUENT WW - ARETUSA WWTP (direct dosage of solid by-products)					**8.0**	**2130**	**50**	**23.9**	**46.1**	**164**	-	-	-
Precotto	-	-	1	9	8.7	1920	30	13	42.4	152	45.45	8.13	6.8
Precotto	-	-	1	9.5	9.1	1964	30	8.7	42.1	162	63.64	8.64	1.0
OoS Soda Solvay	-	-	1	9	9.0	2180	20		48.5	157		-5.26	4.3
OoS Soda Solvay	-	-	1	9.5	9.2	2310	10	6.52	52.3	89.7	72.73	-13.44	45.2
Mix	-	-	1	9	8.9	2180	10	8.26	46.6	154	65.45	-1.13	6.0
Mix	-	-	1	9.5	9.3	2270	0	10.9	49.6	130	54.55	-7.49	20.3
INFLUENT WW - ARETUSA WWTP (OoS Soda Solvay solution at 20 mg/l and Precotto solution at 10 mg/l)					**8.0**	**2130**	**50**	**23.9**	**46.1**	**164**	-	-	-
OoS Soda Solvay	-	-	1	9	9.2	2030	20	4.35	47.2	144	81.82	-2.29	12.0
OoS Soda Solvay	-	-	1	9.5	9.5	2480	60	8.7	53.5	77.5	63.64	-15.97	52.6
Precotto	-	-	1	9	9.1	2090	10	6.3	44.8	173	73.64	2.87	-5.9
Precotto	-	-	1	9.5	9.4	1946	10	10.9	41	128	54.55	11.06	21.5
Mix	-	-	1	9	9.3	2260	10	3.26	50.1	155	86.36	-8.73	5.5
Mix	-	-	1	9.5	9.8	2460	40	6.52	57.3	35.2	72.73	-24.24	78.5

OoS Soda Solavy dosed as solid is the preferable choice

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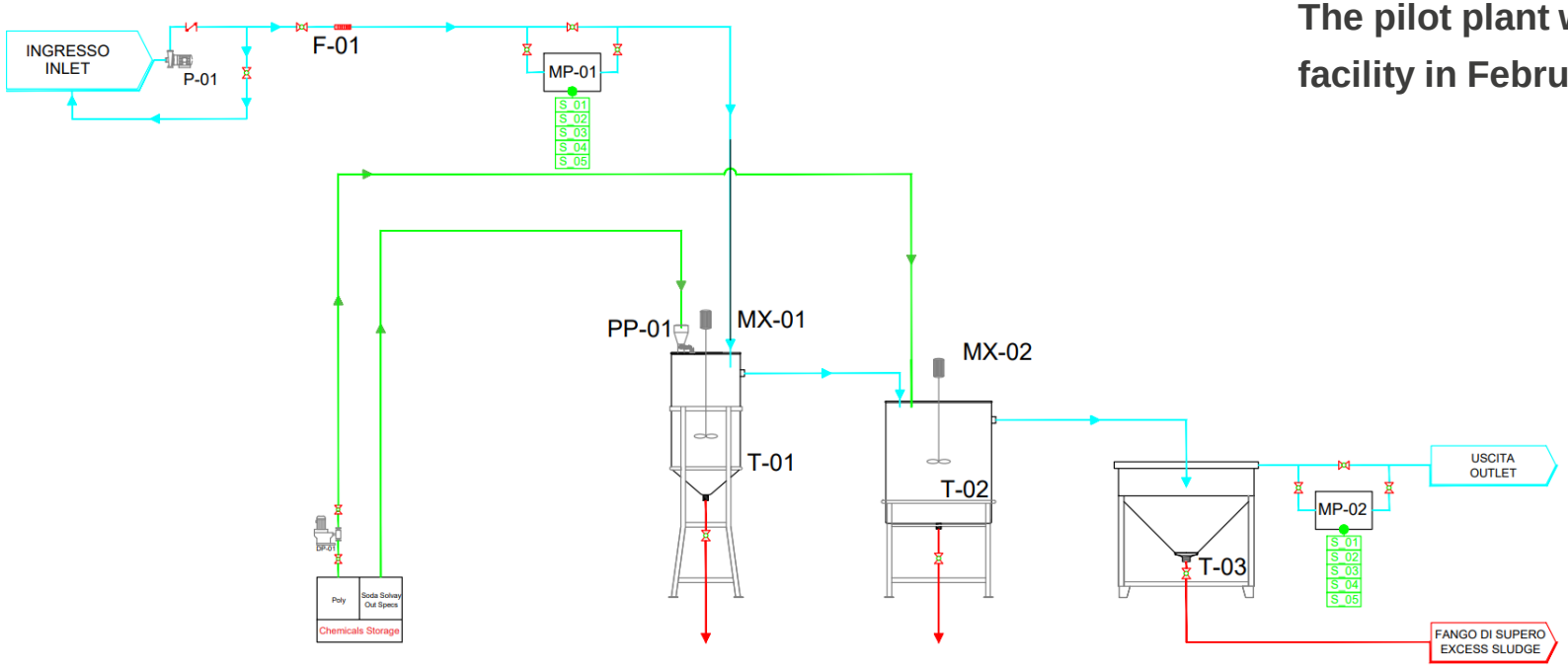
- Pilot plant design based on laboratory data
- Planned experimental campaign to evaluate cost and saving by treating wastewater with by-products



The pilot plant will be installed at ARETUSA facility in February 2024

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ULTIMATE Project

WATER SCARCITY and RESOURCE DEPLETION – WATER REUSE – INDUSTRIAL SYMBIOSIS

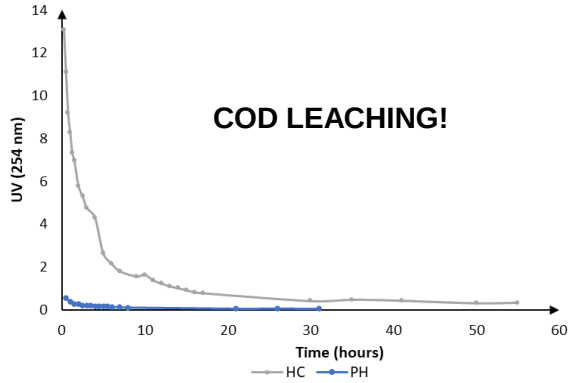
BY-PRODUCTS reuse in ADVANCED TREATMENT PROCESSES for water reuse in industries

Hydrochar for Adsorbption process



Hydrochar (HC) produced from sewadge sludge

Activation procedure needed!



Chemical activation conducted at laboratory scale!

Characterization of Hydrochar – Chemical activation

- Mixing of char pellets with KOH in flakes (KOH to char ratio: 1:1).
- Heating up to 600°C (5°C/min), isotherm for 1 hr and cooling (5°C/min) with N2 purging.
- Washing with 5M HCl and demi water (up to pH 7).
- Drying at 105°C until constant weight.

Pyrolysed Hydrochar produced at Pilot Scale



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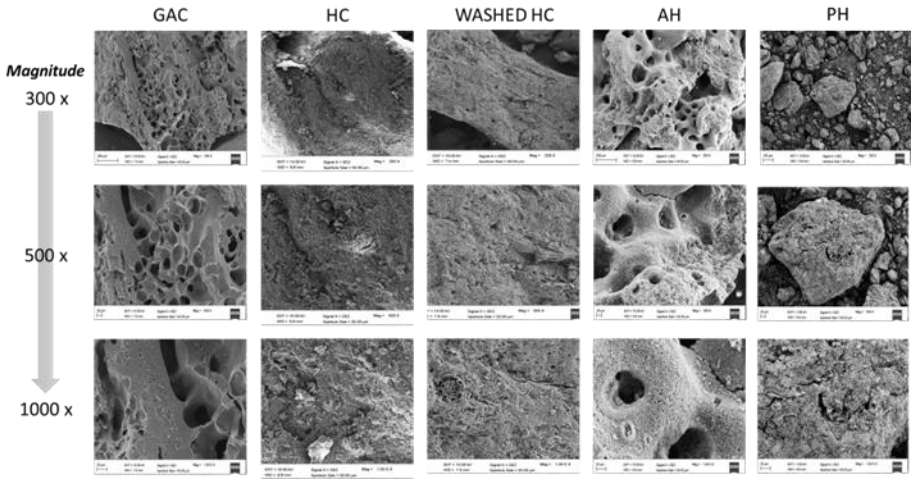

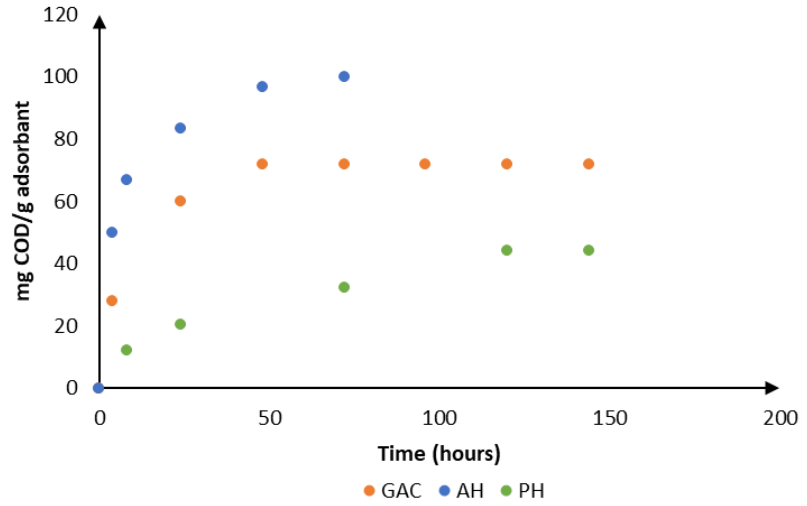

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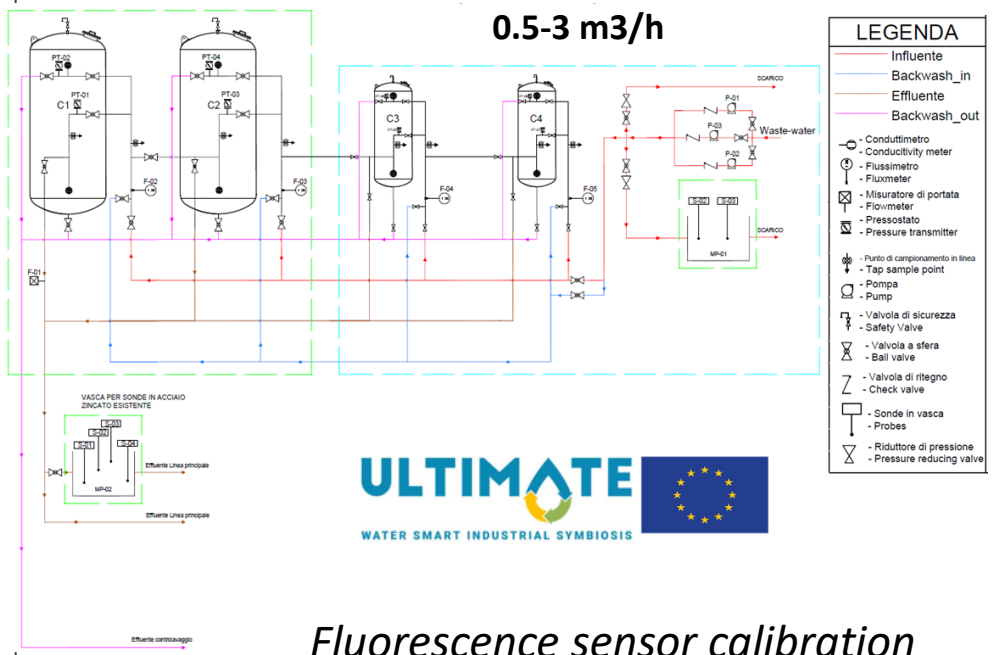
WATER SCARCITY and RESOURCE DEPLETION – WATER REUSE – INDUSTRIAL SYMBIOSIS

BY-PRODUCTS reuse in ADVANCED TREATMENT PROCESSES for water reuse in industries

Hydrochar for Adsorbption process

Adsorption process scale-up



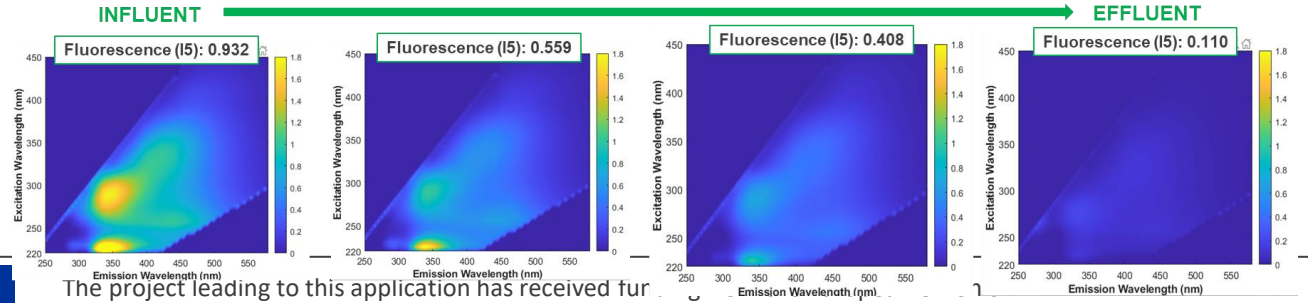


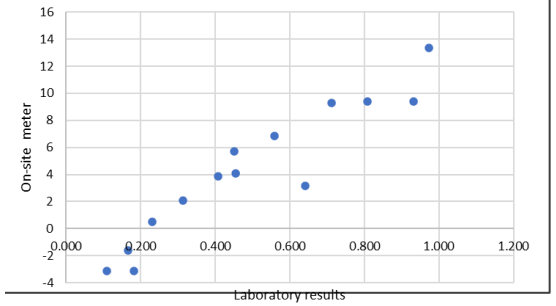






Fluorescence sensor calibration





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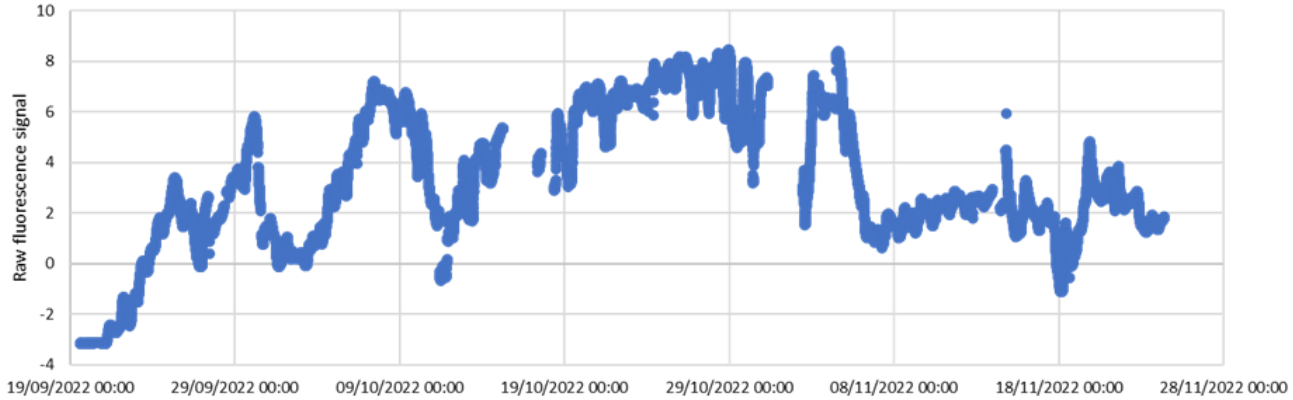
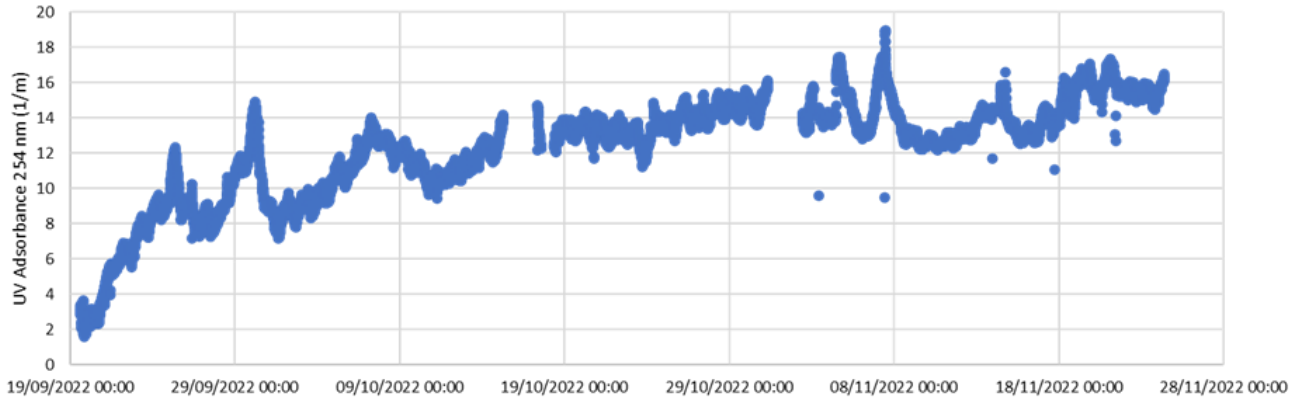
Fluorescence 275/354 nm



UV abs 254 nm



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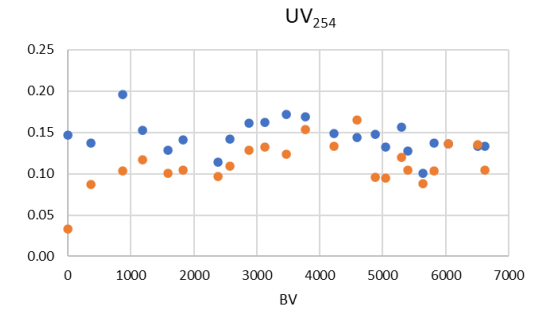

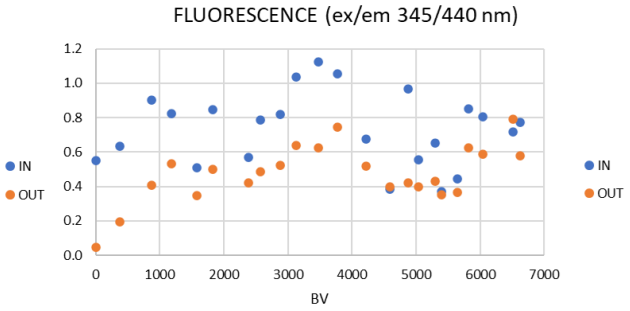

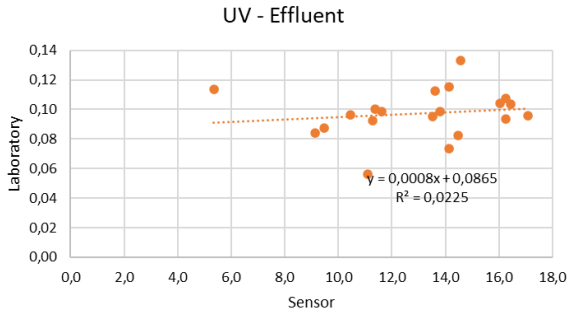

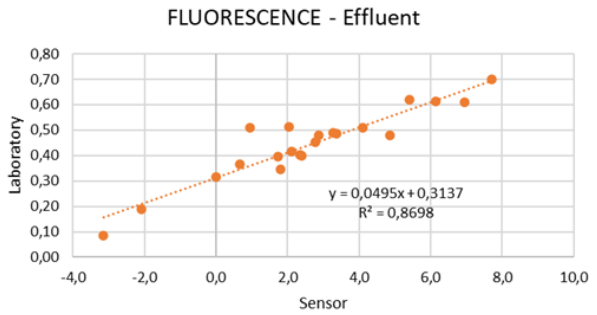

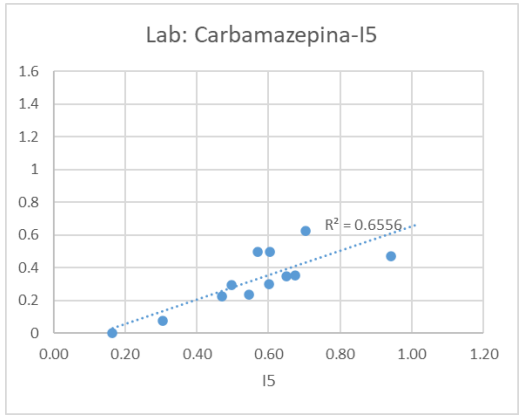

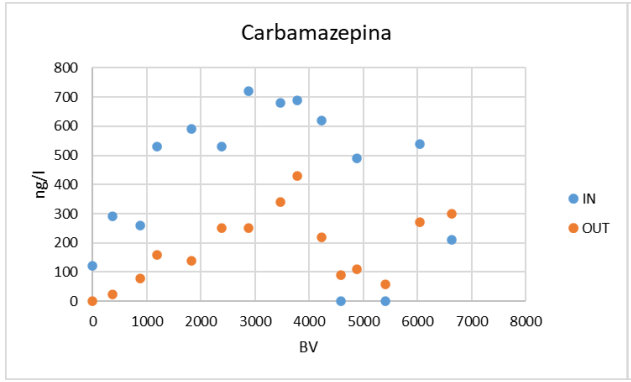

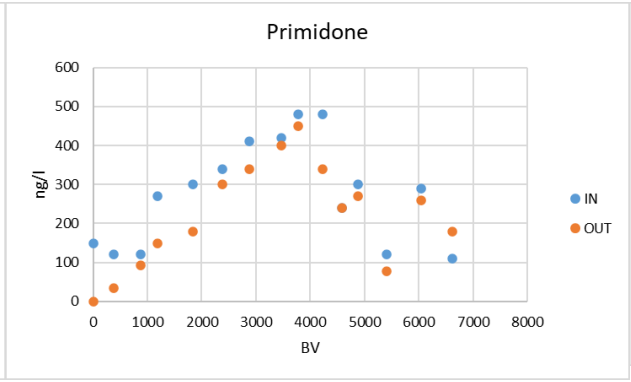

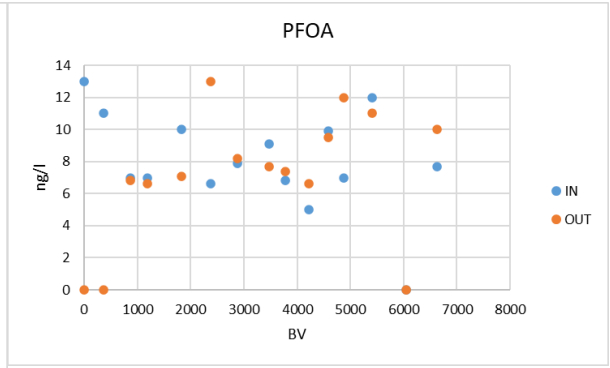

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WATER SMART INDUSTRIAL SYMBIOSIS

Thank You!

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indUstry water-utiLiTy symbiosis for a sMarter wATEr society



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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

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The team



Christophoros Christophoridis
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Myrto Touloupi
Chemist, BSc MSc



Haris Magonis
Environmental Engineer
MEng MSc



Charalampos- Philip Iossifidis
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Dimitri Iossifidis
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Eri Bizani
Chemist, BSc MSc PhD

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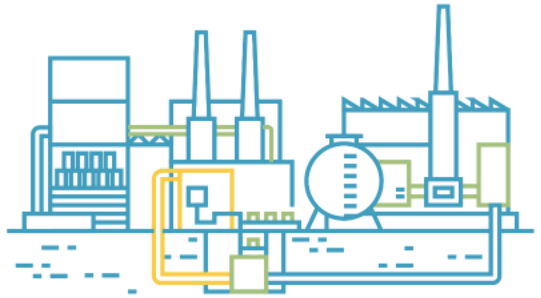
ULTIMATE



indUstry water-utiLiTy symblosis for a sMarter wATEr society



Recover, refine and **reuse wastewater**,



Extract and **exploit energy**



Extract and **exploit materials**

***"ULTIMATE** aims to create economic value and increase sustainability by valorising resources within the water cycle"*

www.ultimatewater.eu

Concept

The ULTIMATE Team

Case Studies

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The concept

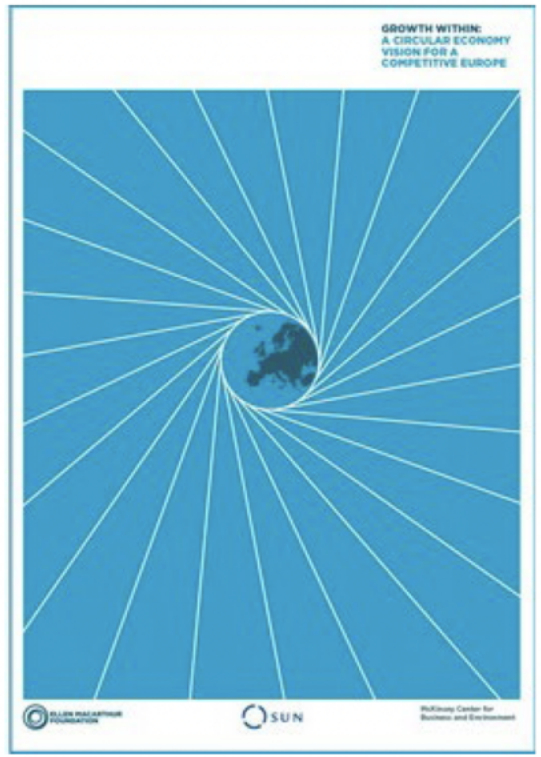
Transition from a linear to a circular economy

Linear Production-Consumption-Disposal chains make Europe vulnerable to

- **Climate changes** that lead to resource scarcity e.g. water
- Intense global **industrial/commercial competition** for energy and raw material
- **Environmental degradation** (costly to monitor and cope with)

Tough to tackle each problem individually
What can we achieve if we tackled them all together?

- **Resilient and competitive industries**
- **Resilient societies to climate change**
- **Enhanced environmental preservation**



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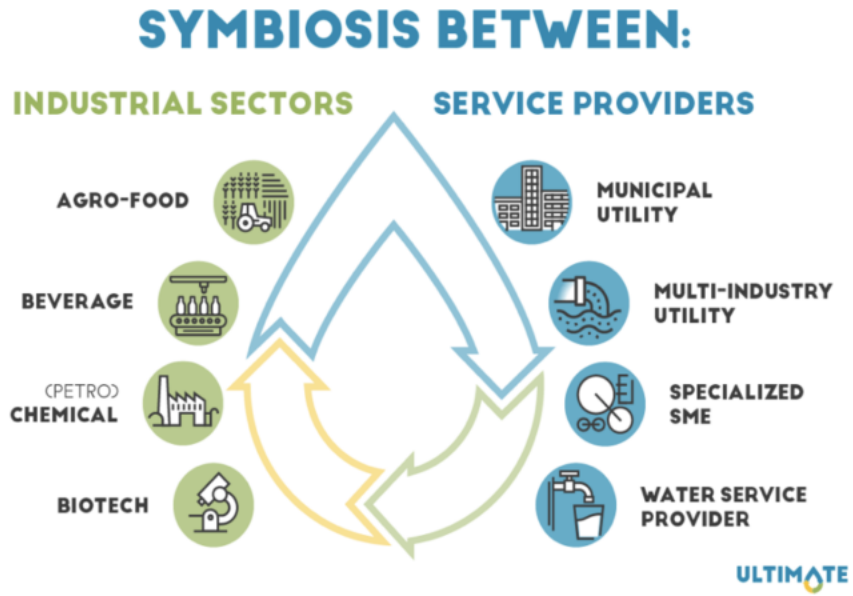
"Industrial Symbiosis"

- Systematic reuse of waste as an industrial resource
- Reduction of impact, management requirement of waste and dependence on imports
- Competitive, economically viable and diversified supply chains
- Contributes to environmental preservation
- Contributes to economic growth - new jobs, new revenue streams



- **Resilient and competitive industries**
- **Resilient societies to climate change**
- **Enhanced environmental preservation**

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Gains in numbers

- SCALER Project - 81 synergy cases; raw material & energy
- Investigation by Strane in 2017 estimated
- Value creation **€33.5B/y**
- €7B/y in taxes
- **€100B/y** savings in environmental impact (CO_2 emissions, human health improvement, resource use, improved ecosystem
- **350.000** jobs created





- **Independent EU study produced similar results**

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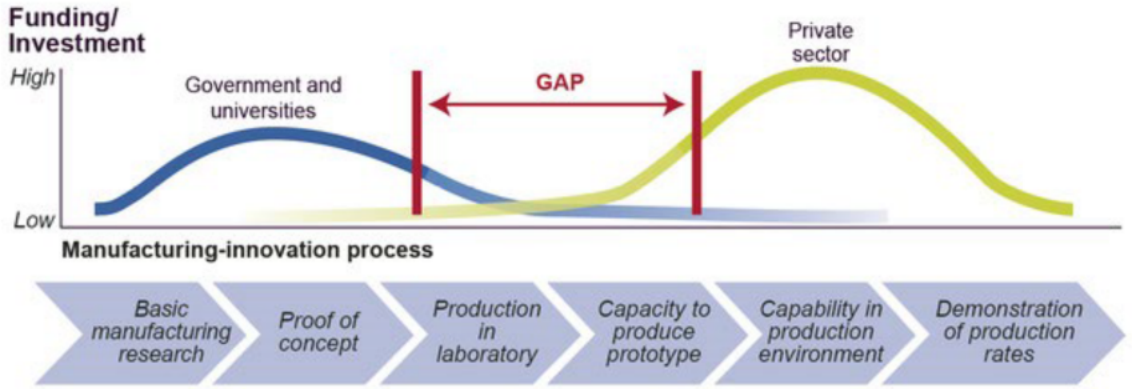
But to get there

- Innovation at this sector is fragmented and is tested in small scale
- Inadequate testing and application in working environments



- Need to apply in significant scale the solutions that arise from the systematic utilization of symbiotically interconnected industries
- Solutions is not just technologies
- Solutions should include factors such as governance, participation and collaboration in business models applied to industrial environments
- Collaboration between, **governments, research, industry, final users and citizens**

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The ULTIMATE Team

27 Partners 11 Countries

Strong partnership of water companies, industrial stakeholders, specialised SMEs, applied research institutes, technology platforms, cities, and regional authorities. Led and coordinated by Dutch water cycle research institute, KWR

- KWR Water B.V.KWR Water B.V. NL
- Fundacio EURECAT ES
- KWB Kompetenzzentrum Wasser Berlin gGmbH DE
- Universita Politecnica Delle Marche IT
- Water Europe BE
- The University of Exeter UK
- National Technical University of Athens –NTUA EL
- Cranfield University UK
- FCC Aqualia SA S
- Suez Smart Solutions FR
- Strane Innovation SAS FR
- European Science Communication Institute (ESCI) gGmbH DE
- The Galilee Society –The Arab National Society for Health Research & Services (RA) IL

Mekorot Water Company Limited IL
Greener than Green Technologies S.A. EL
AquabioLimited UK
Aguas Industriales de Tarragona SA ES
Consorzio Aretusa IT
Agrobics Ltd IL
West Systems SRLIT
Alberta SA EL
SUEZ RR IWS Chemicals France FR
Norwegian University of Science and Technology NO
Kalundborg Wastewater Treatment A/SDK
Novozymes AS DK
X-Flow BV NL
ConsorzioPolo TecnologicoMagona IT

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

9 Case Studies

ULTIMATE will implement Water Smart Industrial Symbiosis in 9 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)



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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

Pilot

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





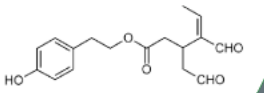
The project leading to this application has received funding form the European Union's Horizon 2020 innovation programme under grant agreement No 869318

Polyphenol Extraction

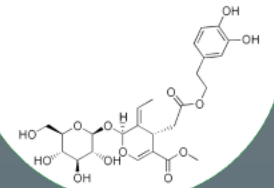
"Let food be thy medicine and medicine be thy food"
Hippocrates 460-377 BC

- 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

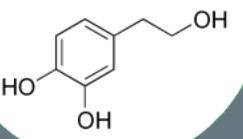
Oleocanthal



Oleuropein



3-Hydroxy tyrosol



Sorbents

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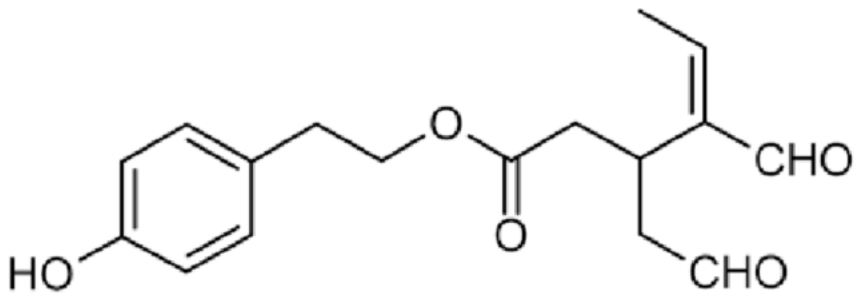
Oleocanthal

Market value:
€1620/g

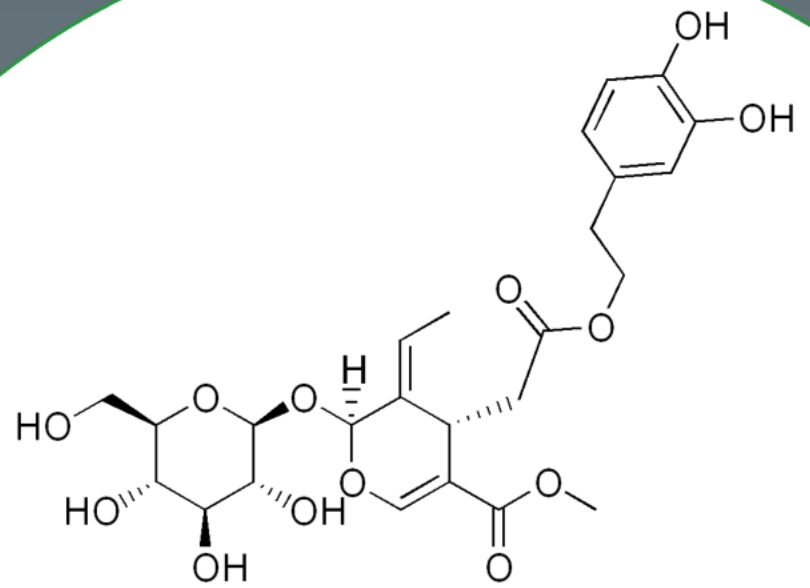


Properties:

- Antioxidant
- Anti-inflammatory
- Anti-cancer
- Reduce risk of AD
- Reduce risk of heart disease

Oleuropein

Market value:
€7.240/g

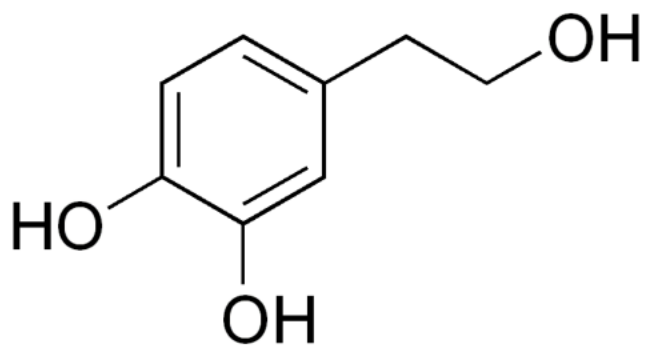


Properties:

- Antioxidant
- Anti-inflammatory
- Anti-cancer
- Protects skin & eyes
- Protection against pathogens

3-Hydroxy tyrosol

Market value:
€7.240/g

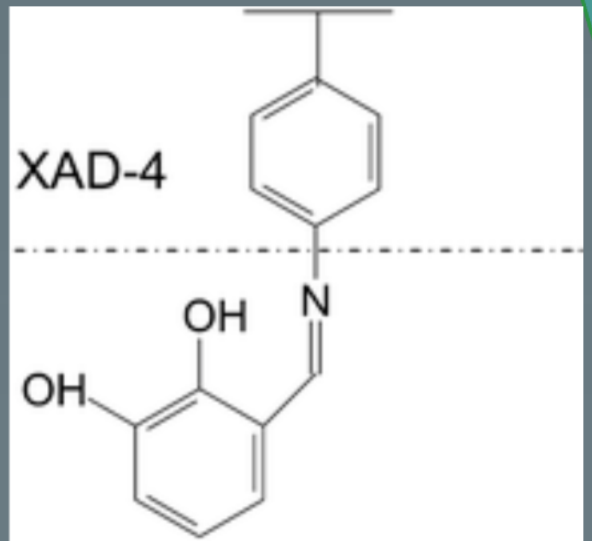


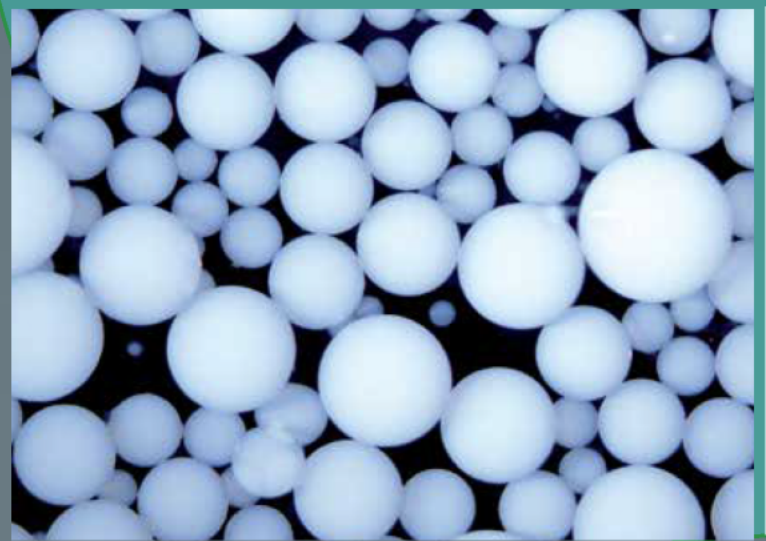
Properties:

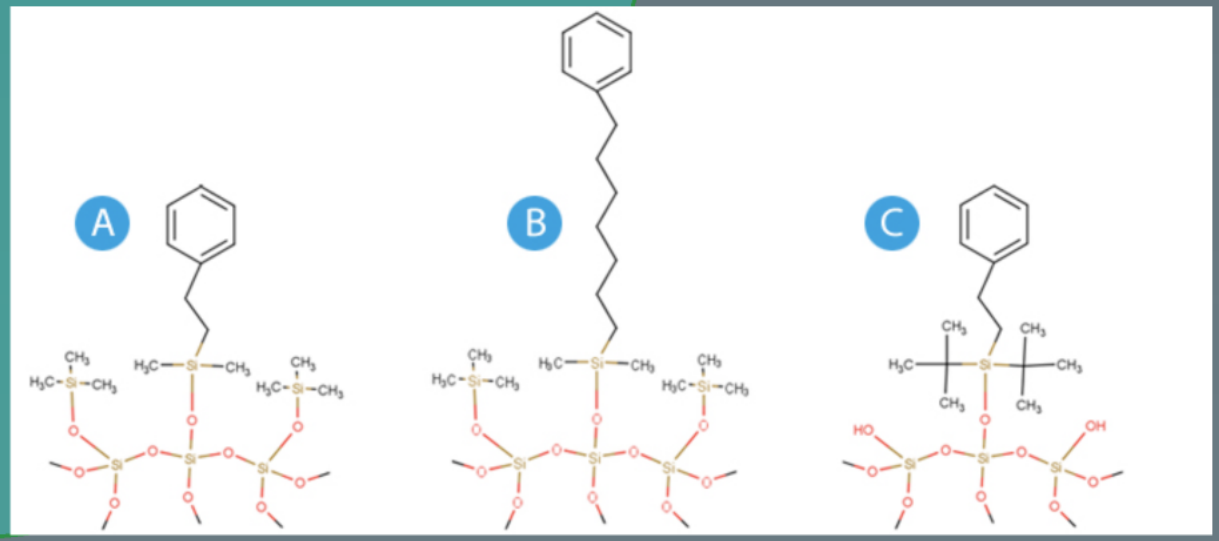
- Antioxidant
- Anti-inflammatory
- Anti-cancer
- Protects skin & eyes
- Protection from pathogens

Sorbents

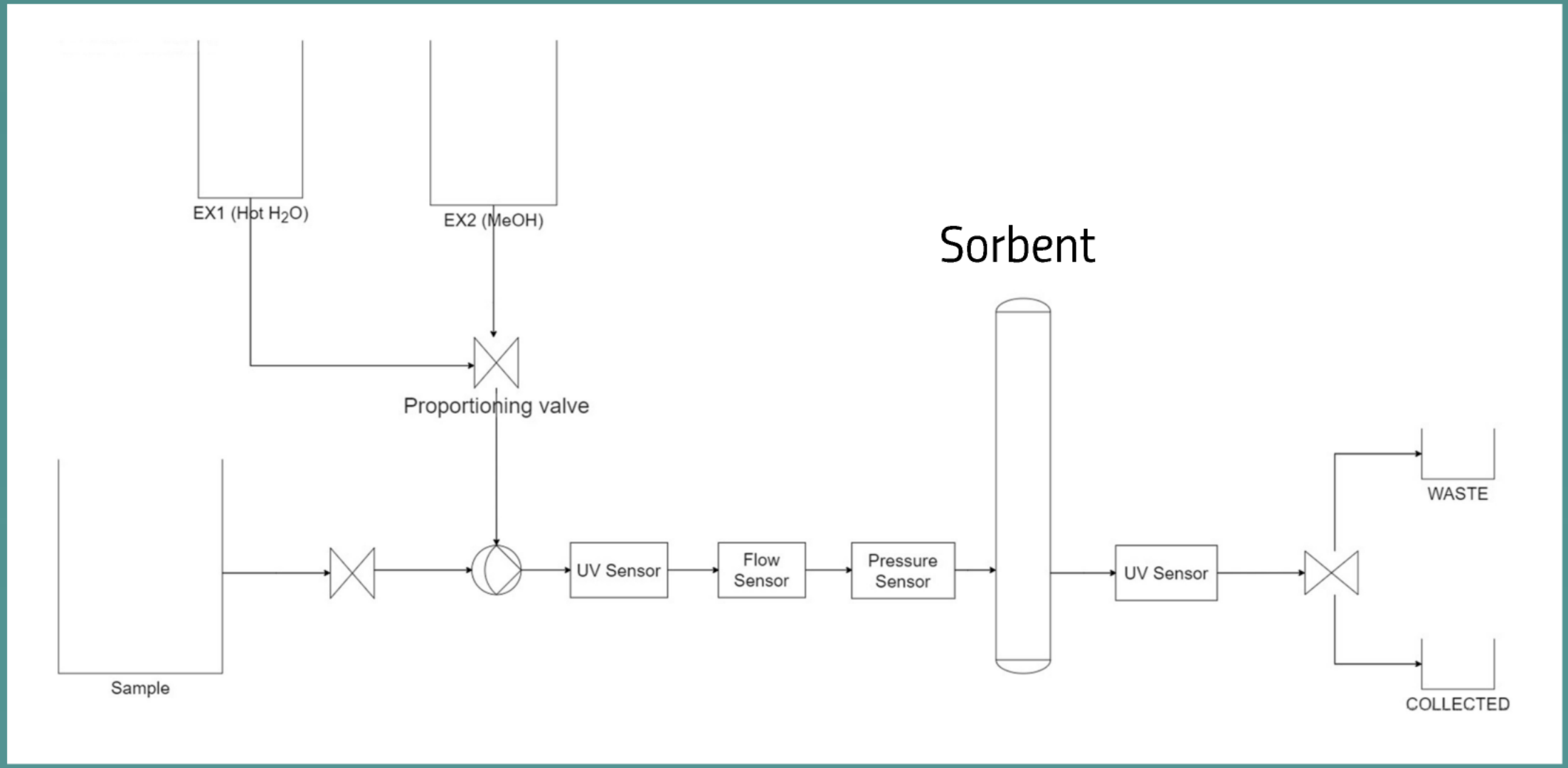
Adsorbent	Material	Structure	Particle size (µm)	Surface Area (m^2/g)	Pore Size (Å)
AmberLite™ FPX66	Resin	Aromatic	700	800	150
AmberLite™ XAD-4	Resin	Aromatic	640	750	100
Phenyl-Hexyl	Silica	Aromatic	15	400	100







Design



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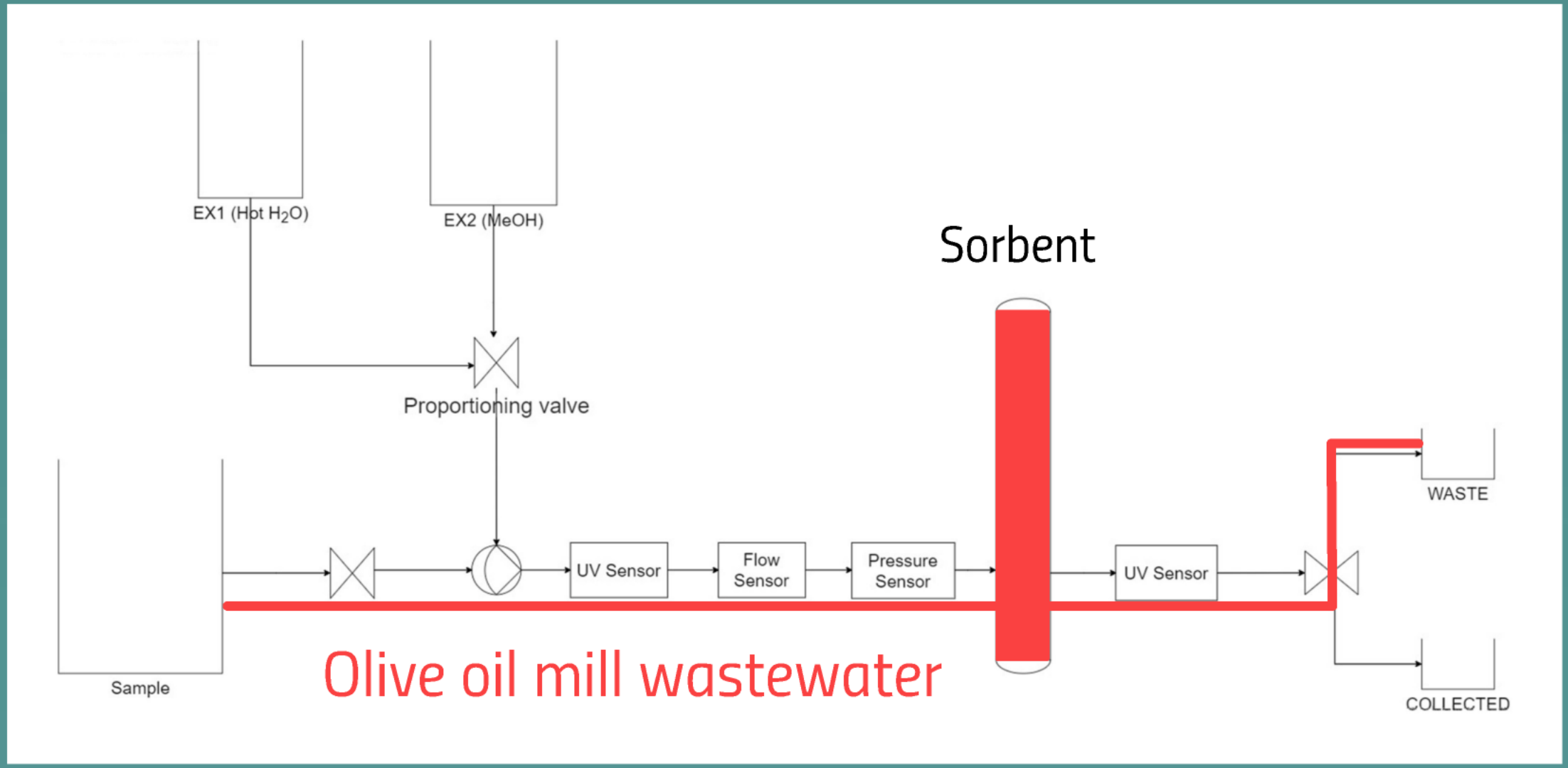
Loading



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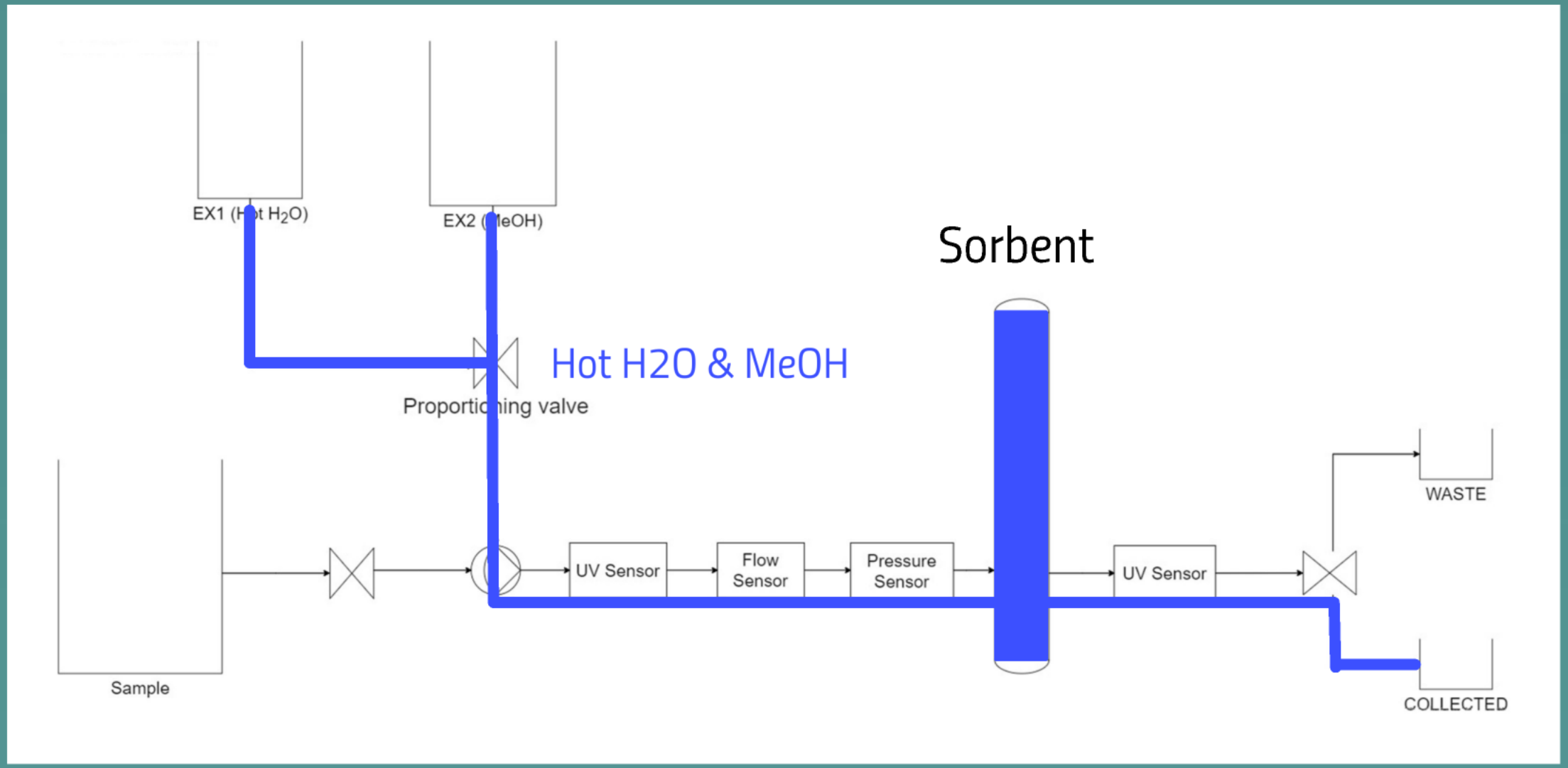
Extraction



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Lab-scale



Results

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

Static Adsorption Methodology

Static Adsorption Results



Dynamic Adsorption

Dynamic Adsorption Methodology

Dynamic Adsorption Results



Recovery

Recovery Results

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

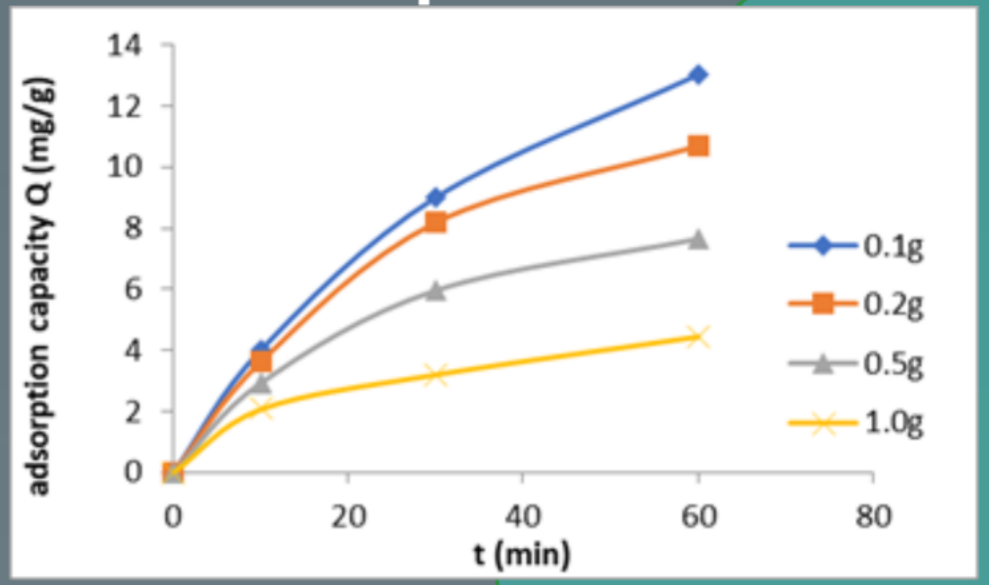
Determine most suitable material

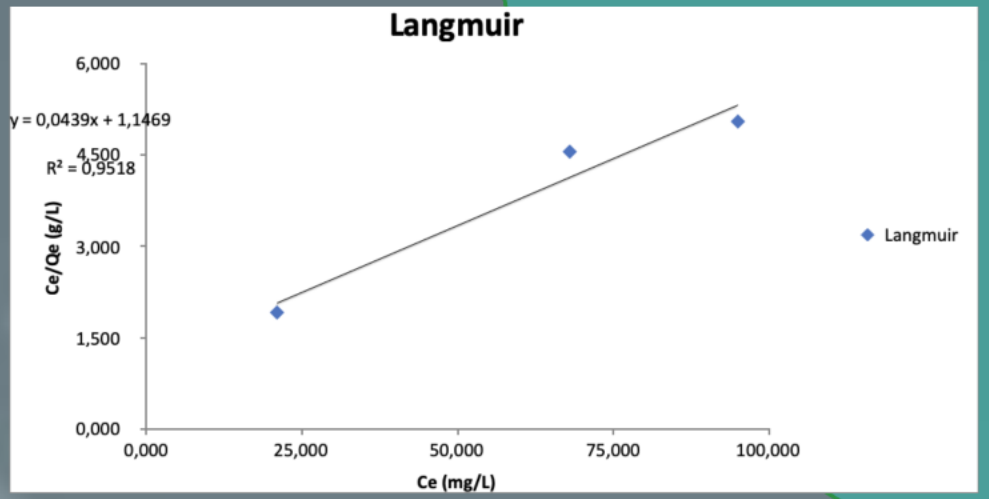
- Batch experiment
- Constant volume of wastewater
- Different quantities of adsorbing material
- Sampling at regular intervals



- Maximum adsorption capacity of each material
- Adsorption kinetics - how fast
- Modelling of adsorption dynamics

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)

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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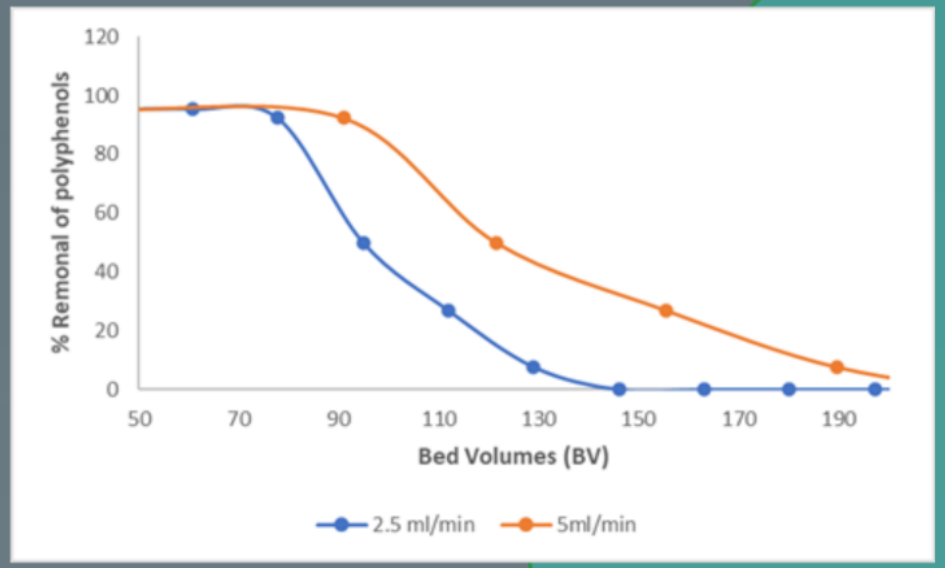
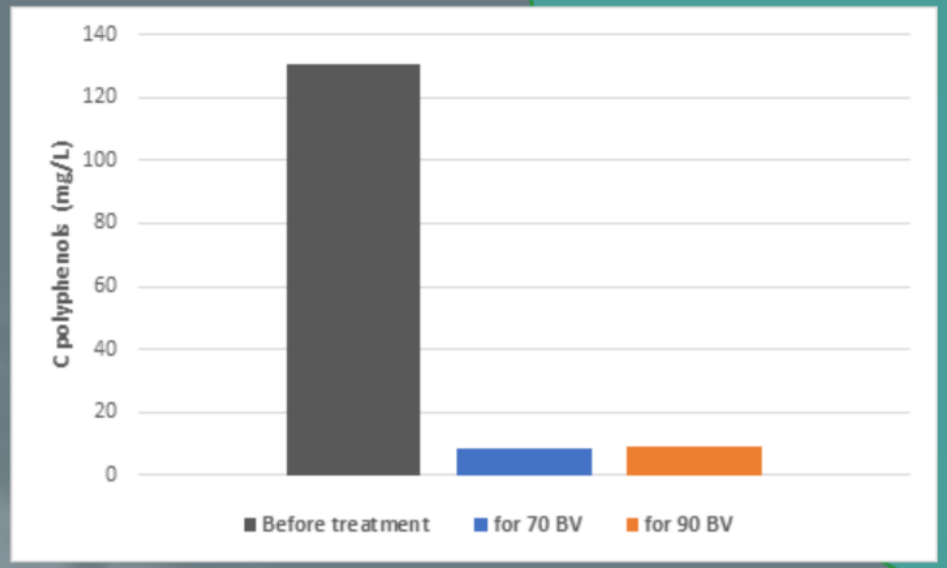
Dynamic Adsorption Results





- 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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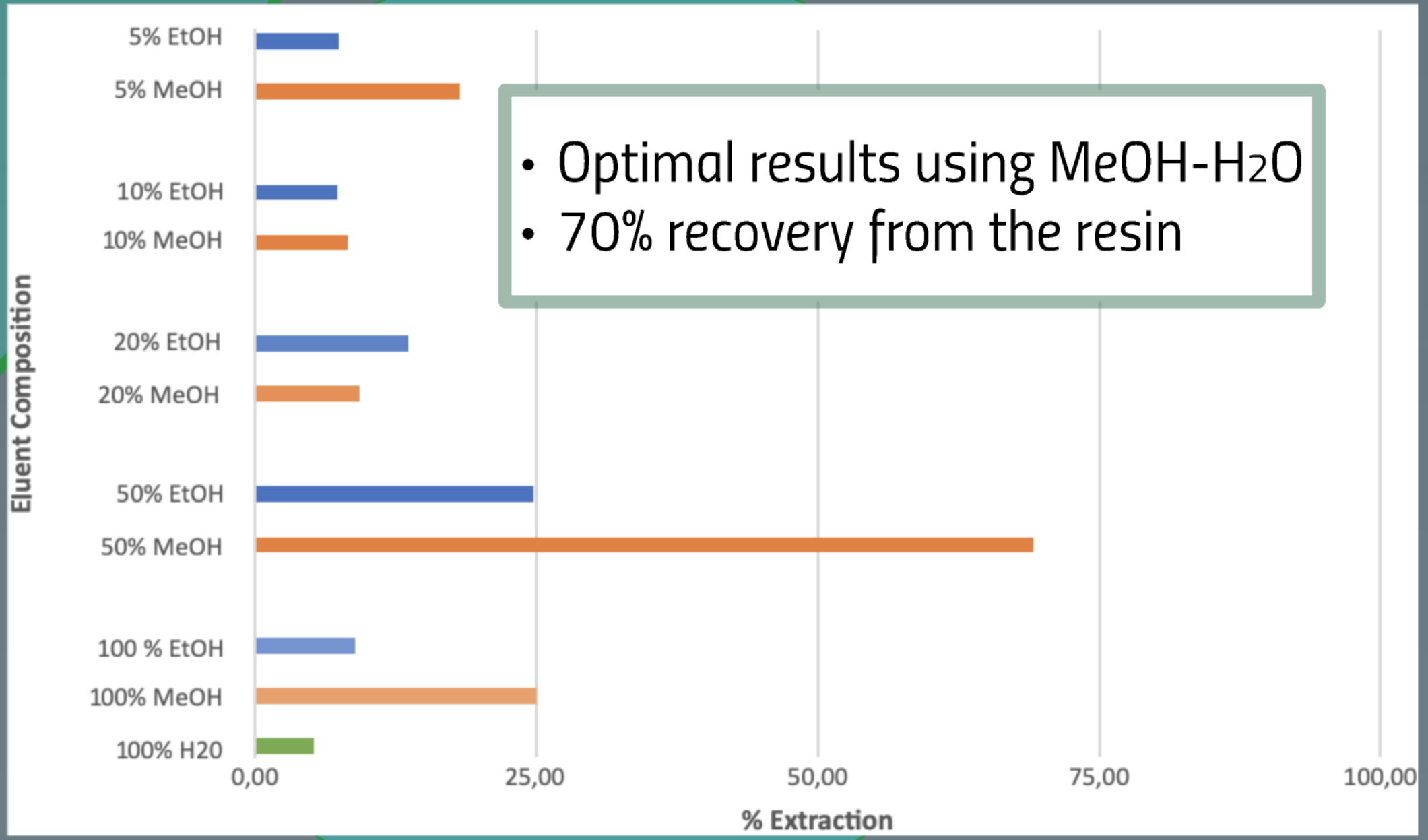
Recovery



- Optimal results using MeOH-H_2O
- 70% recovery from the resin

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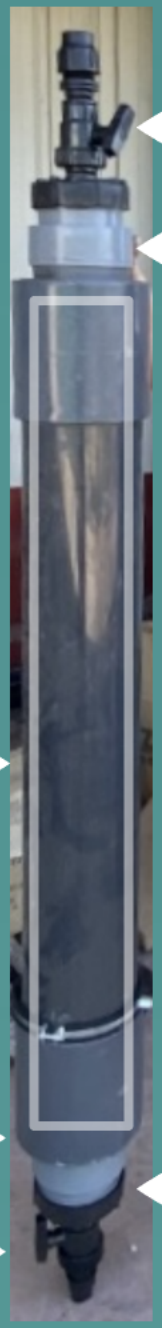
The Pilot Unit





The Design


Valve
Fret
Sponge Filter
Flow
Resin
Sponge Filter
Fret
Valve

Experimental Protocol

Resin Activation: wash with 0.5L UP water per L of resin.
Resin Packing in the form of a slurry
Resin Loading: 1 L/min of OMW until saturated
Extraction:

1. 15 min sonication in H2O (2L of water per L of resin)
2. 15 min sonication in MeOH/H2O (25:75)
3. 15 min sonication in MeOH/H2O (50:50)

Resing regeneration:
Wash with UP water
Sonicate in 5% b.w. NaOH
Repeat until the solution is clear
Wash with UP water



Photo Album


ISOLAB
LABWARE
BORO 3.3
ml
2000
1500
1000



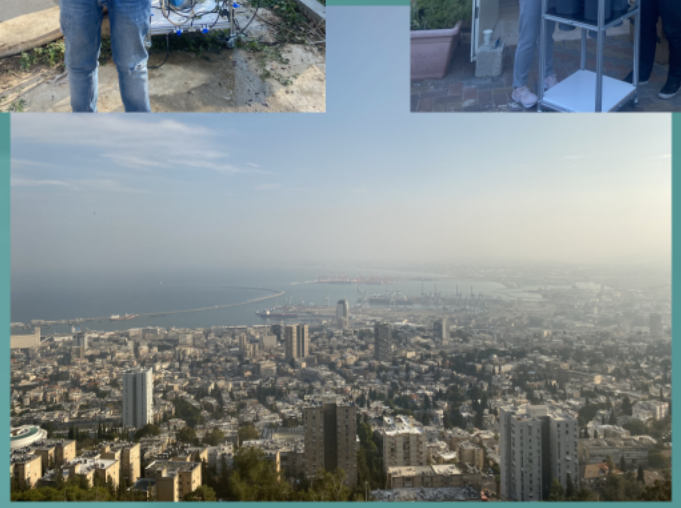

جمعية الجليل
אגודת הגליל
The Galilee Society















ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

CS 6: Karmiel (polyphenols recovery)

K. Baransi-Karkaby, N. Massalha, M. Hassanin, A. Aharoni, H. Raanan Kiperwas,

D. Iossifidis, M. Touloupi, I. Sabbah

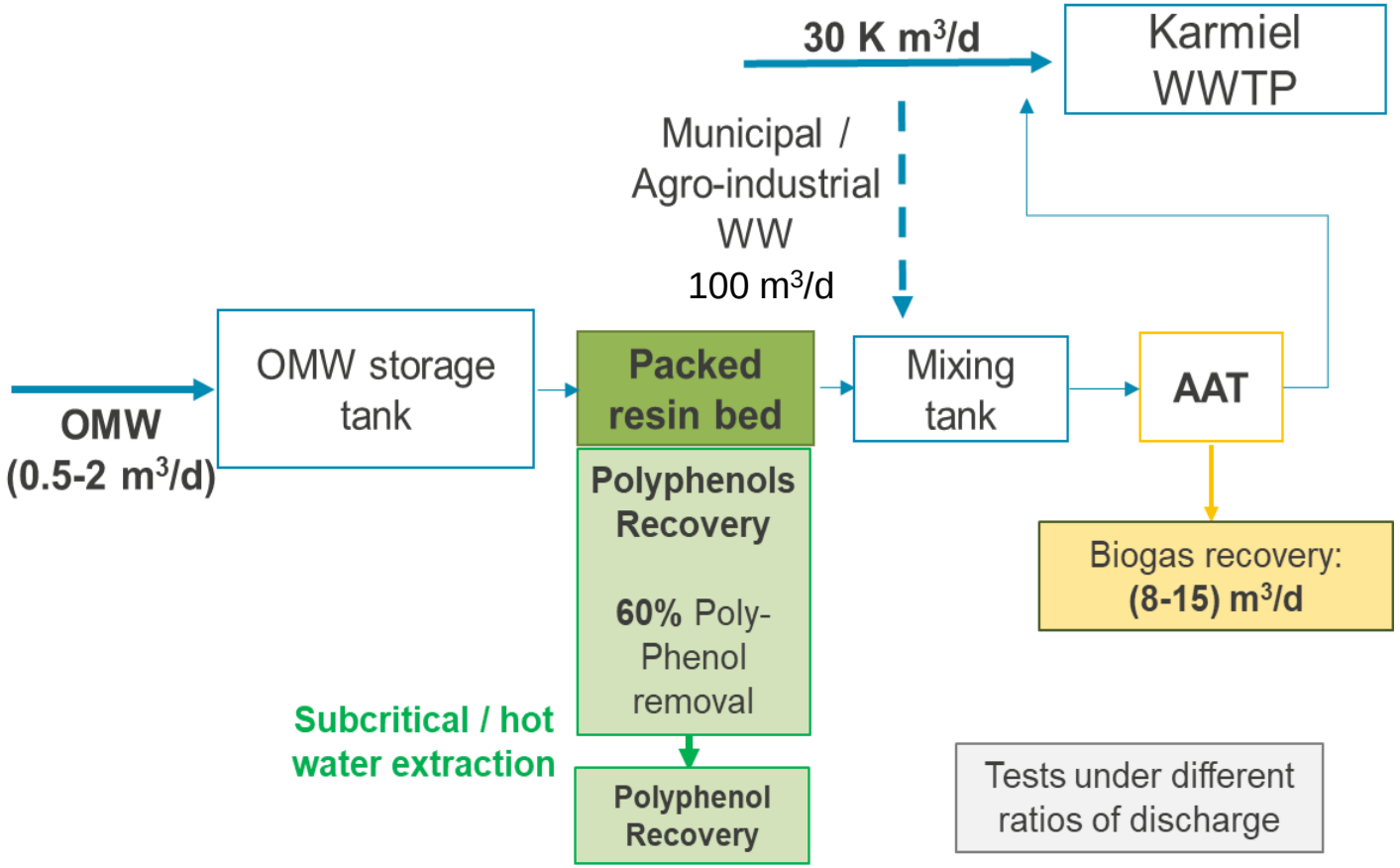


“Material recovery & reuse” workshop: November, 23th 2023

CS6: Material recovery

Subtask: 1.4.5 Recovery of high-value products from olive mill wastewater in Karmiel

Ultimate solution to foster circular economy: Adsorption column with packed resin bed and extraction



TRL: 5→ 7

Quantifiable targets: > 40% Polyphenols recovery

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CS6: Material recovery



Adsorption column with packed resin bed and extraction

	COD mg/L	Poly-Phenols (mg/L) as Tannic Acid
OMW	69000	4546

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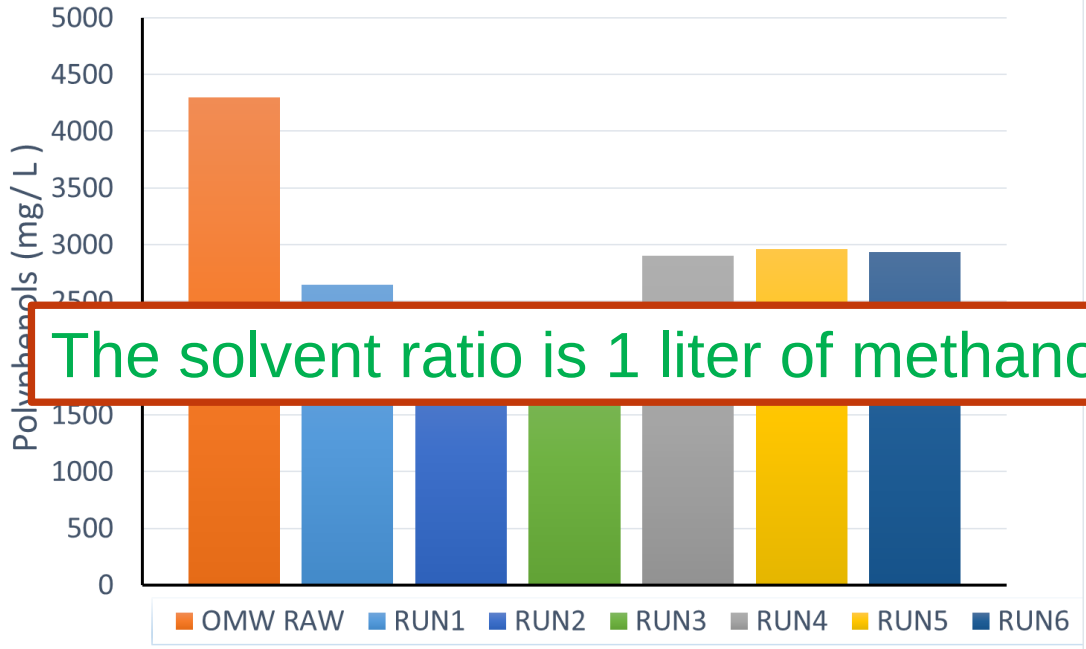
CS6: Material recovery

Resin reuse





The solvent ratio is 1 liter of methanol per 1 liters of OMW

	COD mg/L	Poly-Phenols (mg/L) as Tannic Acid
OMW	69000	4546
OMW after Resin	54468	2541
% Removal	21	44

1 L extracted organics in methanol→ **4.2 g** crude powder per batch (**1 g** polyphenols)

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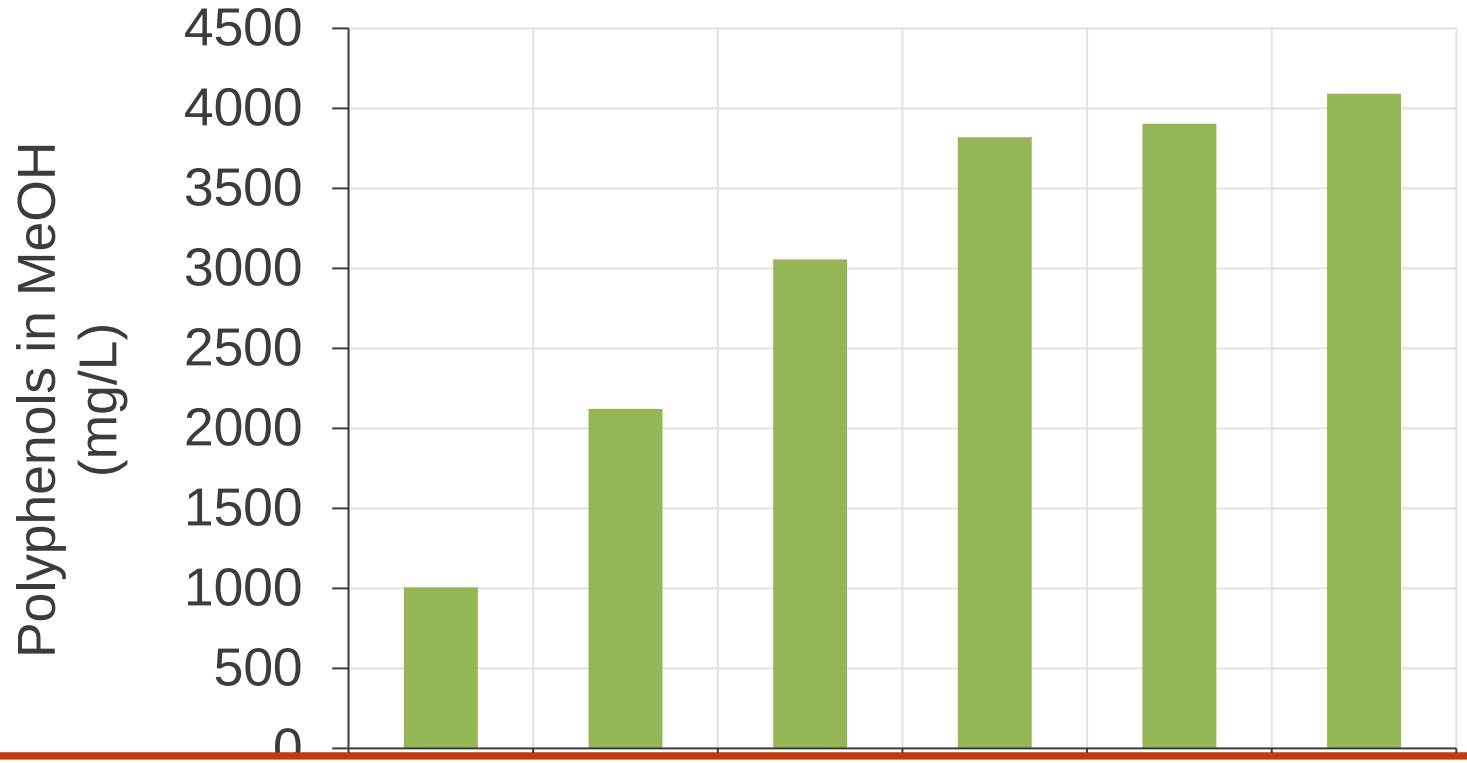
CS6: Material recovery



The recommended solvent ratio is 1 liter of methanol per 4 liters of olive mill wastewater (OMW).

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Isam Sabbah



Katie Baransi Karkaby



Khalid Farah



Nedal Massalha
CTO



Mahdi Hassanin



Avi Aharoni



Hadas

Raanan Kiperwas



Saleh Zatme



Sari Musa



Stav Shimshoni
M.Sc. Student



Dimitri Iossifidis



Myrto Touloupi

Thank you for your attention!

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

Ultimate Webinar / Workshop

Material recovery and reuse



CS8 - SUEZ RR IWS CHEMICALS

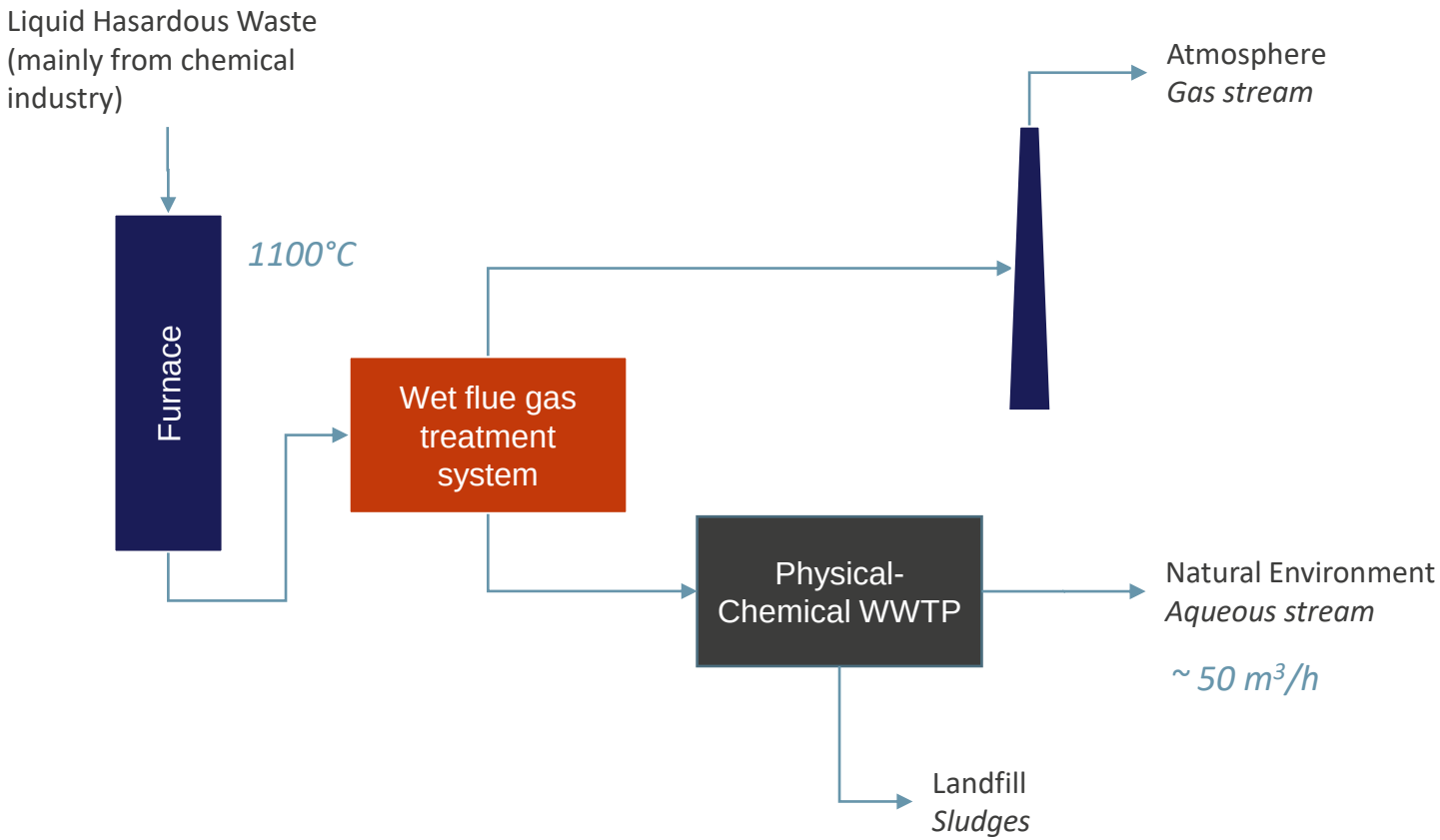
CS8: Sulphur recovery - Context

Subtask: **1.4.7 Recovery of Sulphur and metals at the chemical platform of Roussillon**

→ Hazardous waste incineration unit on the chemical platform of Roussillon

→ Specialized in aqueous waste with high salt and sulfur content.

→ Today, flue gases are efficiently desulfurized, but the sulfur is not recovered.



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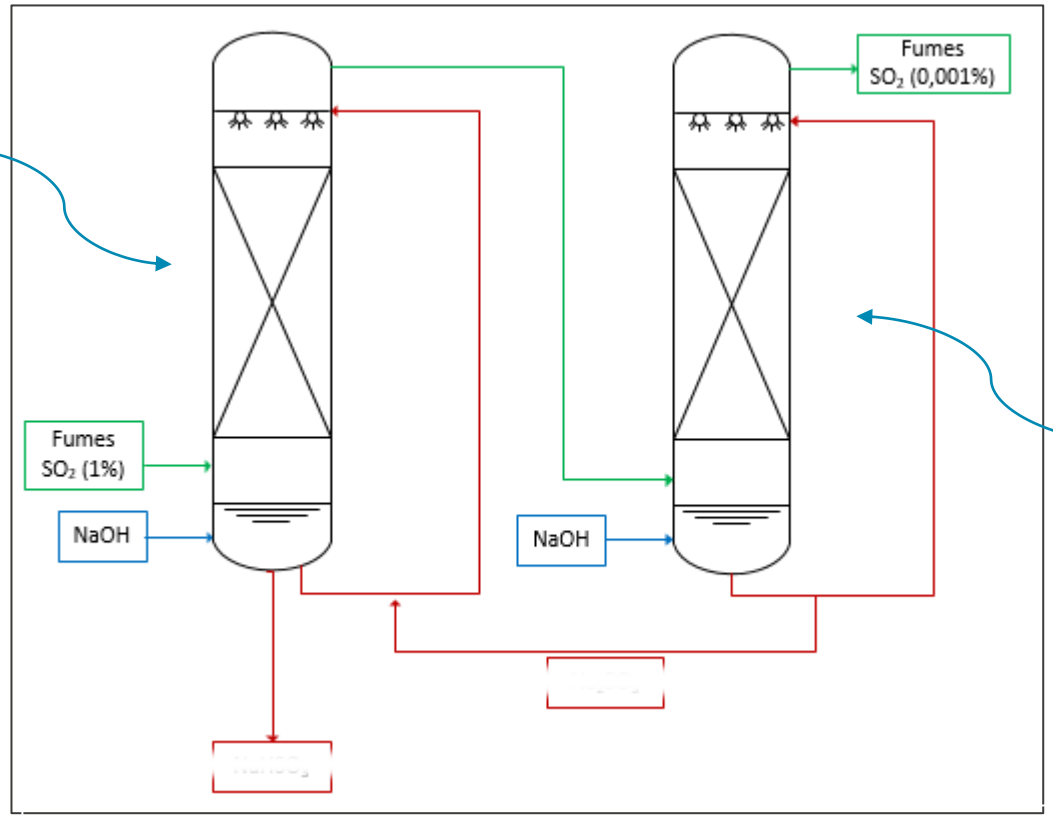
CS8: Sulphur recovery - Principle

Subtask: **1.4.7 Recovery of Sulphur and metals at the chemical platform of Roussillon**

Objective: Recover SO_2 in the form of a marketable solution

Concentrate the solution



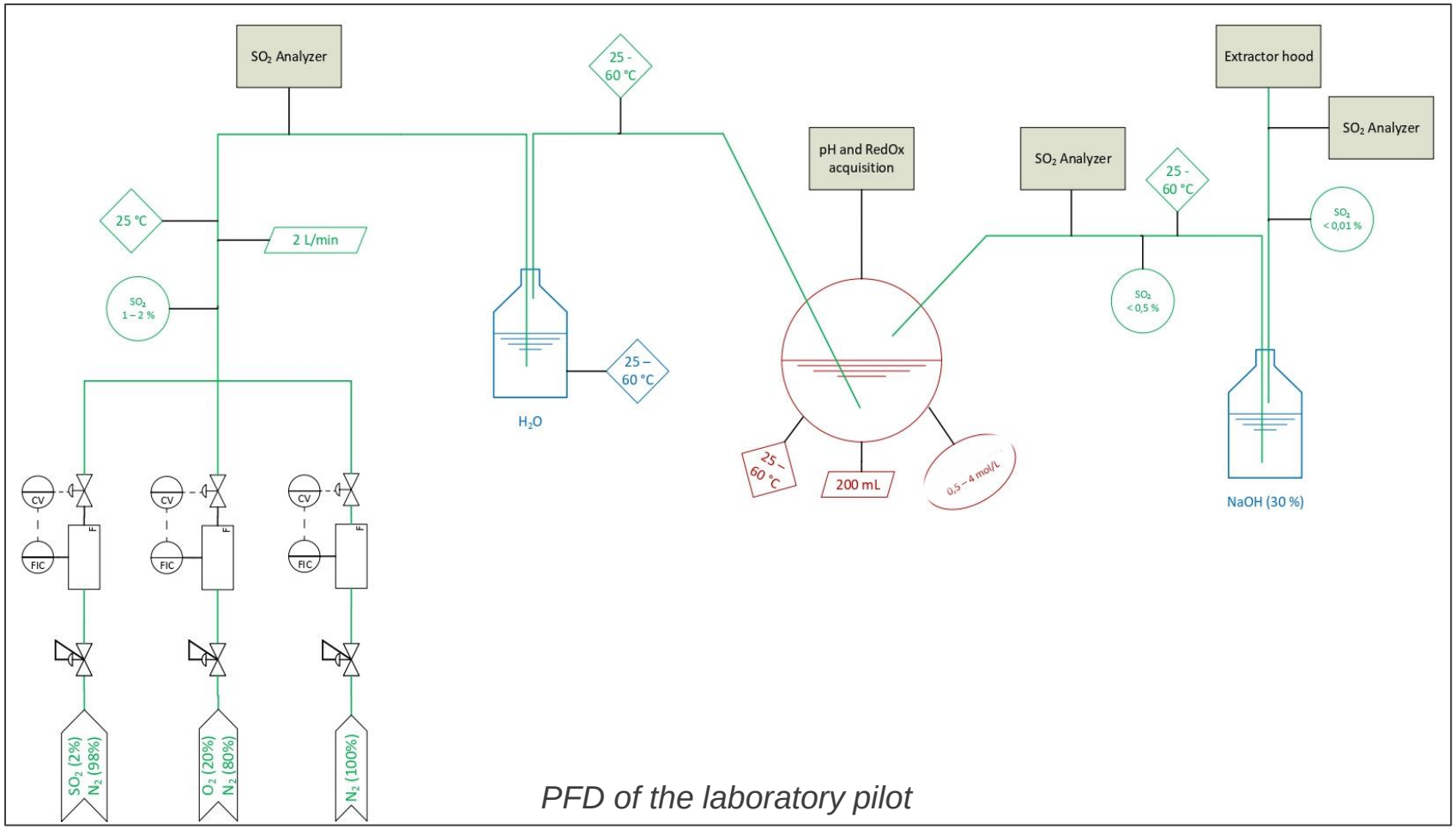
Absorb the remaining SO_2

Principle of the 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

CS8: Sulphur recovery – The laboratory pilot

Subtask: **1.4.7 Recovery of Sulphur and metals at the chemical platform of Roussillon**



PFD of the laboratory pilot

Sizing: Creation of a laboratory pilot able to study the impact of certain operating characteristics on the absorption of SO_2.

Objective: Determine precisely the optimum conditions to absorb SO_2 and concentrate the solution of interest.

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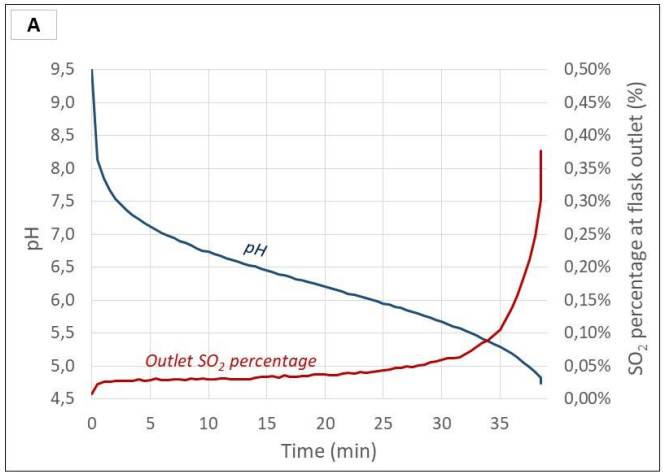
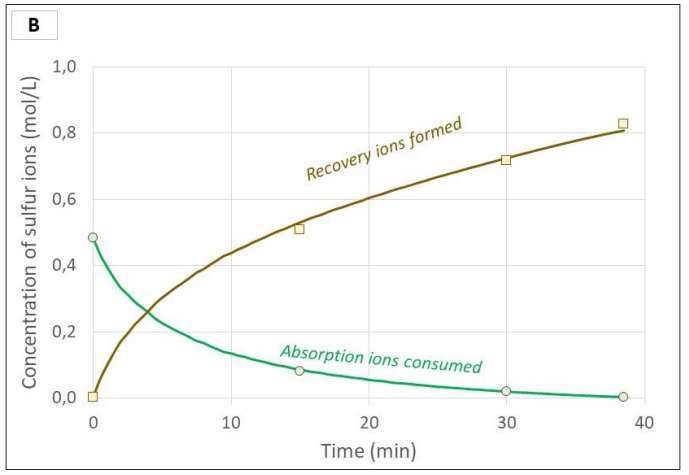
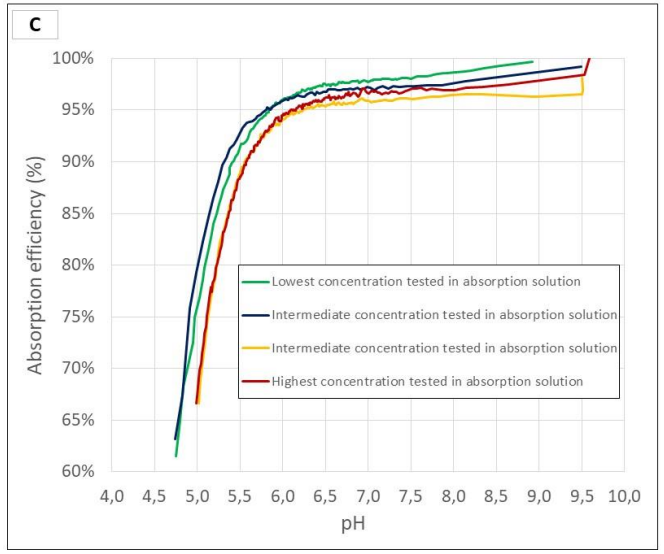
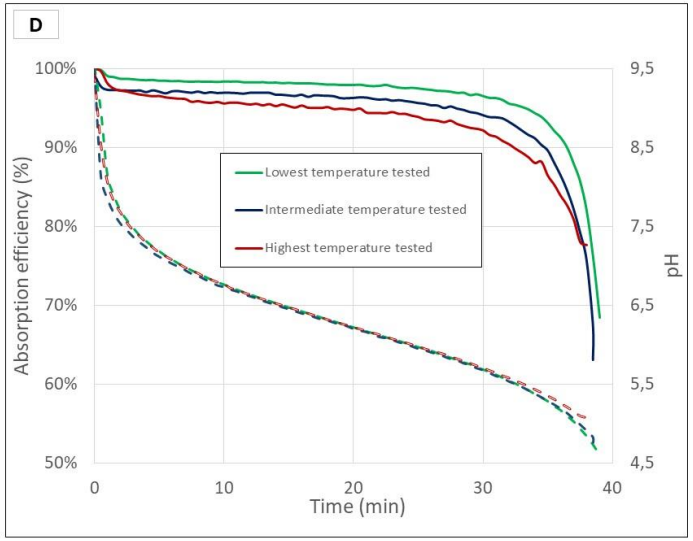
CS8: Sulphur recovery – The laboratory pilot









PHASE 1 : BATCH TESTS

Objective: Study the impact of operating conditions on the absorption reaction

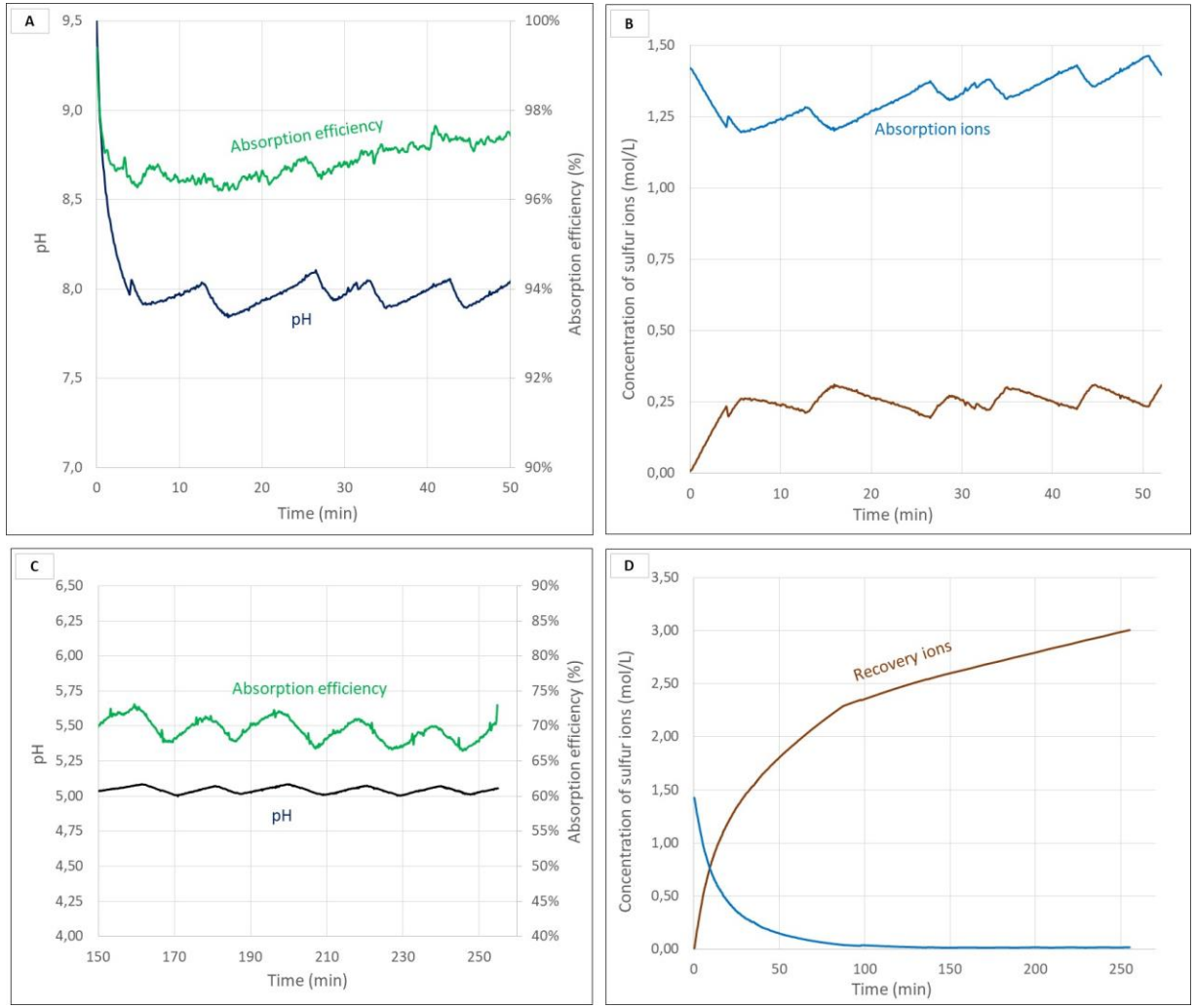
→ **Figure A and B**: if ions required for absorption are present in solution, SO_2 is absorbed in very high yields: The solution used is a very good absorber.

→ **Figure C**: Absorption efficiencies do not depend on concentration in the liquid phase

→ **Figure D**: The lower the temperature, the better the reaction (higher yield)

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

CS8: Sulphur recovery – The laboratory pilot



PHASE 2 : PH CONTROL TESTS

Objective: Study the control pHs to apply and the associated efficiencies

→ **Figure A and B**: At pH 8, absorption yields exceed 96%. The concentration of the absorption solution reached was 1.7 mol/L at this pH.

→ **Figure C and D**: At pH 5, absorption yields are around 70%. The concentration of the recovery solution reached was 3.0 mol/L at this pH.

→ pH control is possible and gives good results: to be confirmed on real flue gases (secondary reactions with other gases to be studied).

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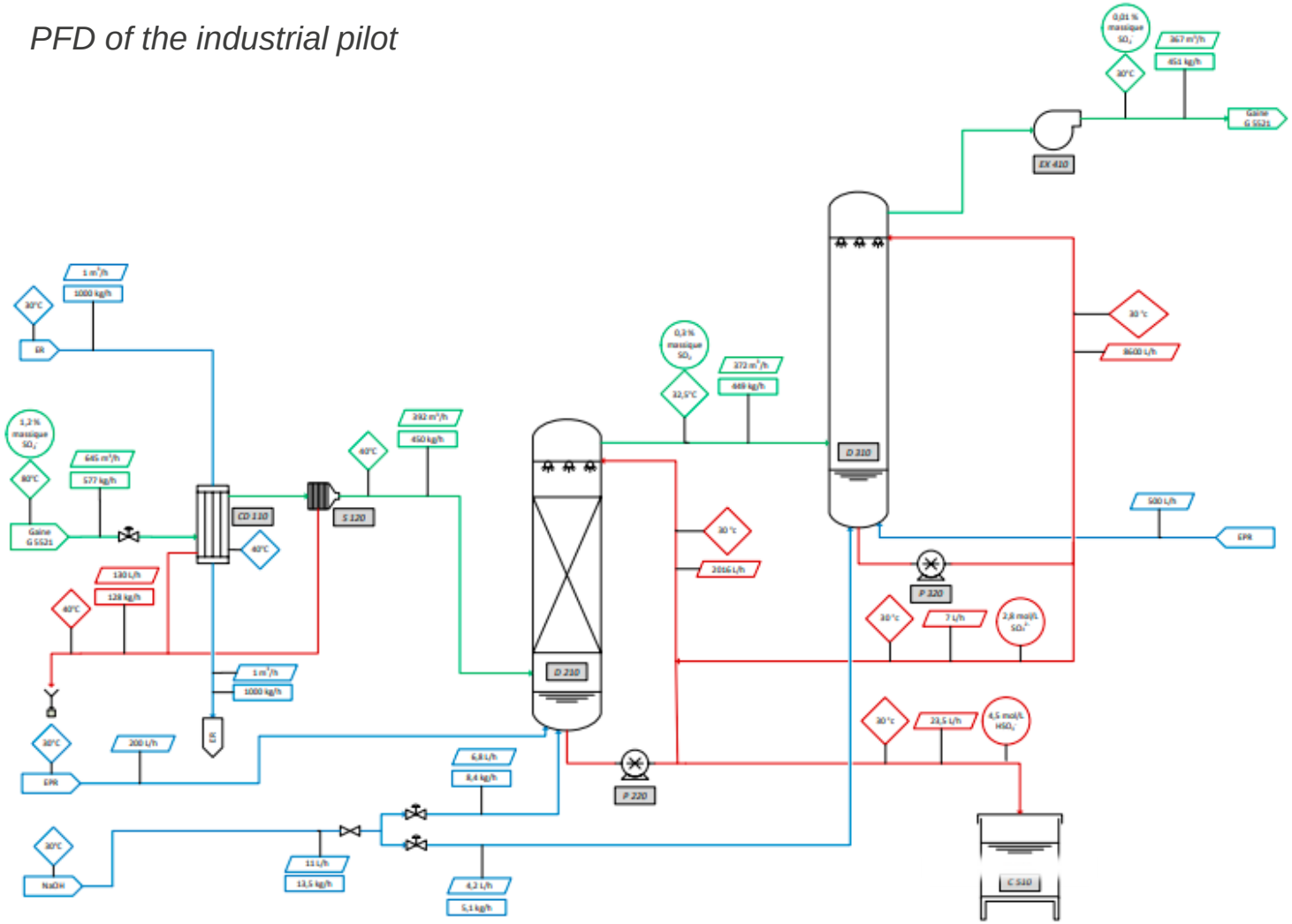
CS8: Sulphur recovery – The industrial pilot

PFD of the industrial pilot



Sizing: Achieved after several key steps :

→ Column sizing ;
→ Realization of the PFD and the mass balance ;
→ Realization of the PID.

Objective: Demonstrate the feasibility of the process under real conditions .

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

CS8: Sulphur recovery – The industrial pilot



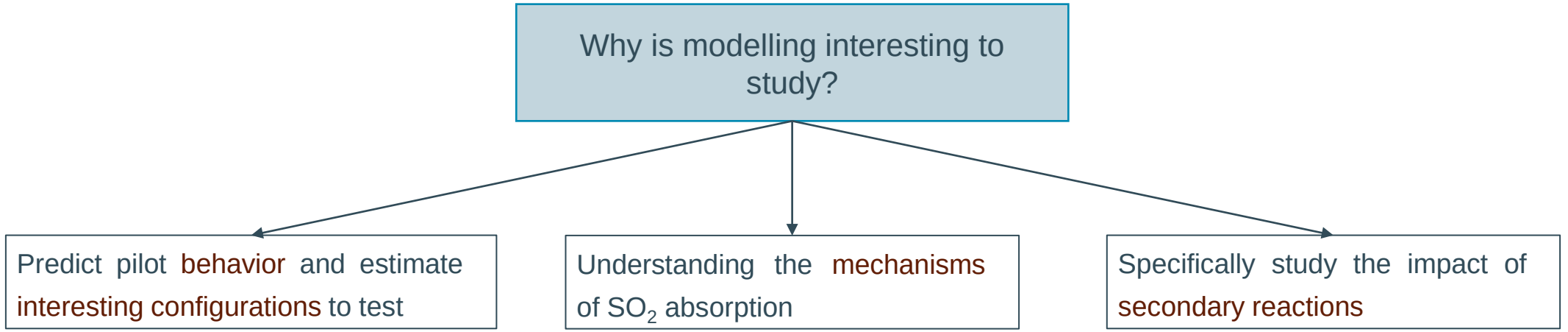


The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

CS8: Sulphur recovery - Modelling

Subtask: 1.4.7 Recovery of Sulphur and metals at the chemical platform of Roussillon

Objective: Create a model able to represent mathematically the industrial pilot



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CS8: Sulphur recovery

Subtask: 1.4.7 Recovery of Sulphur and metals at the chemical platform of Roussillon

Conclusion on the task of Sulphur recovery

Context :

SUEZ is committed to developing new recovery methods and sulfur resources are significant on the industrial site of Roussillon

→ It may be worthwhile to valorize them.

Consequences :

- Laboratory tests, beginning in 2021, have enabled the study of reactions and the impact of operating conditions:
  - The studied solution is a good absorbent and absorption yields are very high when ions are present in solution (pH > 6);
  - Liquid concentrations have no impact on absorption efficiency ;
  - Reducing the temperature would result in higher yields.
- An industrial pilot has been designed, the first tests have been carried out and data analysis is underway.
- A mathematical model representing the pilot is currently being developed.

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

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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

Material recovery & reuse in H2020 WIDER-UPTAKE, NL case study

Peter van Gilst (Waternet, NPSP)

ULTIMATE, CS meeting 22-11-2023

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869283. This presentation reflects only the author's view. The Commission is not responsible for any use that may be made of the information it contains.

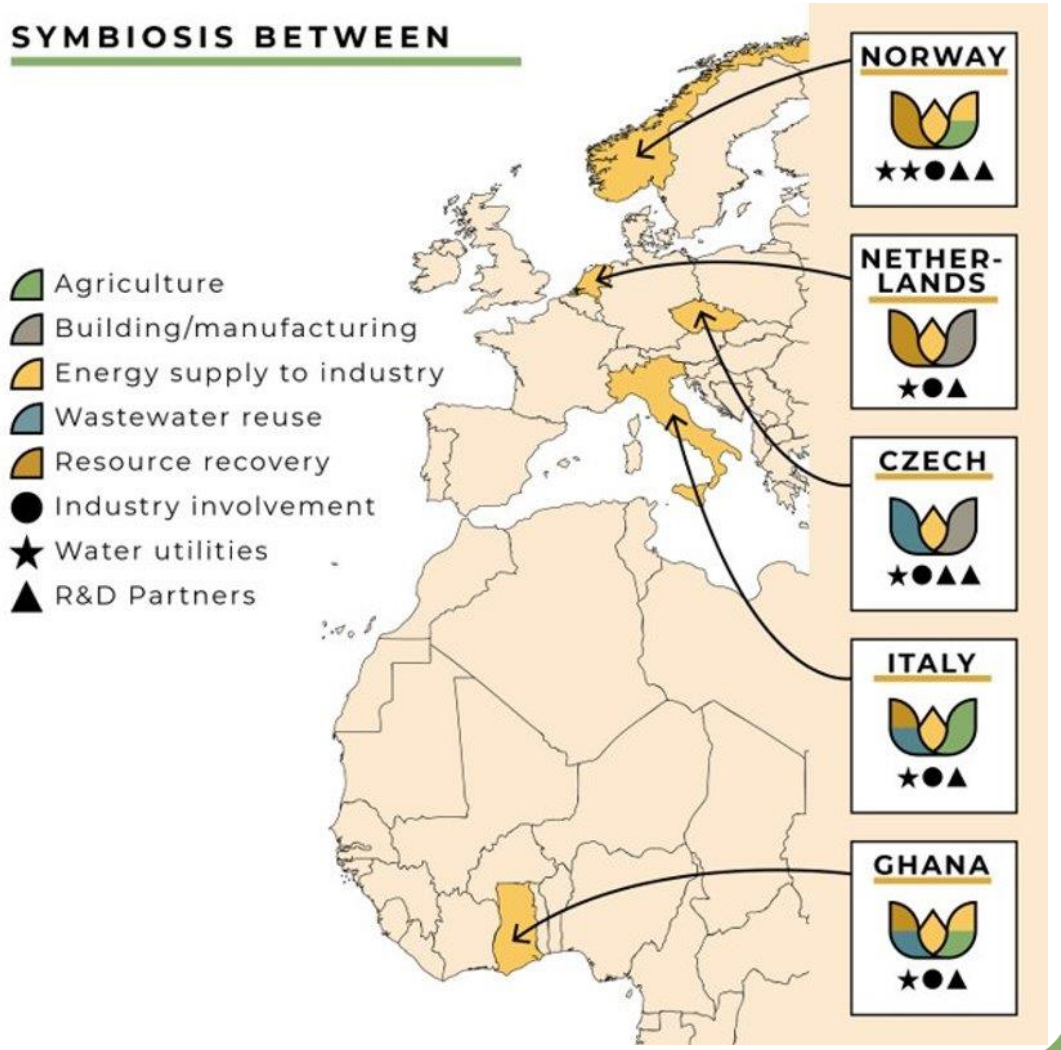
Classificatie: Intern

Wider Uptake of Water-Smart Solutions

Mission: Facilitation of the industrial symbiosis to increase resource efficiency, limit emissions and develop a sustainable business based on water-smart solutions, by overcoming barriers that are not only technological but also organizational, regulatory, social and economic.

Partners:

- 11 water utilities and industries
- 7 research institutes or universities:
- 5 Countries: Netherlands, Norway, Czechia, Italy, Ghana



www.wider-uptake.eu

linkedin.com/company/wideruptakeeu

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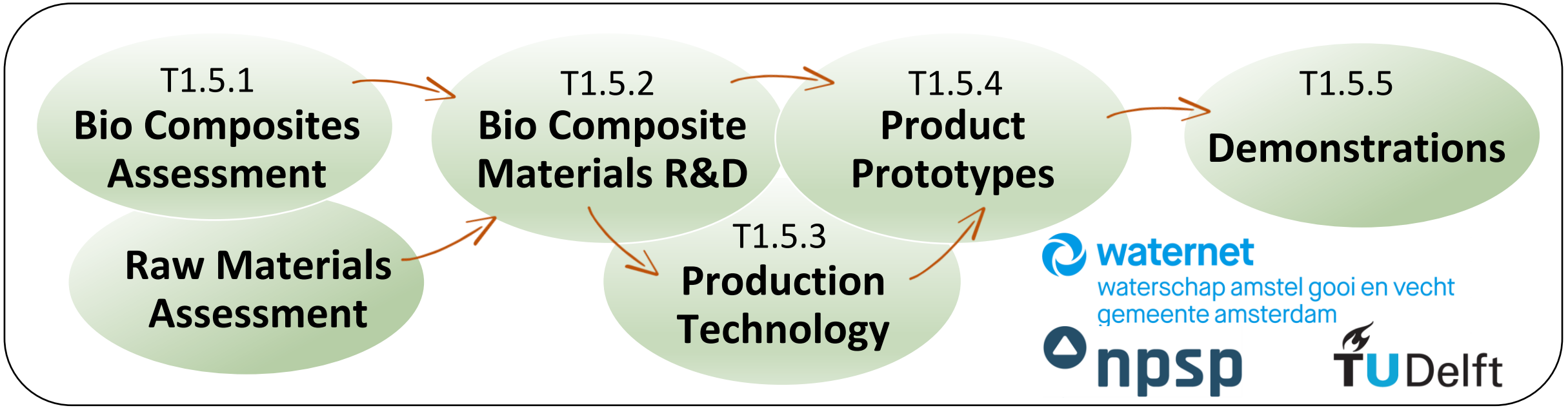
Classificatie: Intern

Wider Uptake NL case study

Production of biocomposite materials and prototype products from water embedded resources



…which demonstrates the upcycling of those resources to marketable products.

This is about the application of raw materials, not the recovery and production of the raw materials themselves.

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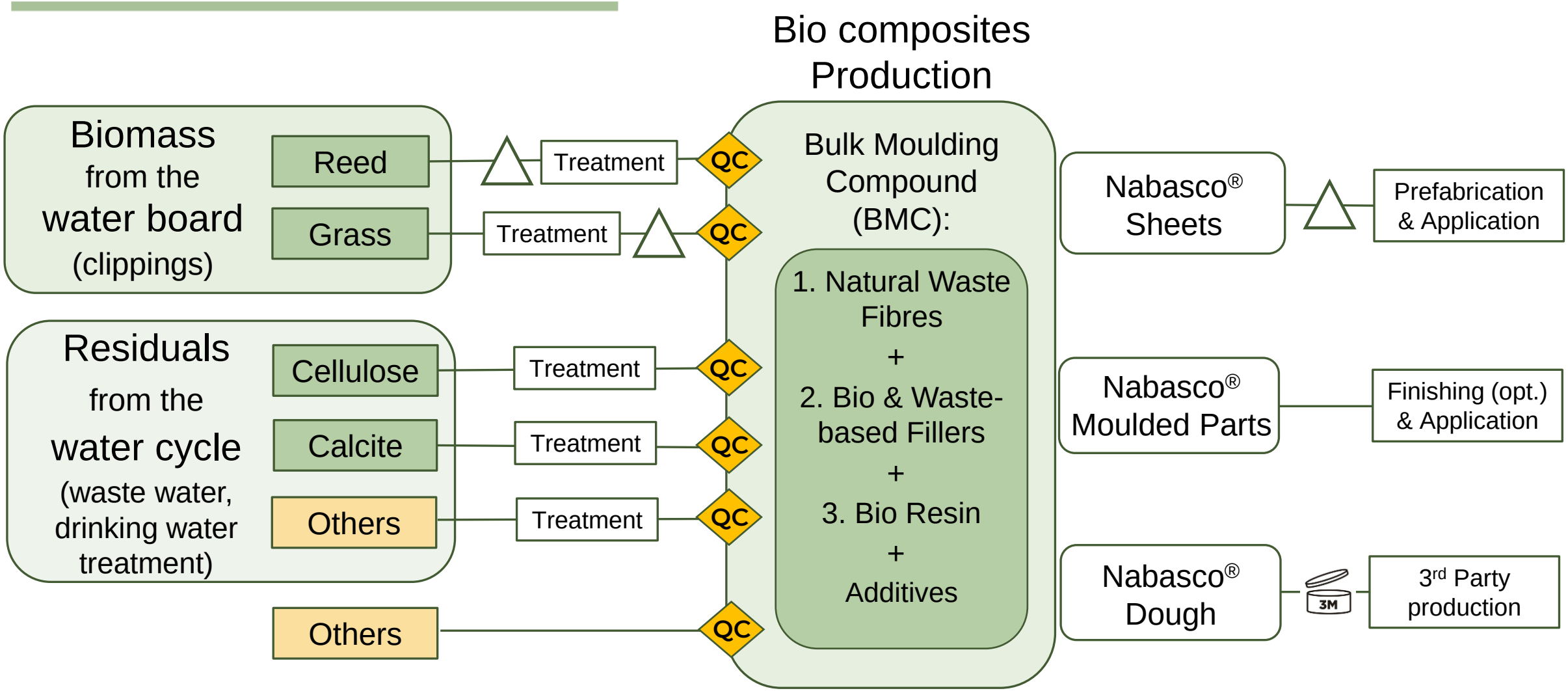
Classificatie: Intern

NL case study: from raw materials to biocomposites



Note: simplified “black box” view

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Classificatie: Intern

NL case study: summary overview

Biomass
- Reed ~~from water board~~
- Verge and dyke Grass

Waste Water treatment
- Cellulose from sewage
- Vivianite from WWTP
- Biochar from sewage

Drinking Water process
- Calcite from DW co's

Agricultural waste
- Bio-based resins
- Bio-based fillers*

*Discrete

N-8012
- Reed*
- Calcite DW
- ~50%-bio UPR

*Waste reed, originally harvested for roofing

N-8020
- Cellulose Sewage
- Calcite DW
- ~50%-bio UPR

N-8040
- Grass or Cellulose
- Bio filler(s)
- 100%-bio PFA resin

2D flat plates*
- Façade cladding
- Water level scales
- Weirs & baffles
- Information panels

*For processing (at present only N-8010, production options for the new materials being worked).

3D moulded parts
- Façade tiles and panels
- Bank protection elements (corr. sheets, pole caps)
- Traffic signs (base)
- Spherical lampshade

1. Façades

2. Bank protection

3. Construction material

4. Signing

5. Design products

Residuals → Raw Materials → Composite Materials → Composite Material Parts → Finished Products → Demo Applications

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Classificatie: Intern

NL case study demo examples: Façade cladding (1)

Making of facade panels for demo application at Waternet







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Classificatie: Intern

NL case study demo examples: Façade cladding (1)

Facade cladding (in progress) at Waternet pump station in A’dam Waterleidingduinen (water filtration area)





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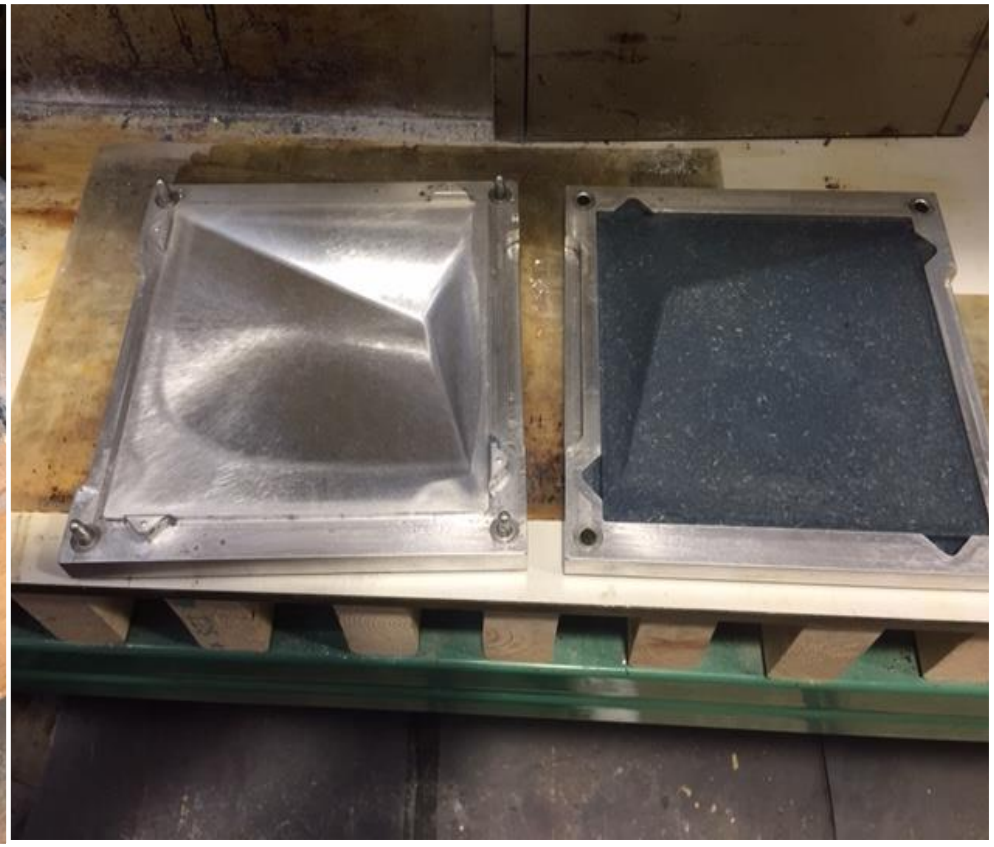
Classificatie: Intern

NL case study demo examples: Façade cladding (2)

Making of façade tiles for Exploded View Beyond Building (exhibition pavilion)







Exhibited at Dutch Design Week 2021, Floriade 2022 and Kamp C 2023.

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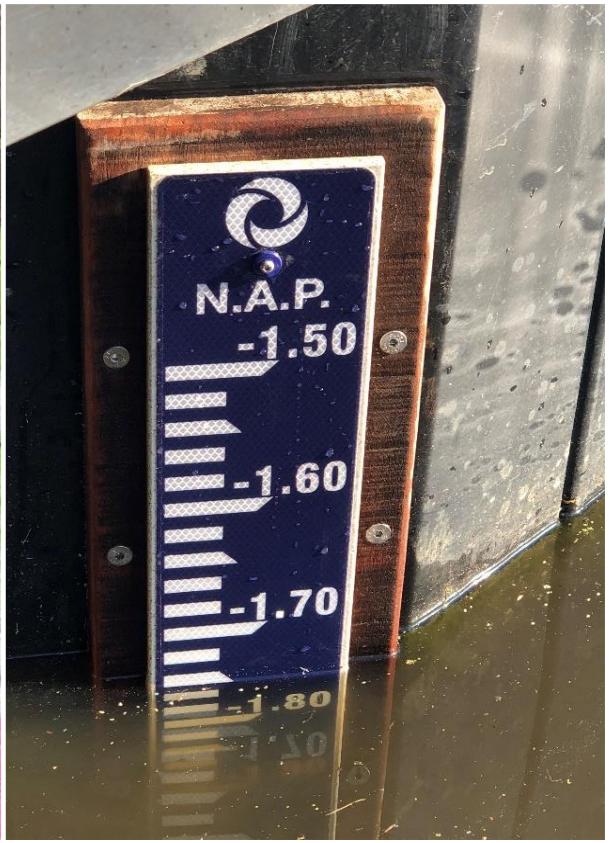
Classificatie: Intern

NL case study demo examples: Design, Signing

Spherical lampshade, nautical sign, water level scale







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Classificatie: Intern

NL case study demo examples: Traffic sign redesign

~100% bio and waste-based material, increasingly sustainable





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Classificatie: Intern

NL case study: requirements and challenges…

1. Raw materials requirements
   - Availability (test quantities, supply outlook)
   - Specifications (mechanical and chemical properties, processing and storage conditions)
   - Supply consistency (quality, economics)
   - Marketable (relevant data and declarations, not treated as mere waste)

Note:

- Natural and waste-based ingredients are not as pure as synthetic materials.
  - ➢ Varying properties and contaminations according to place of origin and seasonal influences; and for the natural fibres, weather conditions during growth and collection.
- Minimum processing and ordering volumes combined with best-before dates, can create barriers for scaling up new materials.
  - ➢ Impact on costs and therefore on competitiveness of the new materials.

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Classificatie: Intern

NL case study: requirements and challenges…

2. Bio composites requirements
   - Mechanical and esthetical fit for application (at all)
   - Competitive vs. alternatives (functional, cost effective; ECI & MCI)
   - Reproducible quality

Note:

- Bio and waste-based ingredients
  - ➢ Provide more hassle to produce with (potentially disruptive in continuous production)
  - ➢ May require investment and drive cost of inventory
- Bio and waste-based materials generally lag on physical properties and cost per equal weight
  - ➢ More material required to provide comparable performance
  - ➢ Suboptimal chain and cost efficiency (yet to scale)

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Classificatie: Intern

NL case study: requirements and challenges…

3. Policies & Regulations

- National implementations of Waste Directive
  - NL case law for clippings not applicable cross border
  - Process to declare Recell® as product, not waste, still going on
- True pricing may stimulate competitiveness of new sustainable materials
  - E.g. CO2 shadow pricing by Municipality of A'dam municipality and Province of Utrecht
- Sustainability performance valuations (ECI, MCI)
  - ➢ Are renewable bio-based materials fairly valued (CO2 sequestration in ECI, recycling promise in MCI)?

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Classificatie: Intern

Thank you for your attention!

Any questions?



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Water Europe Market Place reference
https://mp.watereurope.eu/d/CaseStudy/37

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Classificatie: Intern

WP3: Demonstration of renewable desalination and sustainable brine management

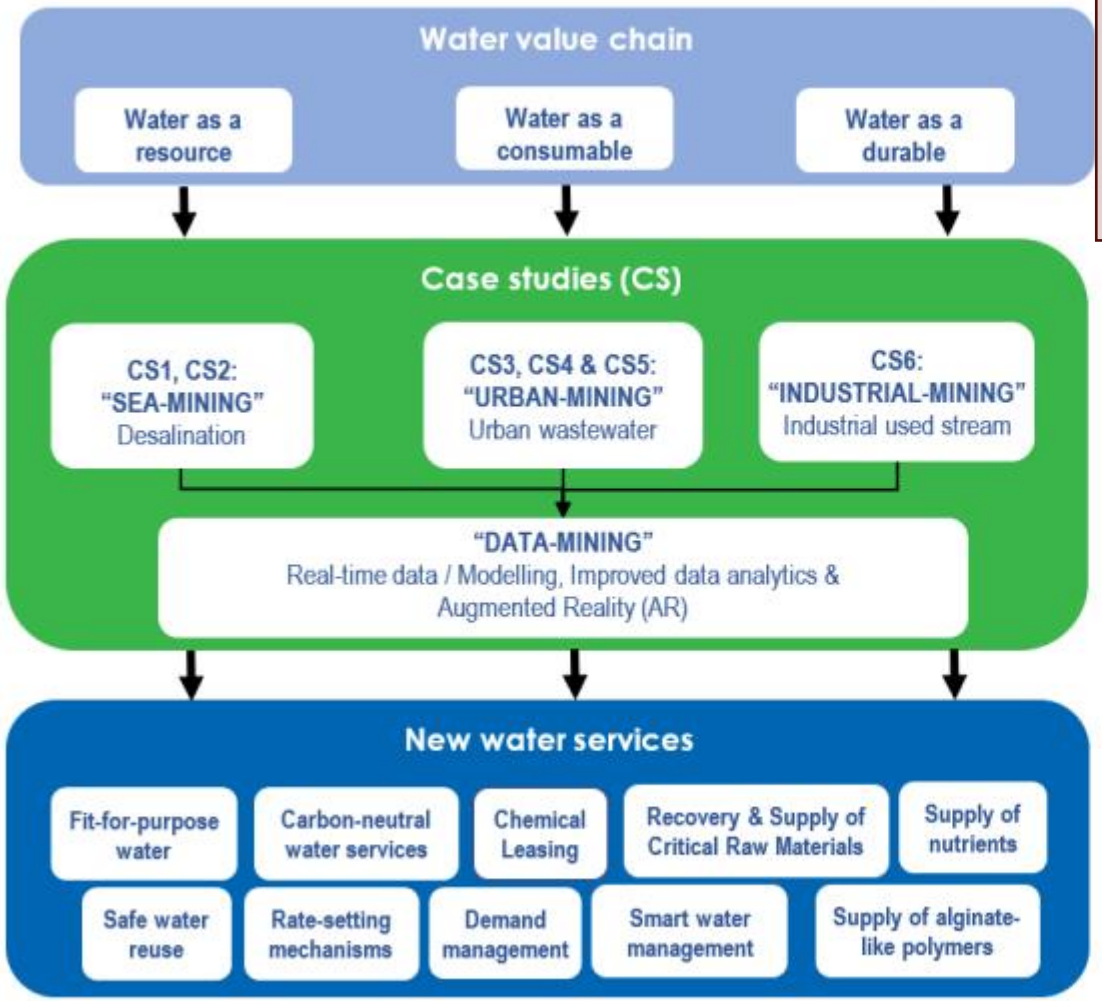
Materials recovery and reuse

Presenter: Rodoula Ktori, TU Delft

Email: r.ktori@tudelft.nl

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

Sea-Mining


Water value chain
Water as a resource
Water as a consumable
Water as a durable
Case studies (CS)
CS1, CS2: "SEA-MINING" Desalination
CS3, CS4 & CS5: "URBAN-MINING" Urban wastewater
CS6: "INDUSTRIAL-MINING" Industrial used stream
"DATA-MINING"
Real-time data / Modelling, Improved data analytics & Augmented Reality (AR)
New water services
Fit-for-purpose water
Carbon-neutral water services
Chemical Leasing
Recovery & Supply of Critical Raw Materials
Supply of nutrients
Safe water reuse
Rate-setting mechanisms
Demand management
Smart water management
Supply of alginate-like polymers

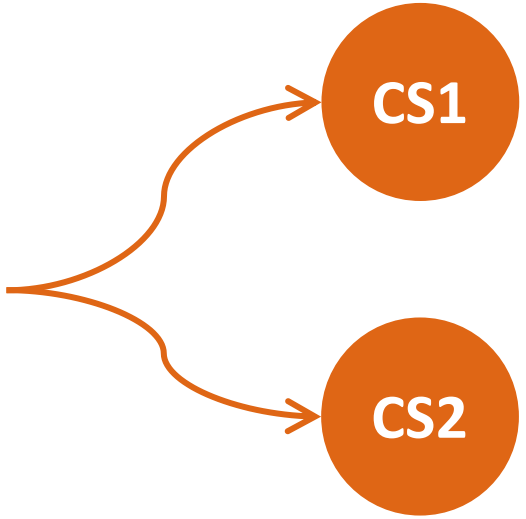

SEA-MINING
ITALY - see Table 3
SPAIN, see Table 4


URBAN-MINING
NETHERLANDS – see Table 5
PORTUGAL – see Table 5
CYPRUS – see Table 6
SPAIN – see Table 7


INDUSTRIAL-MINING
NETHERLANDS – see Table 8
INDIA – see Table 8

Overview – **Partners & Case studies**

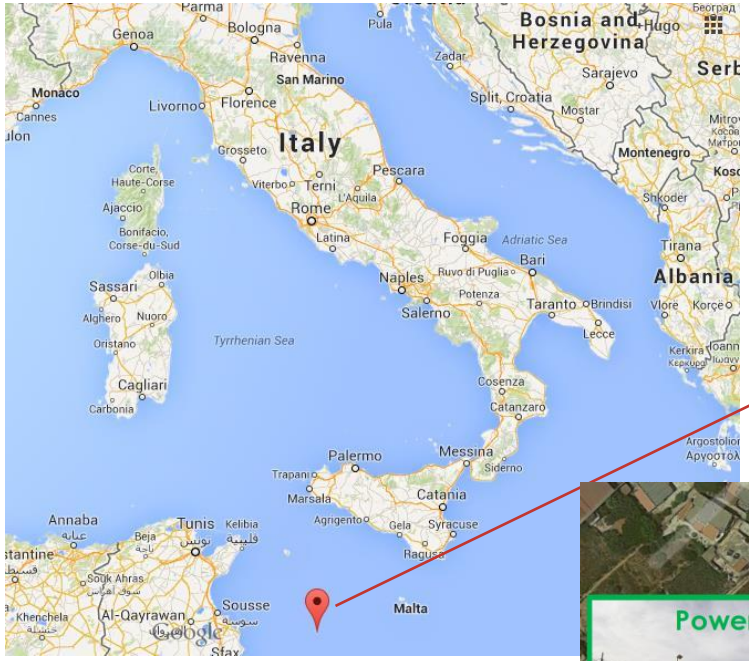
"Demonstration of renewable desalination and sustainable brine management "



General overview

- **Objective**: Demonstrate the compelling advantages of advanced desalination combined with renewable energy (solar) and waste heat, while contributing to energy savings through softening pre-treatment, and improved water and other value added resource recovery
- **Targets/KPIs:**
  - 50% of energy requirements will be covered by renewable energy and waste heat,
  - reduction in energy consumption by 10%,
  - double water recovery to at least 80%,
  - magnesium purity > 90%, sodium chloride purity > 90%

Case study 1: Installation and demonstration of Seawater treatment chain in Lampedusa, Italy

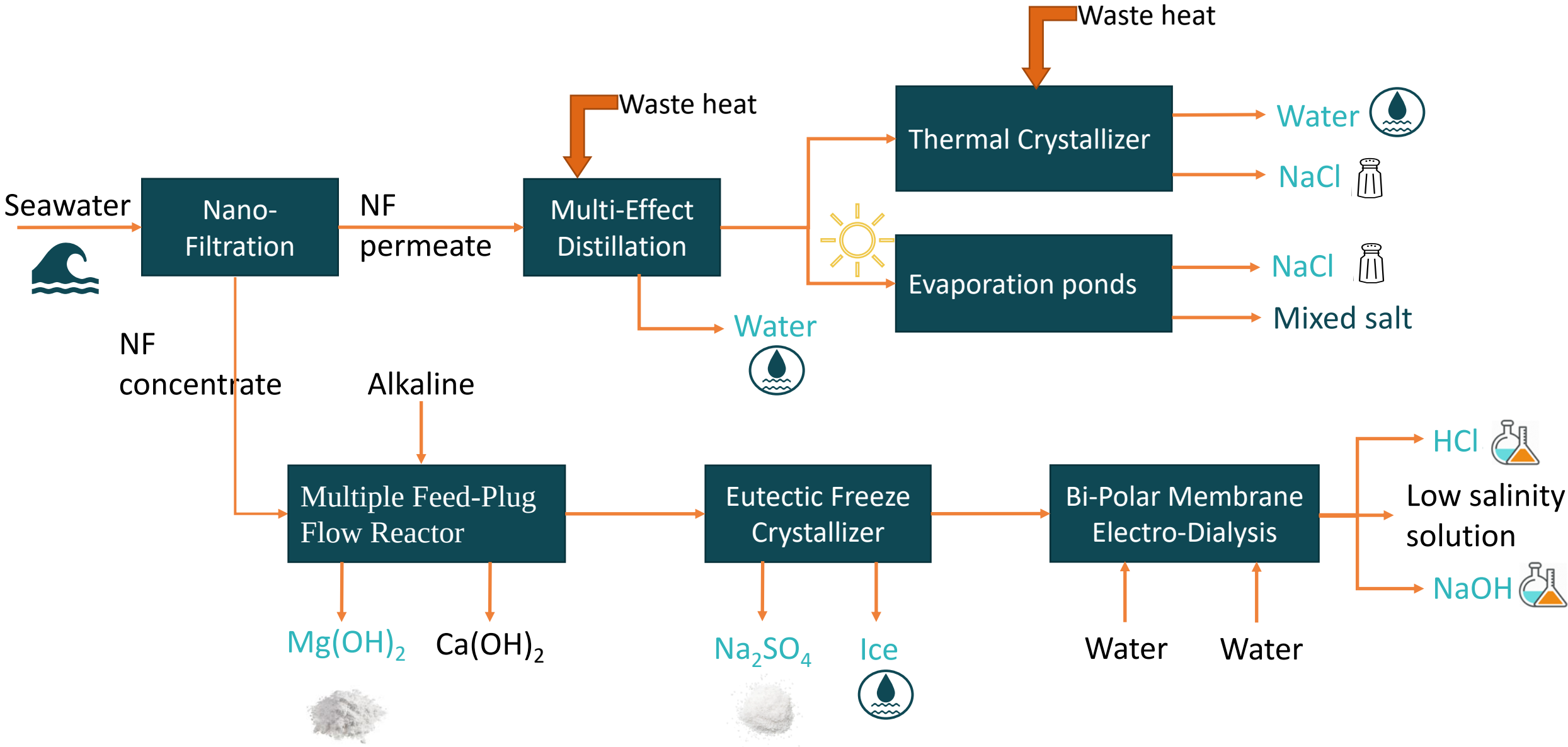




Desalination plant covers 100% of the total drinking water needs of the island.
The energy consumption of the desalination sector accounts for approx. 10% of the total energy consumption



Case study 1: Sea-mining in Lampedusa





Thank you!

CS3: Faro/Olhão Nereda® WWTP
Kaumera results overview

Philipp Wilfert, TU Delft

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

I. Introduction

II. Kaumera activities in WaterMining
- Kaumera Pilot results

III. Outlook

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

I. Introduction

- Águas do Algarve S.A. is the partner owning the case study
-
- Expectations on Water Mining
  - High value products from the sludge with local use
  - Changing mindset: WWTP as resource factories
  - Involve stakeholders

I. Introduction

Faro/Olhão WWTP:

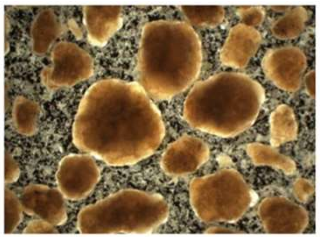
- Population equivalent **113.200 p.e.**
- Urban Wastewater



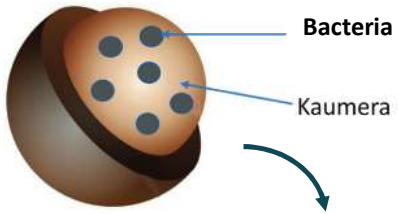


Aerobic granular sludge (Nereda®):

- ✓ < area; < energy consumption
- ✓ Granules with bacterial Exopolysaccharides (EPS) = biopolymer
  - ➢ e.g., use on agricultural soils (**biostimulant; water absorbent**; coating binder)
  - ➢ Binder in composits, flame retardant



Aerobic granular sludge



Granule

kaumera



water mining

KAUMERA prototype











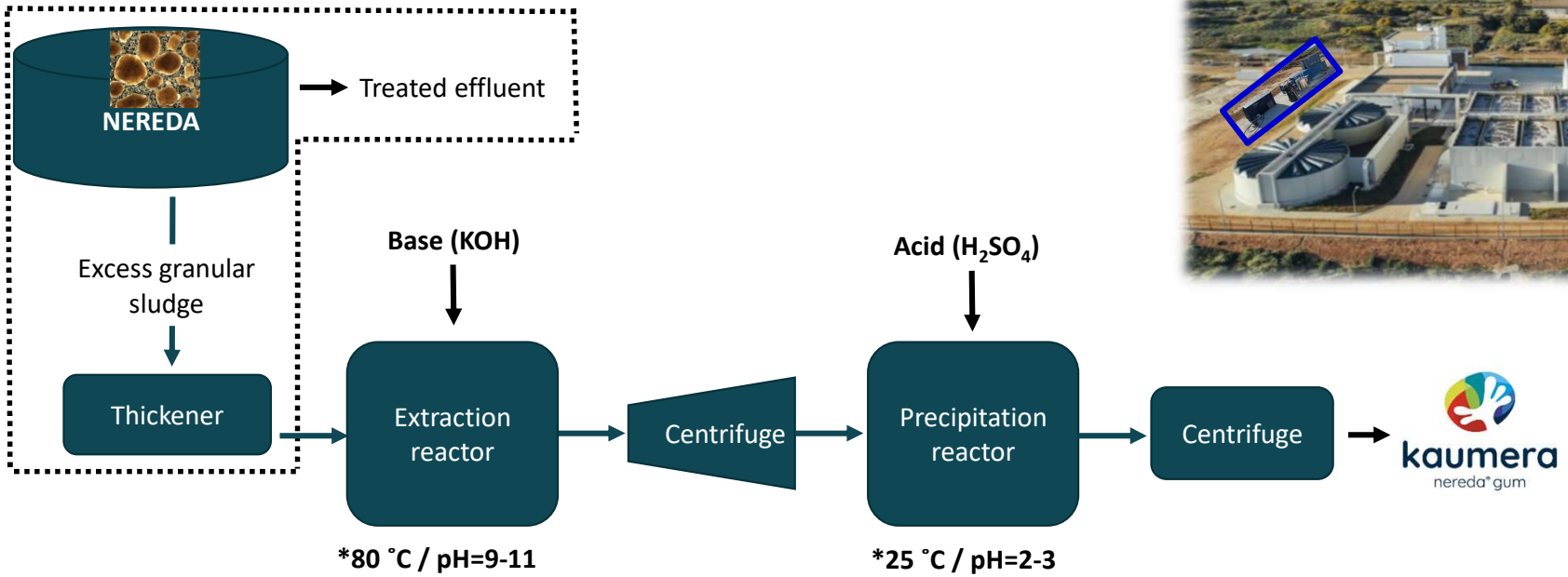


Roadshow:

- Varying Wastewater
- Data collection (upscaling)
- Bring to the stakeholders
- Engage stakeholders

KAUMERA prototype





water mining

produce VALUABLE POLYMER out of WASTE

KAUMERA prototype at the Faro/Olhão WWTP

- September 22: assembly, testing and start-up of the prototype
- October – December 2022: optimization and operation of the prototype





KAUMERA prototype at the Faro/Olhão WWTP

- Operation smooth
- Kaumera yield was very good,



KAUMERA prototype results:

- **Composition (NL vs. Pt)**
  - Proteins: more in Pt
  - Sugars: more in NL

KAUMERA prototype results:

Indication: Faro with higher yield but lower yield stress

KAUMERA prototype results NL vs Pt

- **There are differences!**

- **Relate to applications?**
  - Coating for seeds -> yield stress
  - **Water absorption**
  - **Biostimulation**
  - Flame retardancy
  - Composite material



Summary



- **Trials / Pilot projects for use of kaumera – the product must adapt to customer needs and not the other way around (e.g., fertigation)**
  - **Binder and biostimulant**
  - **Water absorption**
- **Develop Kaumera market (technology is there!)**
- **Go on with WaterMining approach: e.g., Circularity, Social, Environment, Sustainability LCA findings**

Philipp Wilfert







water mining

ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

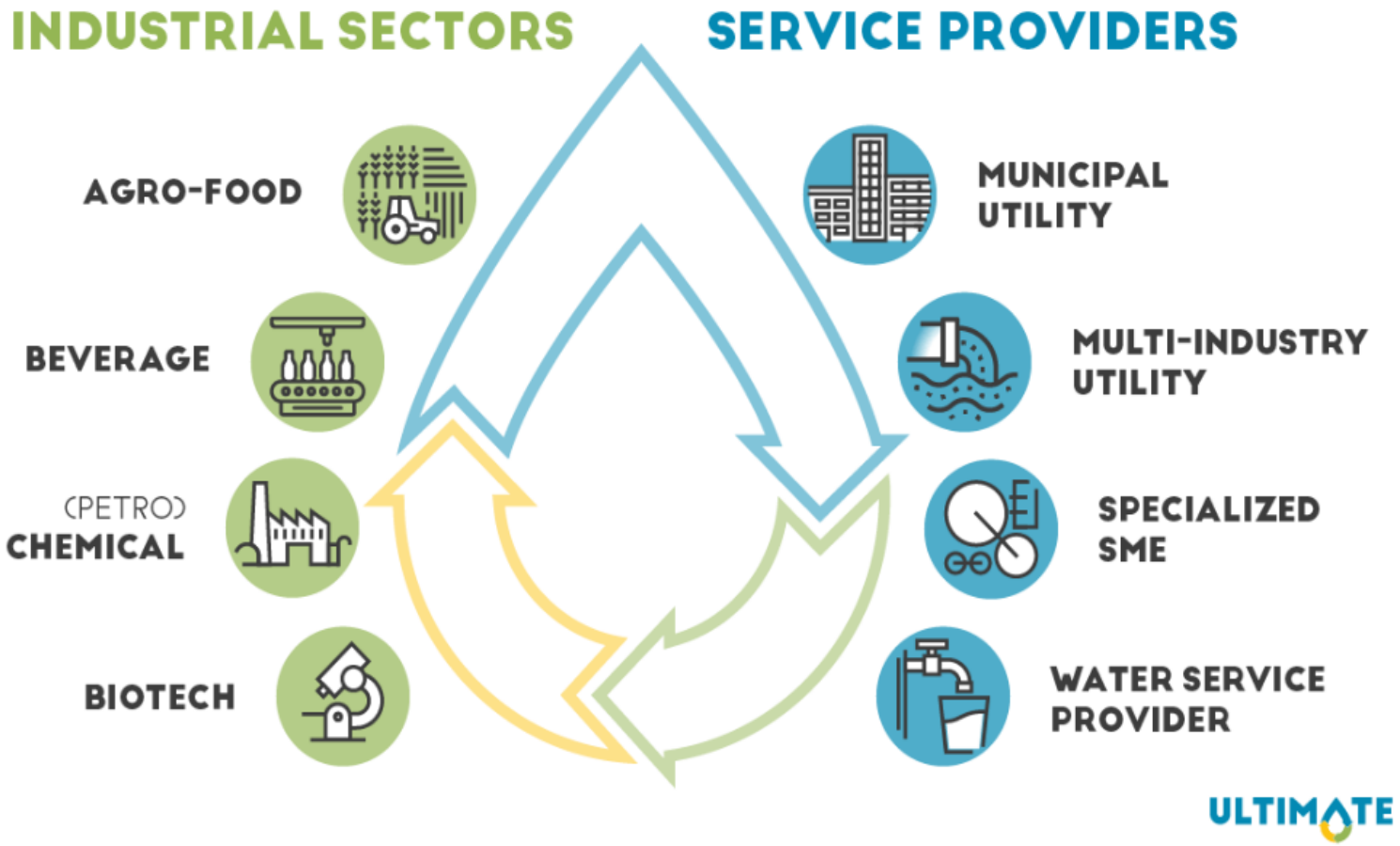
Industry water utility symbiosis for a smarter water society: webinar on digitisation/monitoring

A. Kleyböcker, C. Bruni and A. Naves Arnaldos



Sept. 26th 2023

WATER SMART INDUSTRIAL 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

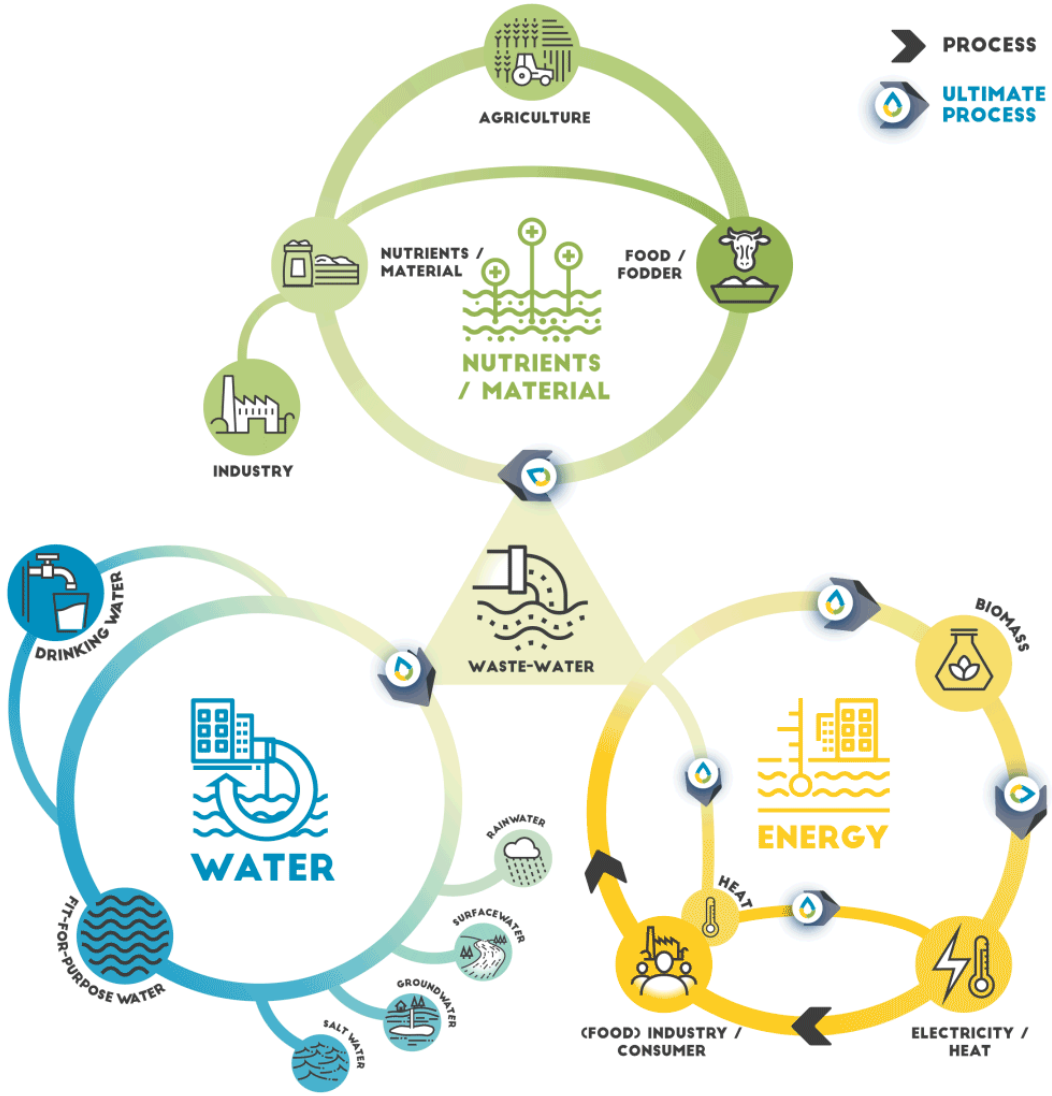
Coordinator: KWR

9 Case Studies



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



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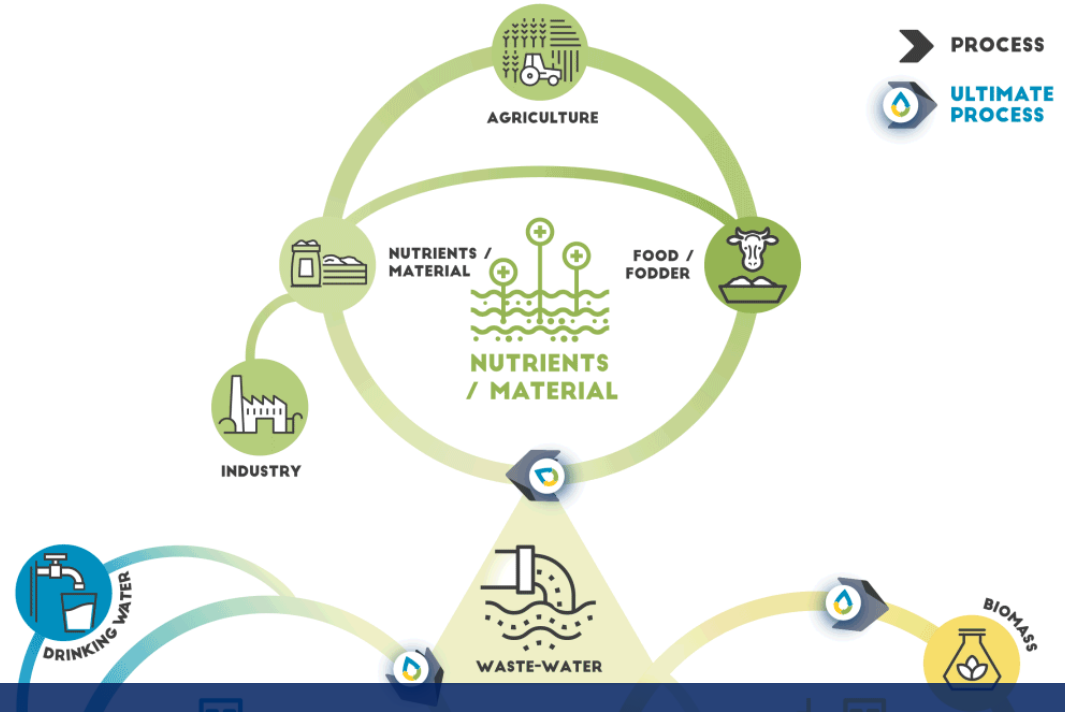
Ultimate solutions involve circular economy technologies



- Membrane technologies
- Adsorption technologies
- Electrostimulated systems

- 24 pilot plants
- 4 control and/or early warning systems
- 6 concept studies

- 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

Water recovery:
9 of 9 pilot plants are operational

Membrane technologies

- Reverse osmosis (RO) + membrane distillation
- Novel ultrafiltration membrane (UF) + RO
- Nanofiltration (NF) + RO
- Small bioreactor platform (SBP)
- Anaerobic membrane bioreactor + RO

Adsorption technologies

- Zeolite column for NH_4 removal
- Recovery of polyphenols/antioxidants

Other systems

- Electrodialysis for removal of salts
- Advanced oxidation processes



Material recovery:
8 of 10 pilot plants are operational

Nutrients/materials:
- Ammonium and phosphate rich water
- Ammonium sulphate
- Struvite
- Sulphur

High added-value products:
- Antioxidants
- Polyphenols

Reuse of byproducts as/for:
- Adsorption material
- Clari-flocculant
- Advanced oxidation processes
- Thermal carbonisation to produce adsorbents

Electrodialysis



Adsorption system using byproducts



Adsorption of antioxidants



Adsorption of polyphenols



$(NH_4)_2SO_4$ production



Struvite production



Energy recovery:
6 of 7 pilot plants are operational

Biogas production technologies

- Anaerobic membrane bioreactor (AnMBR)
- Electrostimulated anaerobic reactor (ELSAR)
- Immobilised high rate anaerobic reactor (AAT)
- AAT combined with AnMBR and PAC

Biogas valorization

- Solid oxide fuel cell

Heat recovery system

- from AnMBR effluent

AAT



AnMBR



ELSAR



SOFC



AAT + AnMBR



Digitisation: monitoring/control systems

Monitoring and matchmaking system
- to avoid high chloride concentrations in reclaimed water

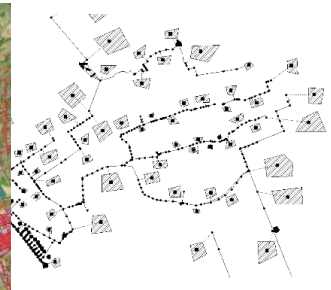
Early warning and monitoring system
- for membrane fouling in anaerobic reactors

Joint control system for two wastewater treatment plants

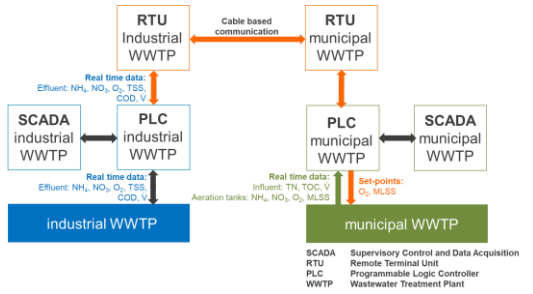
Monitoring & matchmaking system

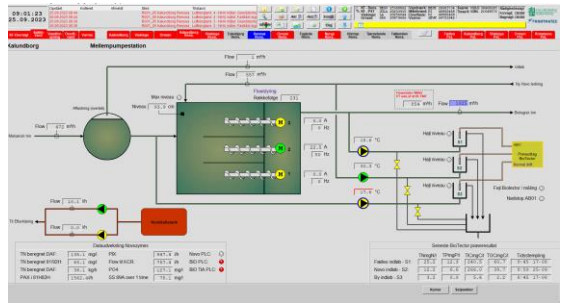






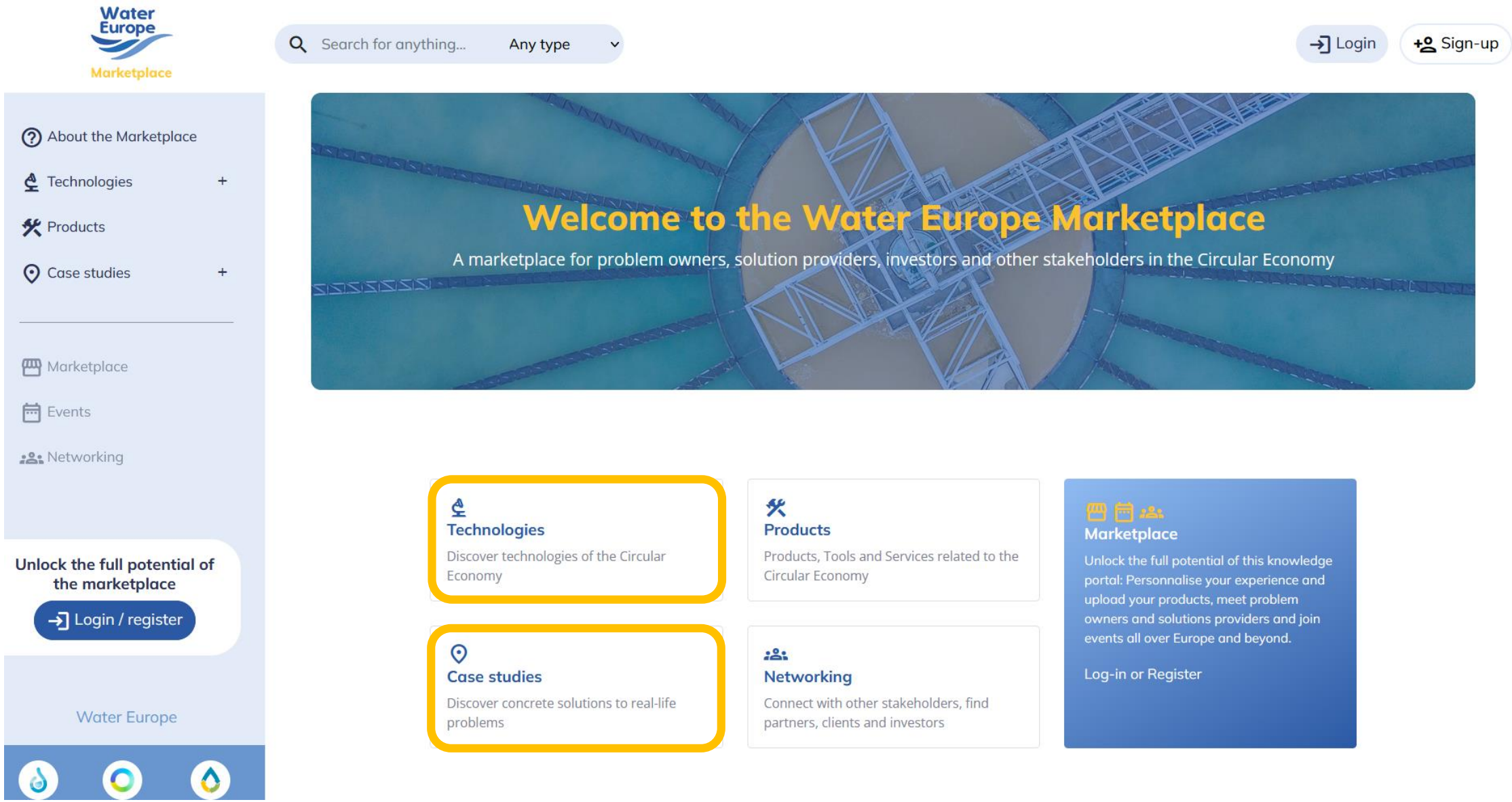
Joint control system





Water Europe Marketplace: Technology Evidence Base

https://mp.watereurope.eu



ULTIMATE technology factsheets

→ 14 factsheets: online

→ 5 factsheets: under review

→ 2 factsheets until Nov. 23



Adsorption with sludge-based renewable adsorbents



Ammonium sulphate production (air stripping & scrubbing)



Anaerobic Membrane Bioreactor (AnMBR) with degassing unit



Immobilised high rate anaerobic reactor



Aquifer Thermal Energy Storage



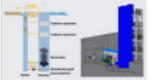
Electrodialysis



Sulphur Recovery



Joint control system for two wastewater treatment plants



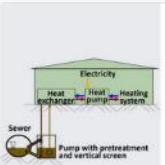
Electrostimulated anaerobic reactor



Membrane distillation



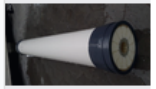
Softening, coagulation and flocculation with alternative by-products



Low grade heat recovery from wastewater



Solid oxide fuel cell using biogas

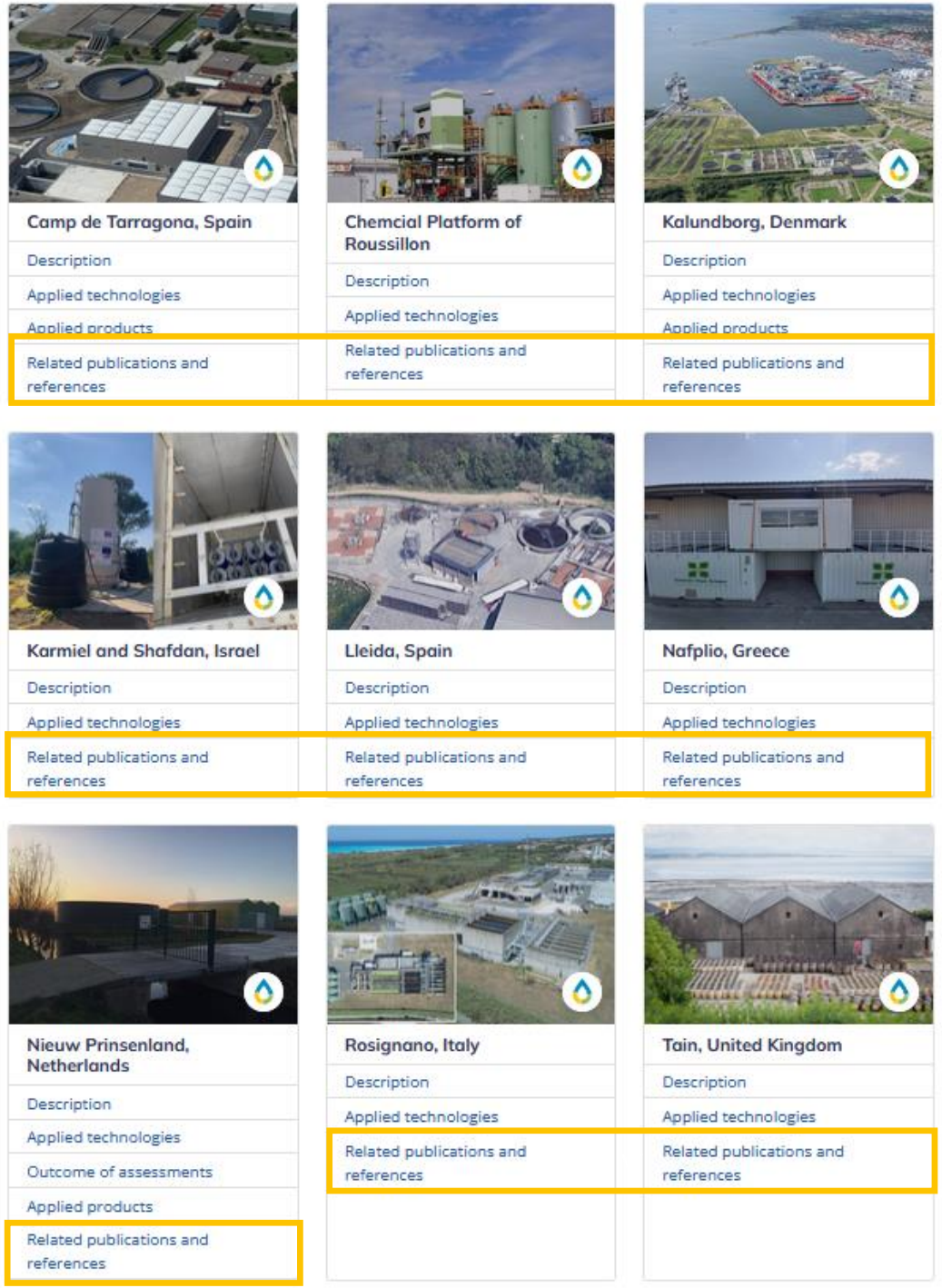


Ultrafiltration & nanofiltration membranes as pre-treatment for reverse osmosis

Case study factsheets

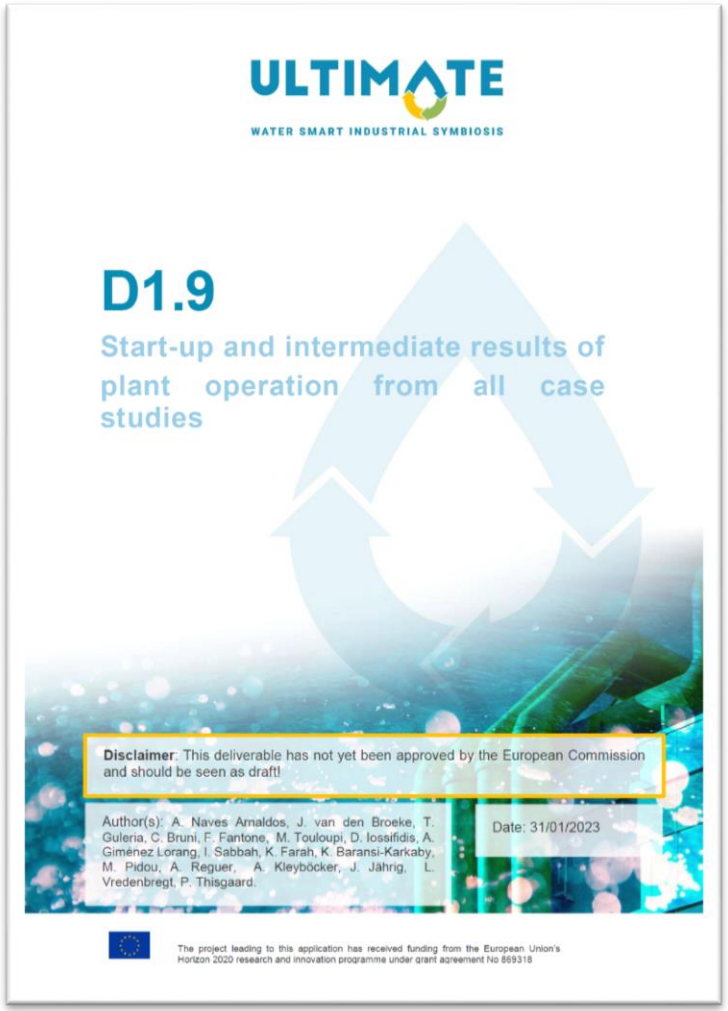
→ 9 CS factsheets

→ Deliverables/results accessible



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

Report about pilot plants (Jan. 2023)



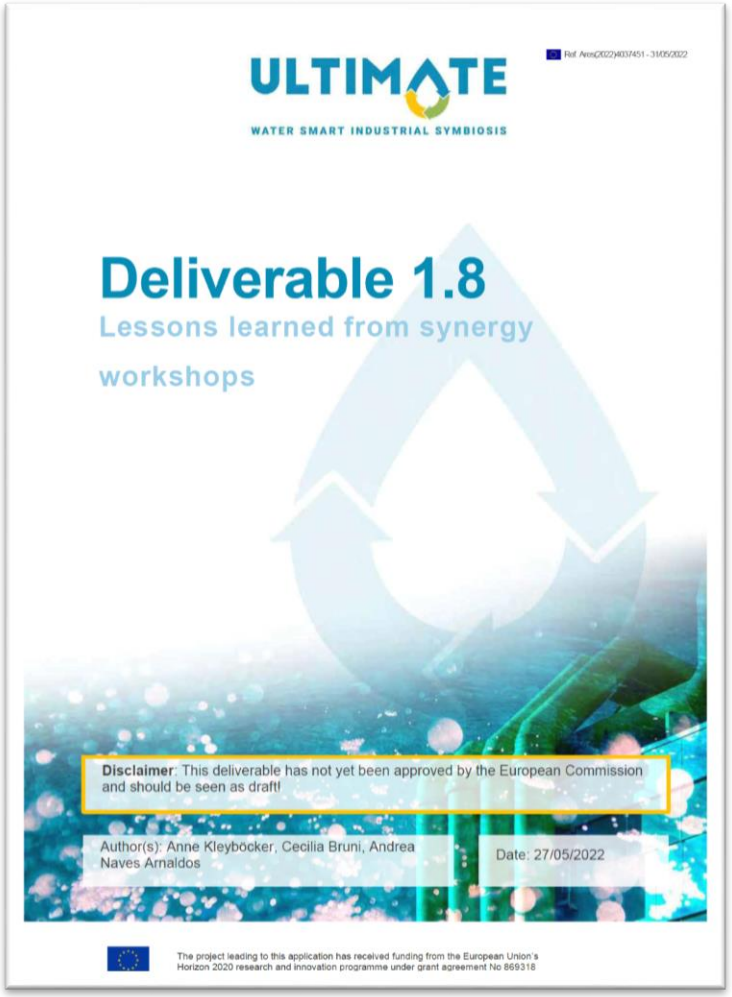
- **Start-up of pilot plants**
- **Intermediate results**

→ Accessible at:

https://ultimatewater.eu/results/

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

Report about synergy workshops (May 2022)



- Membrane & adsorption technologies
- Biogas& heat recovery systems
- Material & nutrient recovery systems
- Digitalisation
- Secret of sucessful symbioses

→ Accessible at:

https://ultimatewater.eu/results/

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Agenda

13:10	**CS3 Rosignano**: Early warning and match-making system to reduce high chlorine concentrations in fit-for-purpose water *Cecilia Bruni (UNIVPM)*
13:30	**CS5 Lleida**: Early warning and monitoring system for membrane fouling *Ángel Robles (UV/UPV)*
13:50	**Short break**
14:00	**CS9 Kalundborg**: Joint control system for an industrial and a municipal wastewater treatment plant *Jan Schütz (KWB)*
14:20	**B-WaterSmart**: Short-term water demand forecast tool in city districts and matchmaking tool for available water qualities *Katharina Gimbel & Marcel Juschak (IWW Zentrum Wasser)*
14:40	**Discussion**
15:00	**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. Based in the recording, we will prepare detailed minutes of the meeting including all the questions of the participants and our answers.

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ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

Early warning and match-making system to reduce high chlorine concentrations in fit-for-purpose water.

C. Bruni, N. Ciuccoli, D. Settesoldi, C. Palermo, F. Fatone



September, 26th 2023.

ARETUSA urban-industrial symbiotic system

ASA
WWRP Operator

TERMOMECCANICA ECOLOGIA
Tech provider

45%

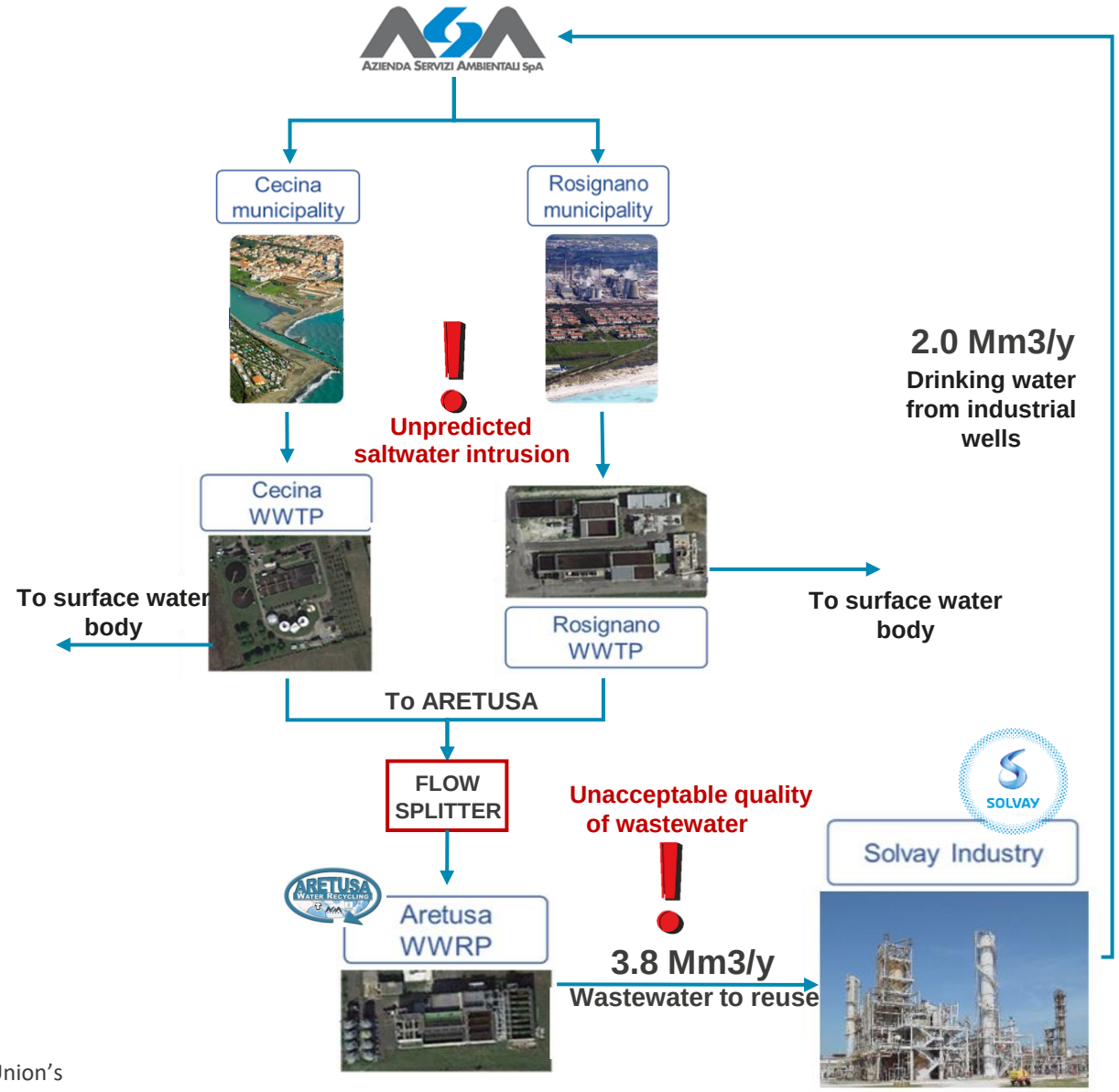
45%

ARETUSA
Consortium

10%

SOLVAY CHIMICA ITALIA
User of the recycled water





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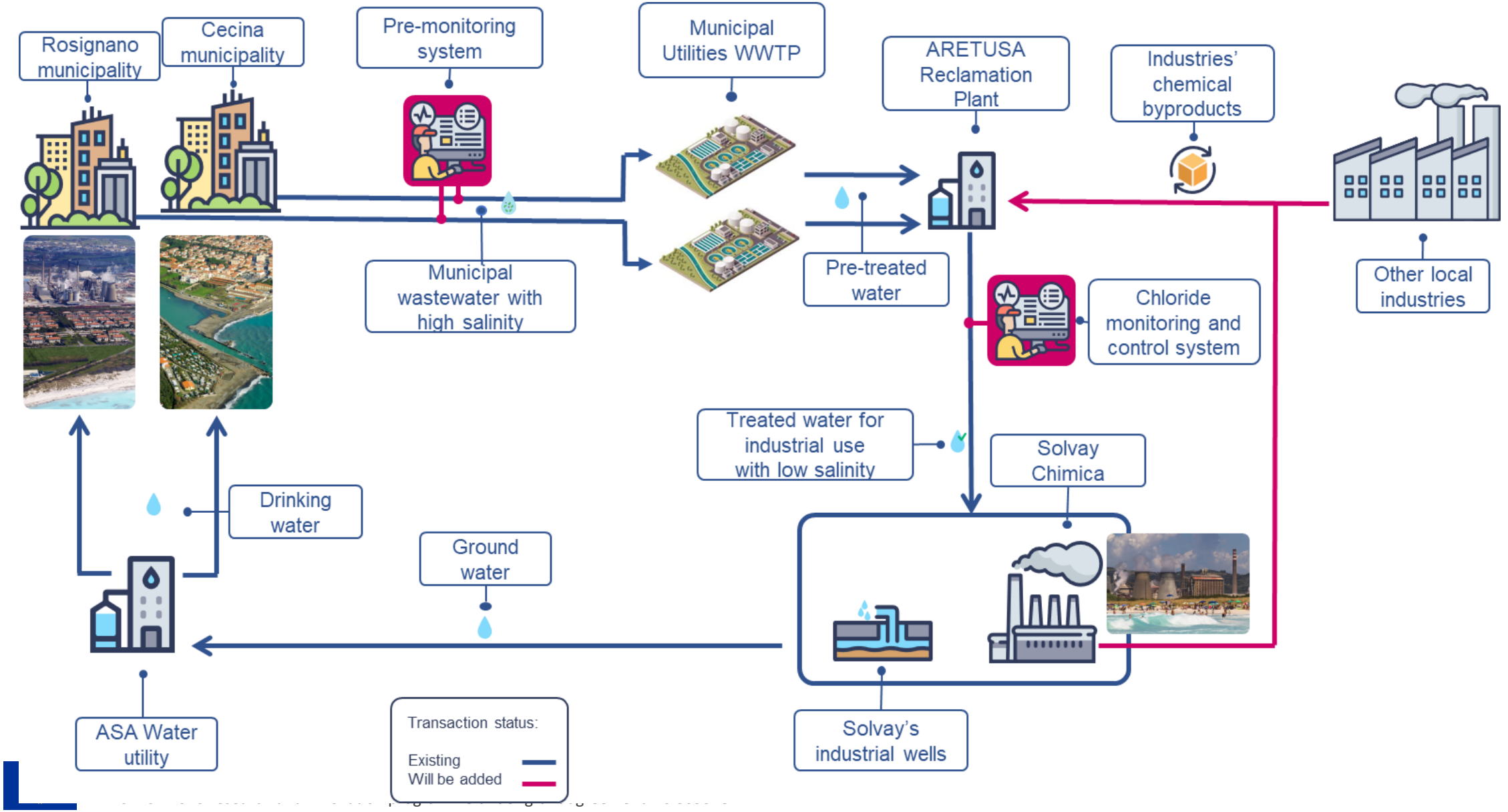
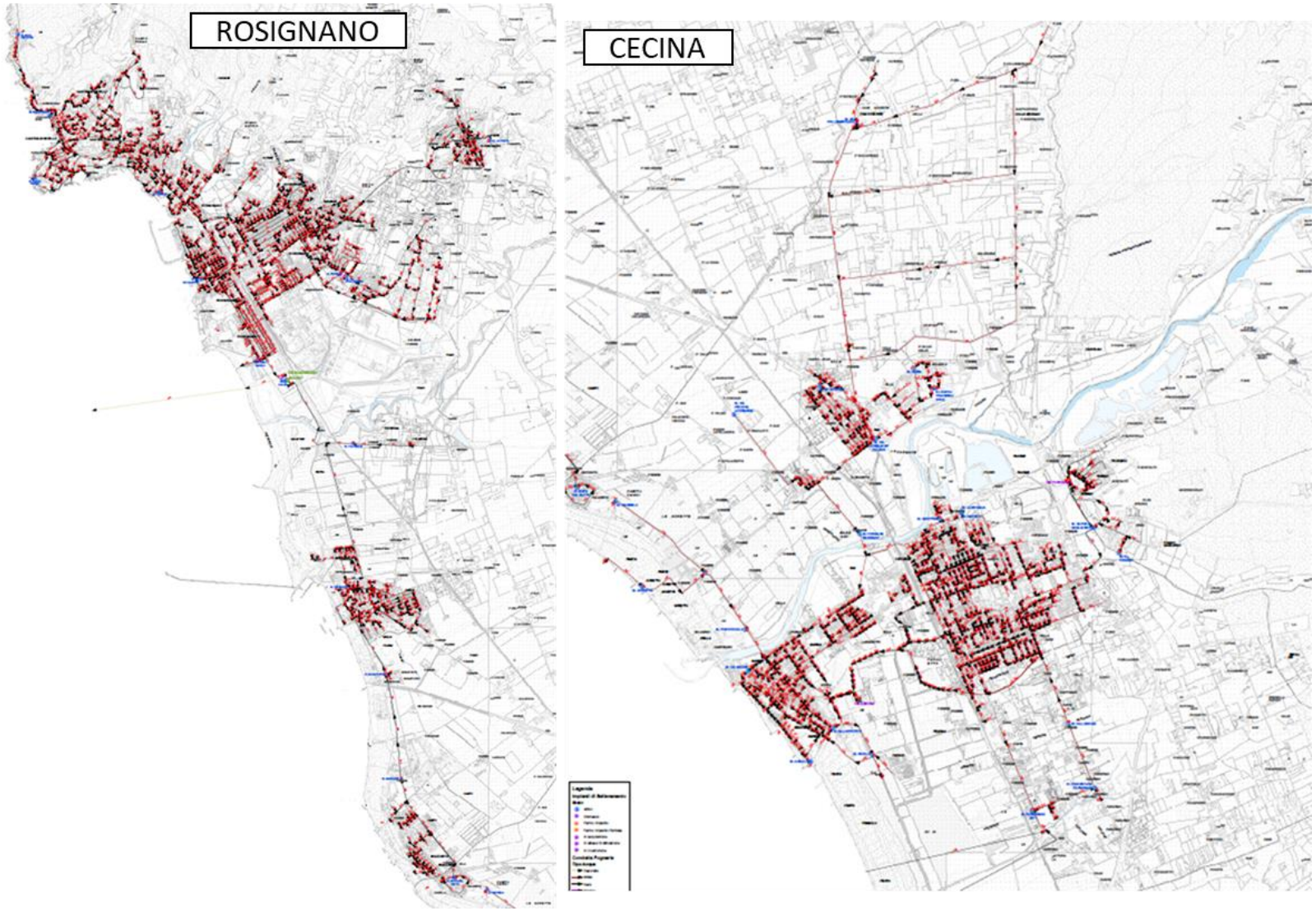
ARETUSA urban-industrial symbiotic system



Modelisation of the sewer network



- ✓ Geometric information
- ✓ Pumping stations
- ✓ Sampling campaign
- ✓ Flowmeters and conductivity meters
- ✓ Sanitary flow
- ✓ Rainfall data
- ✓ Calibration at wastewater treatment plant

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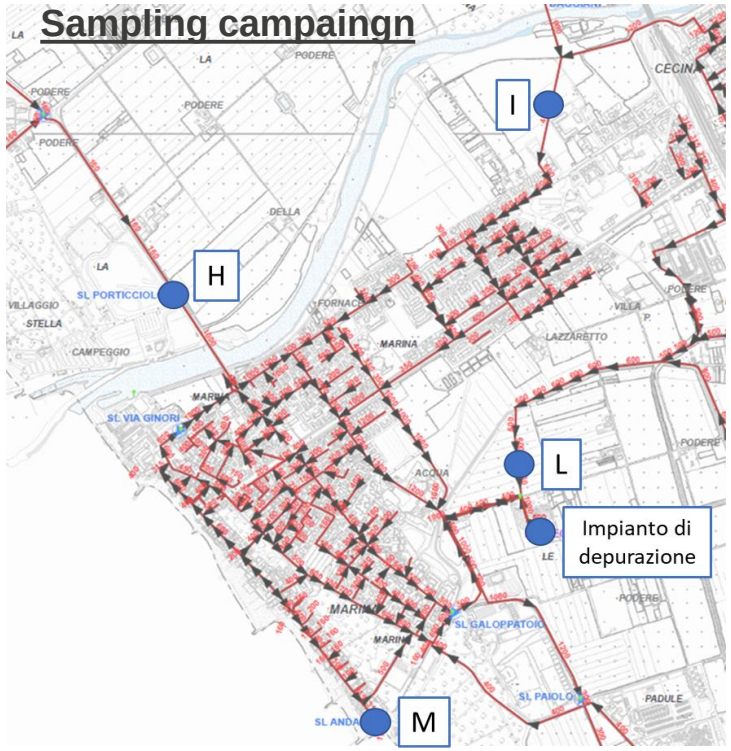
Modelisation of the sewer network

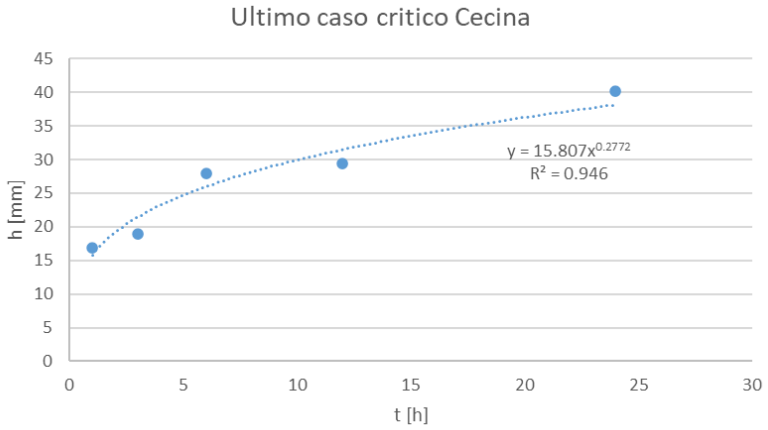
Sampling campaingn

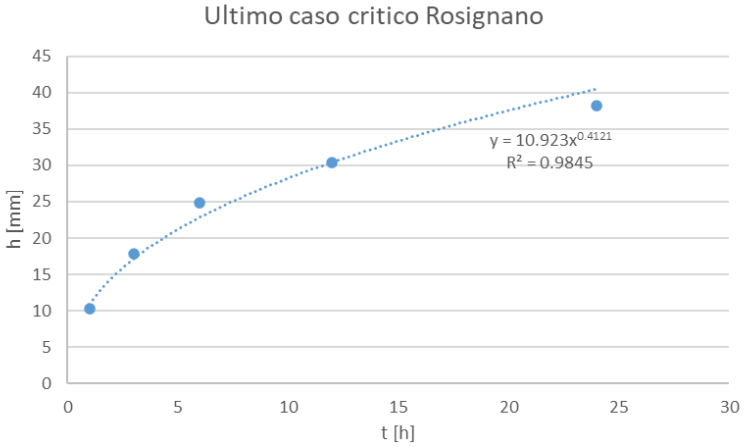


Punti campionamento Cecina		H	I	L	M	IN	OUT
Conducibilità	µS/cm	1824	1617 ± 563	1754 ± 718	2152 ± 926	2258 ± 304	1920 ± 313
pH		6.3	6 ± 0.2	6 ± 0.2	6.1 ± 0.4	6.6 ± 1	6.8 ± 0.9
COD	mg/l	356	88 ± 122	220 ± 142	33 ± 33	194 ± 88	20 ± 7
N-NH4	mg/l	59 ± 25	17 ± 18	41 ± 13	24 ± 25	31 ± 9	4 ± 2
TSS	mg/l	84	72 ± 106	67 ± 67	14 ± 15	74 ± 55	5 ± 4
Cloruri	mg/l	308 ± 5	321 ± 133	373 ± 91	534 ± 233	446 ± 85	416 ± 99
N-NO3	mg/l	0.46 ± 0.49	0.85 ± 0.23	0.09 ±	1.96 ± 2.07	0.64 ± 0.44	7.39 ± 1.47
PO4	mg/l	12	5 ± 5	9 ± 4	6 ± 4	11 ± 6	6 ± 4
SO4	mg/l	127	102 ± 18	75 ± 21	182 ± 247	101 ± 32	115 ± 20
Na	mg/l	202 ± 4	176 ± 50	223 ± 50	309 ± 124	256 ± 41	256 ± 52
K	mg/l	17	9 ± 3	51 ±	16 ± 7	17 ± 3	18 ± 3
Ca	mg/l	96 ± 12	121 ± 17	113 ± 10	111 ± 28	137 ± 23	143 ± 26
Mg	mg/l	51	56 ± 10	47 ± 7	48 ± 18	54 ± 8	57 ± 9

Rainfall data

http://www.sir.toscana.it/consistenza-rete

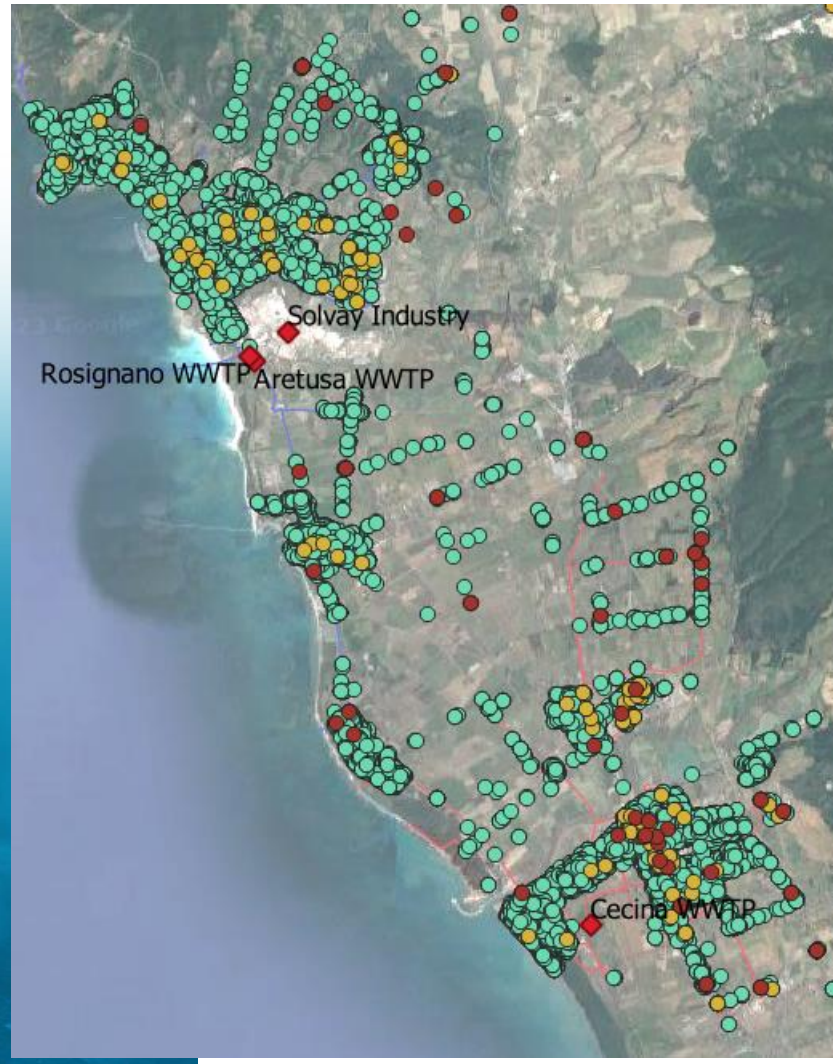




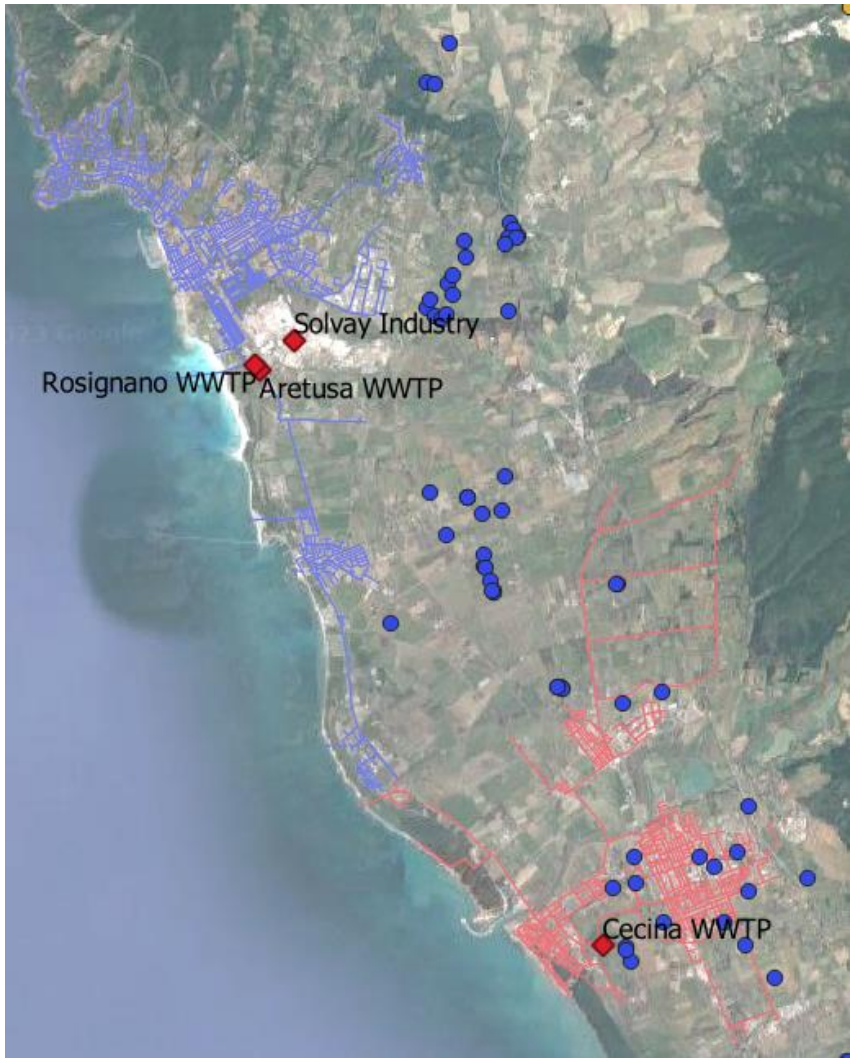
Evento di precipitazione		Cecina	Rosignano
TR 1Y (evento minimo)	mm	19.15	14.5
TR 5Y (evento medio)	mm	63.7	60.6
TR 10Y (evento massimo)	mm	78.6	75.6

Modelisation of the sewer network

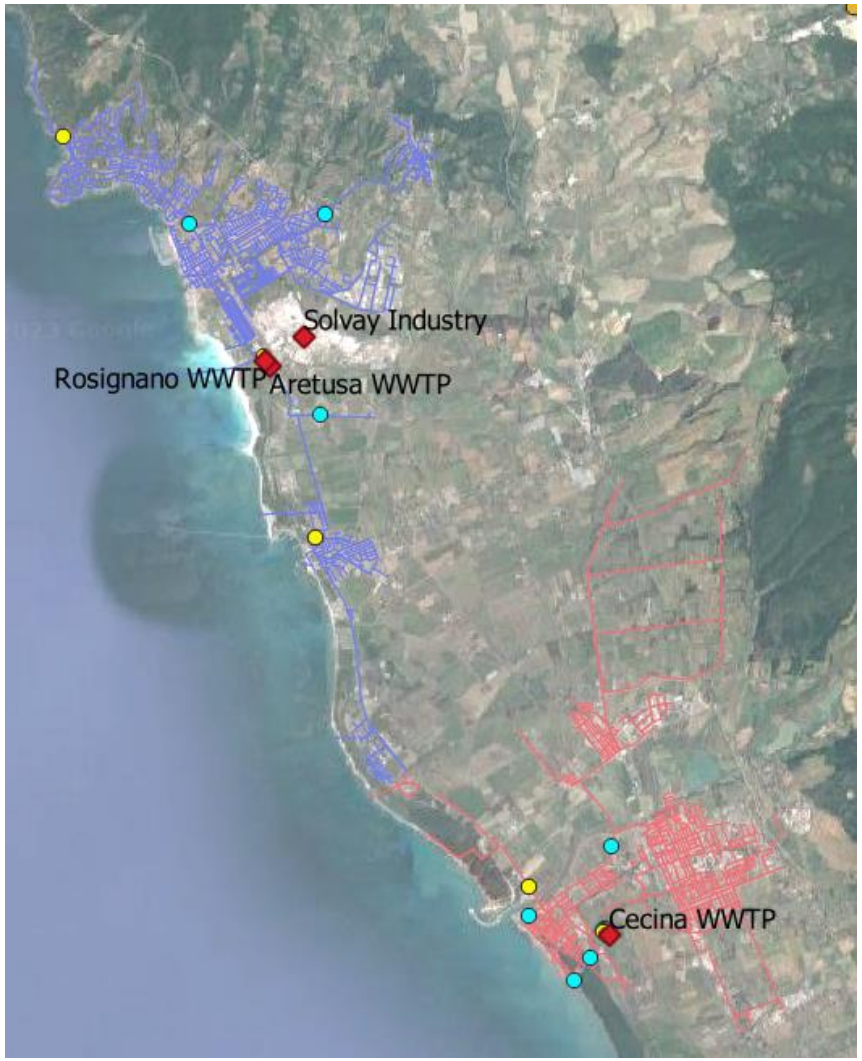
Users distribution



Wells



Flowmeters and conductivity meters



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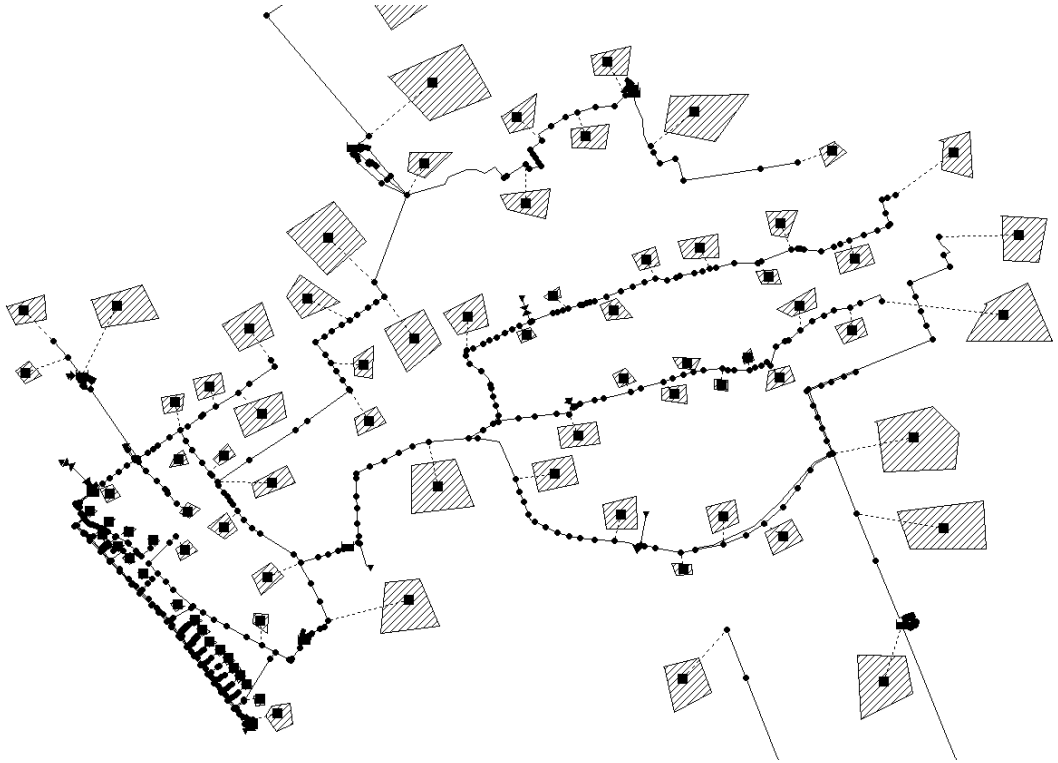
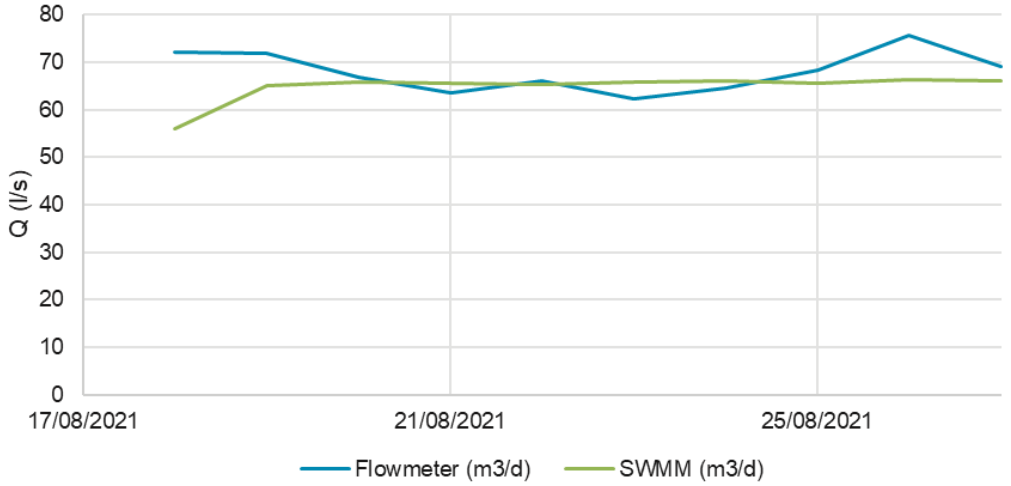
Modelisation of the sewer network

Cecina





	Sampling data	SWMM data	Error %
COD	195	239	22
N-NH4	35	41	15
TSS	74	95	29
Cloruri	446	356	-20

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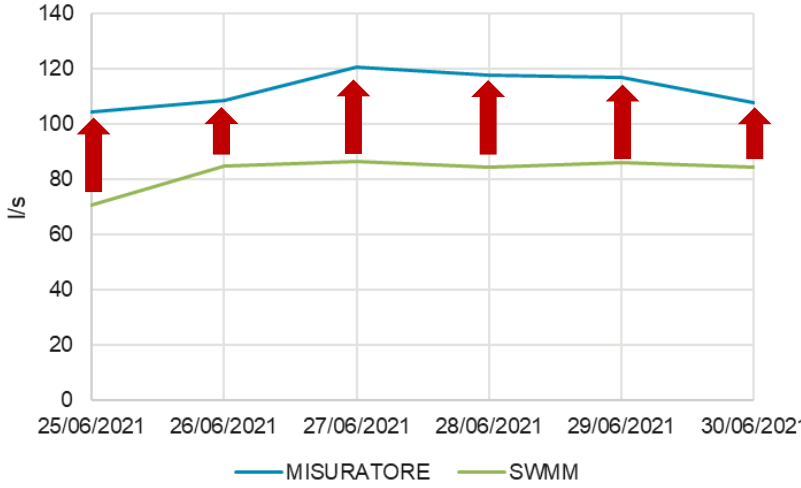
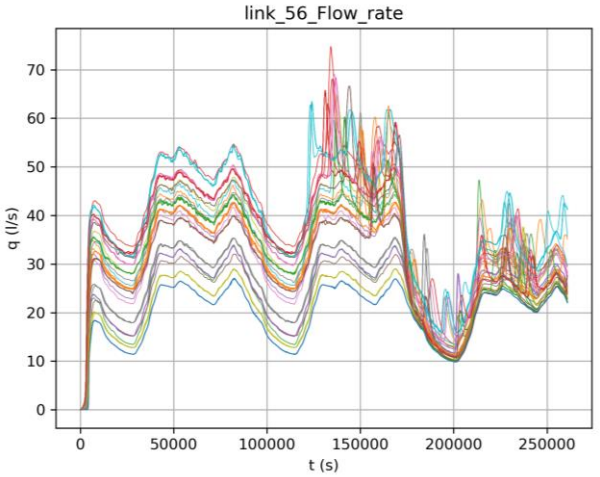
Modelisation of the sewer network

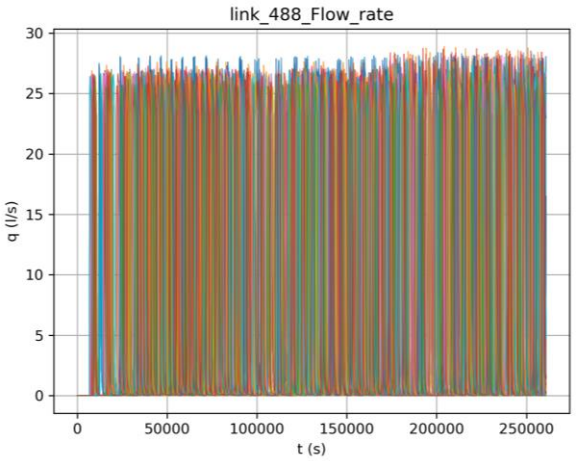
Rosignano





Cooperation with colleagues from Kielce university



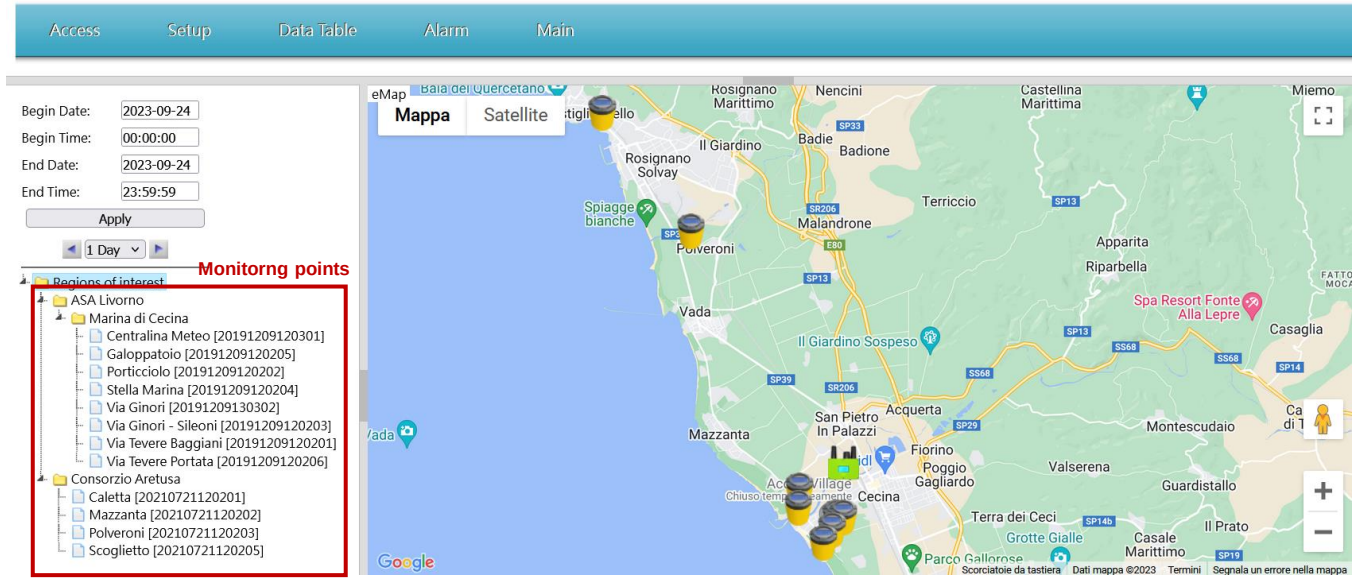


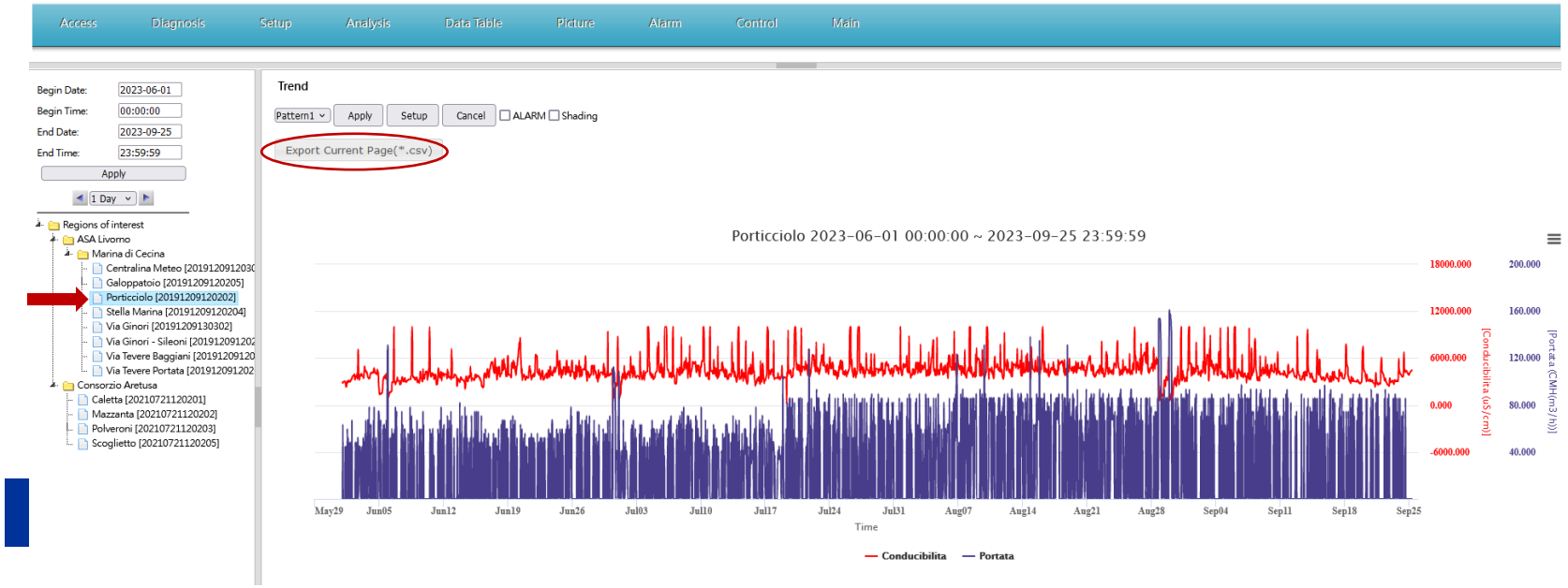
	Sampling data	SWMM data	Error %
COD	171	206	21
N-NH4	20	20	4
TSS	66	86	31
Cloruri	414	371	-10

n's
18

Data collection

Monitoring at sewer network





Time	Conducibilita	Portata
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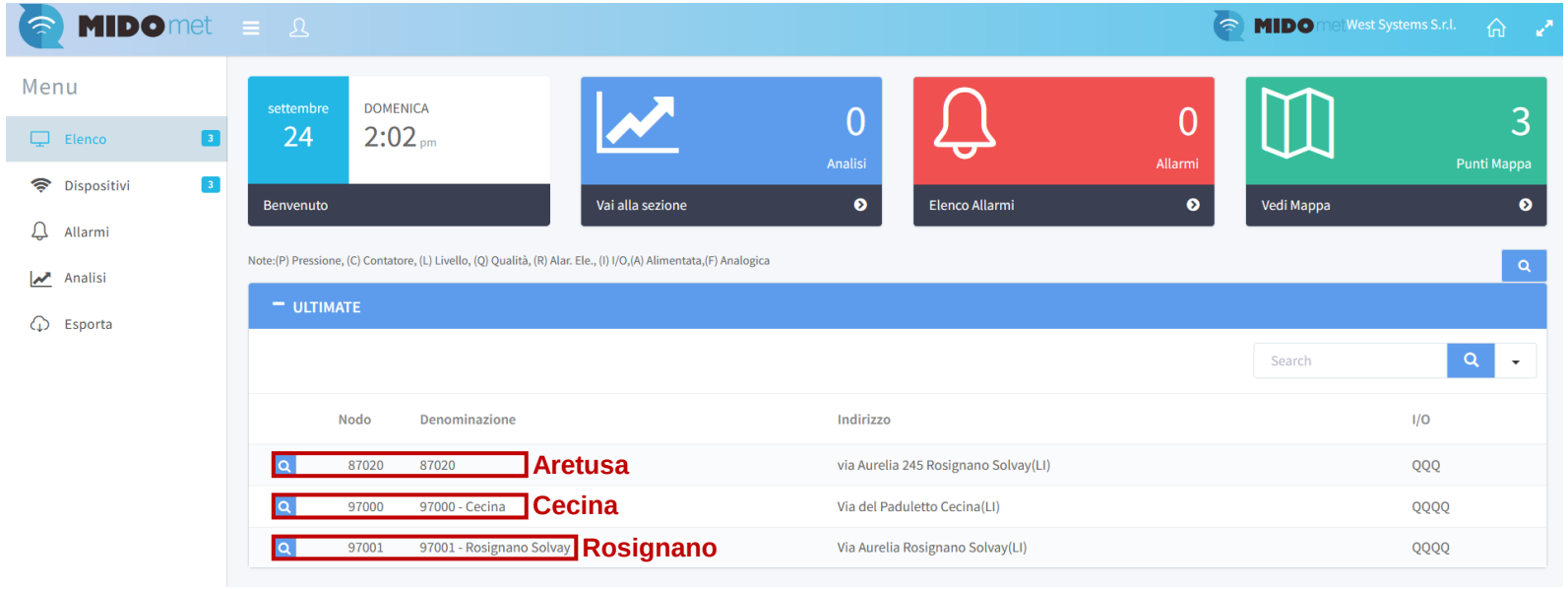
01/06/2023 00:45	2815,093262	63,7488
01/06/2023 01:30	2918,299072	0
01/06/2023 02:15	2959,37085	0
01/06/2023 03:00	3005,181396	0
01/06/2023 03:45	3025,190674	0
01/06/2023 04:30	3040,987549	0
01/06/2023 05:15	3048,359131	0
01/06/2023 06:00	3046,253174	0
01/06/2023 06:45	3026,243896	45
01/06/2023 07:30	2766,123291	0
01/06/2023 08:15	2870,908691	0
01/06/2023 09:00	2310,64917	0
01/06/2023 09:45	2717,679688	41,2488
01/06/2023 10:30	2342,242676	45
01/06/2023 11:15	2651,859619	0
01/06/2023 12:00	3075,213867	0
01/06/2023 12:45	2828,257324	60,0012
01/06/2023 13:30	2905,13501	0
01/06/2023 14:15	2907,767822	0
01/06/2023 15:00	2973,061279	52,4988
01/06/2023 15:45	3133,661865	0

Data collection

Monitoring at the WWTPs





Elenco Letture Nodo ID 97000 97000 - Cecina				
UTC	Data	Lettura		Stato
1643517840	30/1/22 5:44	1861.898071	uS/cm	OK
1643528100	30/1/22 8:35	1943.625488	uS/cm	OK
1643529600	30/1/22 9:00	1940.373535	uS/cm	OK
1643533200	30/1/22 10:00	1902.968262	uS/cm	OK
1643536800	30/1/22 11:00	1891.100098	uS/cm	OK
1643540400	30/1/22 12:00	1867.649292	uS/cm	OK
1643544000	30/1/22 13:00	1843.211548	uS/cm	OK
1643547600	30/1/22 14:00	1833.856812	uS/cm	OK
1643551200	30/1/22 15:00	1842.407471	uS/cm	OK
1643554800	30/1/22 16:00	1833.210571	uS/cm	OK
1643558400	30/1/22 17:00	1853.767212	uS/cm	OK
1643562000	30/1/22 18:00	1860.960815	uS/cm	OK
1643565600	30/1/22 19:00	1867.50708	uS/cm	OK
1643569200	30/1/22 20:00	1880.179077	uS/cm	OK
1643572800	30/1/22 21:00	1901.503174	uS/cm	OK
1643576400	30/1/22 22:00	1909.637451	uS/cm	OK
1643580000	30/1/22 23:00	1905.854126	uS/cm	OK
1643583600	31/1/22 0:00	1914.061768	uS/cm	OK
1643587200	31/1/22 1:00	1917.538208	uS/cm	OK
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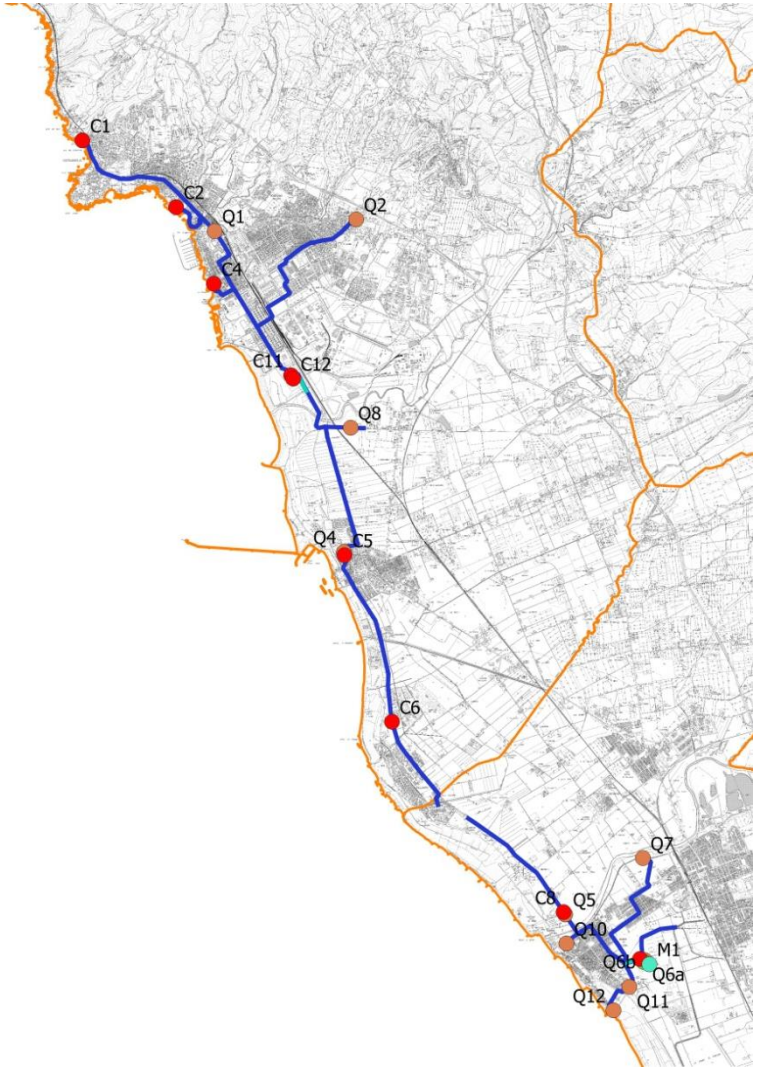
1643594400	31/1/22 3:00	1881.111084	uS/cm	OK

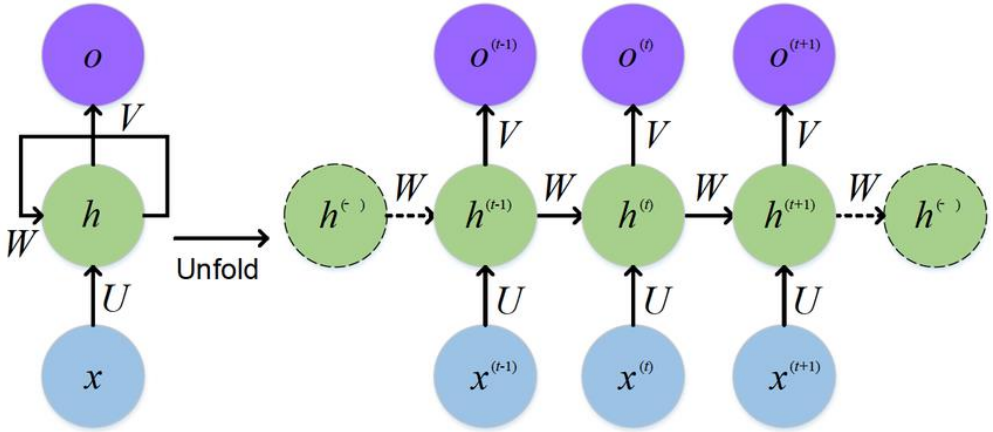
Early warning system



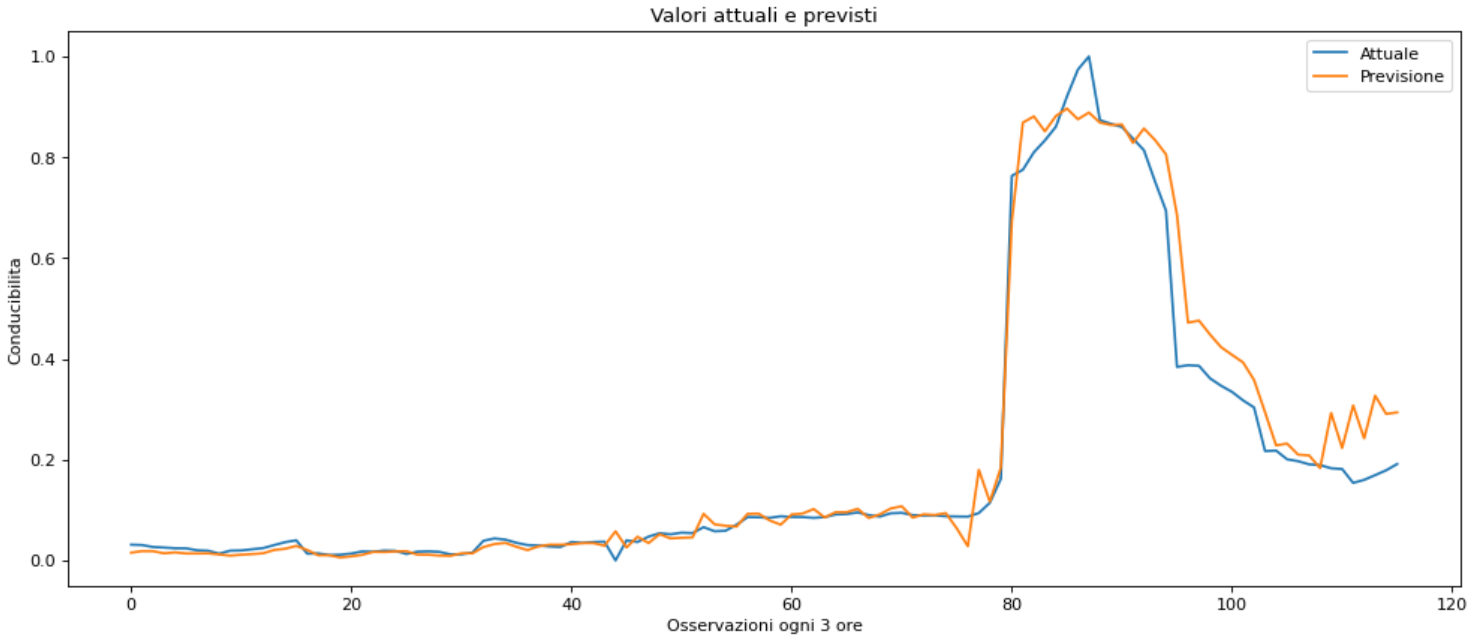
ID	Comune e Indicazione	Alias	Misura
Q1	Rosignano(Via Aurelia-Rotonda coop)		Portata
Q2	Rosignano(Via della Repubblica - Condotta da Marittimo)		Portata
Q4	Rosignano(Soll. Telesio)		Portata
C5	Rosignano(Soll. Telesio)		Conducibilità
Q5	Cecina(Soll. Porticciolo)	Porticciolo [20191209120202]	Portata
C8	Cecina(Soll. Porticciolo)	Porticciolo [20191209120202]	Conducibilità
Q6 a	Cecina(Cancello, in. Depuratore - Collettore proveniente da NORD)		Portata
Q6 b	Cecina(Cancello, in. Depuratore - Collettore proveniente da Cecina Marina)	Via Tevere Portata [20191209120206]	Portata
Q7	Cecina (Pista ciclabile)	Via Ginori [20191209130302]	Portata
Q8	Polveroni	Polveroni [20210721120203]	Portata
Q10	Cecina(Soll. Ginori)	Via Ginori Sileoni [20191209120203]	Portata
Q11	Cecina(Soll. Galoppatoio)	Galoppatoio [20191209120205]	Portata
Q12	Cecina(Soll. Andalù)	Stella Marina [20191209120204]	Portata
C1	Rosignano(Soll. Quercetano)		Conducibilità
C2	Rosignano(Soll. Caletta)	Caletta [20210721120201]	Conducibilità
C4	Rosignano(Soll. Scoglietto)	Scoglietto [20210721120205]	Conducibilità
C6	Rosignano(Soll. Mazzanta)	Mazzanta [20210721120202]	Conducibilità
C10	Cecina dep. Out	Via del Paduletto Cecina(LI) [97000]	Conducibilità
C11	Rosignano dep. Out	Via Aurelia Rosignano Solvay(LI) [97001]	Conducibilità
C12	ARETUSA in	via Aurelia 245 Rosignano Solvay(LI) [87020]	Conducibilità
M1	Cecina (Uffici depuratore)	Centralina Meteo [20191209120301]	Pioggia cumulata e vento
ID	Tipo di strumento presente	Reperimento dati (Cloud)	Consistenza
Q1	Area velocity su centina		
Q2	Area velocity su centina		
Q4	Elettromagnetico Endress Promag 400		
C5	Sonda di conducibilità induttiva - B&C Electronics		
Q5	Elettromagnetico Endress Promag 400	Bimatik	01/08/2020 00:00-14/06/2023 23:45
C8	Sonda di conducibilità induttiva - HACH	Bimatik	01/08/2020 00:00-14/06/2023 23:45
Q6 a	Area velocity attualmente su palo		
Q6 b	Misuratore di portata laser flow WATEC SIGNATURE	Bimatik.	01/10/2022 00:00-23/04/2023 21:00
Q7	Misuratore Radar di livello e velocità	Bimatik	01/10/2022 00:00-14/06/2023 23:45
Q8	Elettromagnetico Endress Promag 400	Bimatik	17/05/2022 16:45-14/06/2023 23:45
Q10	Elettromagnetico Endress Promag 400	Bimatik	27/02/2020 00:00-14/06/2023 23:45
Q11	Elettromagnetico Endress Promag 400	Bimatik	01/08/2020 00:00-14/06/2023 23:45
Q12	Elettromagnetico Endress Promag 400	Bimatik	01/10/2022 00:00-01/03/2023 09:00
C1	Sonda di conducibilità induttiva - B&C		
C2	Sonda di conducibilità induttiva - B&C	Bimatik	01/10/2022 00:00-15/03/2023 16:00
C4	Sonda di conducibilità induttiva - B&C	Bimatik.	22/11/2022 16:30-31/12/2022 23:30
C6	Sonda di conducibilità induttiva - B&C	Bimatik.	13/10/2022 15:30-23/12/2022 08:00
C10	Sonda conducibilità conduttiva - AquaLabo	MidoMet	25/03/2021 13:26-06/06/2023 23:00
C11	Sonda conducibilità conduttiva - AquaLabo	MidoMet	25/03/2021 14:00-08/06/2023 02:00
C12	Sonda conducibilità induttiva - B&C	MidoMet	12/05/2022 12:21-07/06/2023 02:00
M1	Stazione meteo MTX con pluviometro e coppette per il vento	Bimatik.	01/10/2022 00:00-14/06/2023 23:45

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

Early warning system

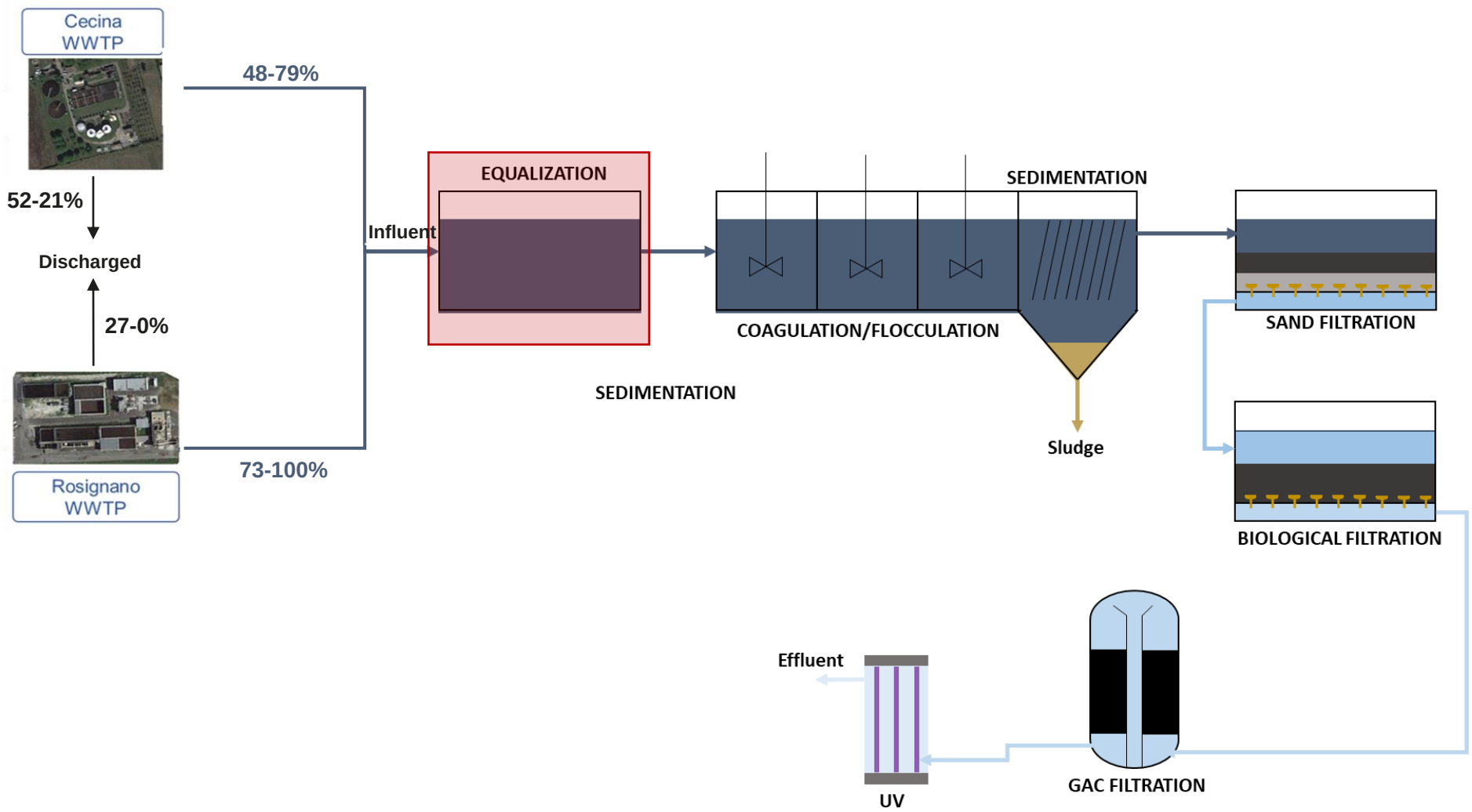


Recurrent neural networks (RNN) (recurrent neural network) are typically used for data time series analysis.
Recurrent neural networks is a class of neural networks that include neurons linked together in a cycle. The output values of an upper layer are used as the input of a lower layer.



Example of the application of the neural model on the Rosignano network for the first 15 days of March 2023 using the data of station C2 (Caletta)

Smart equalization



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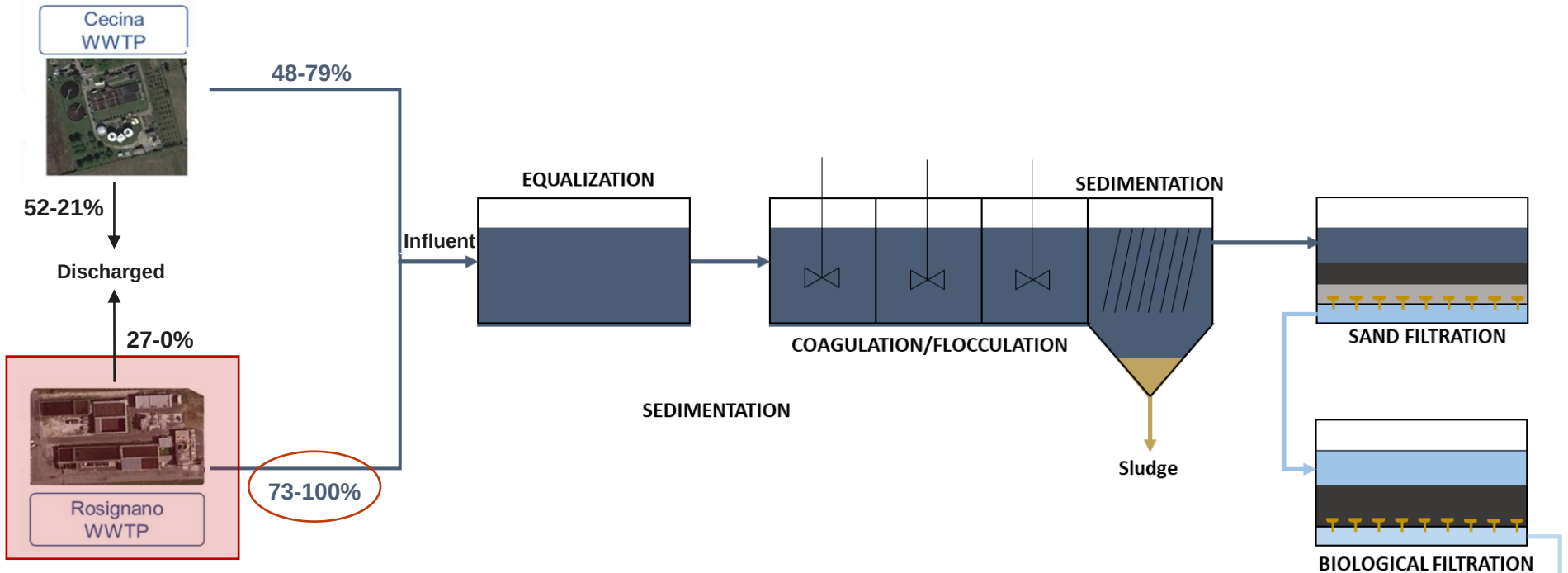
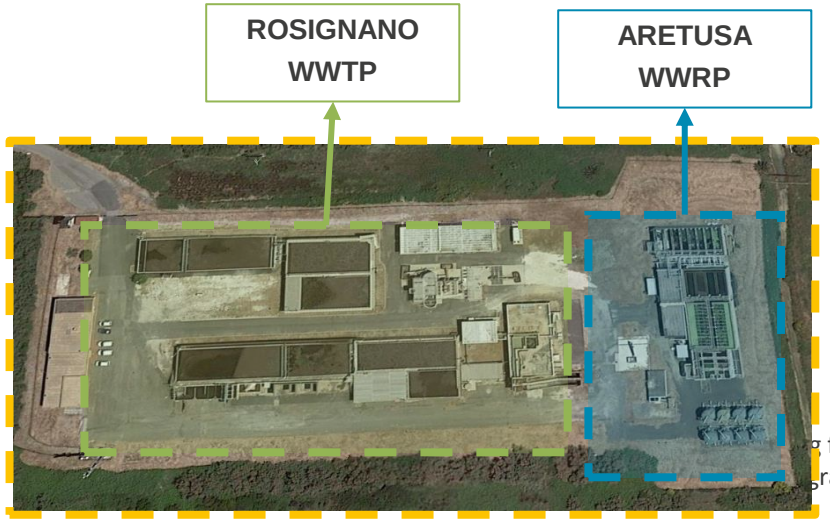
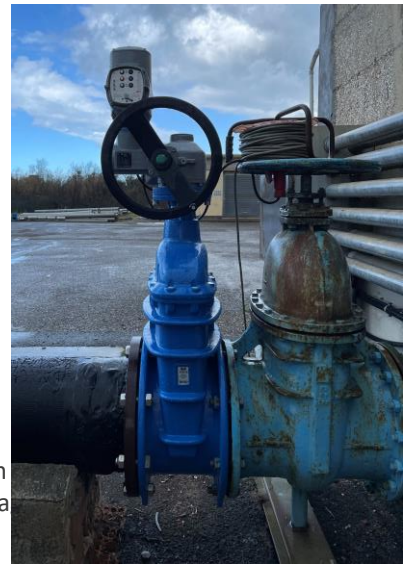
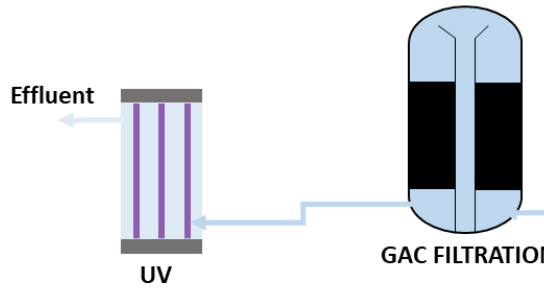
Smart equalization







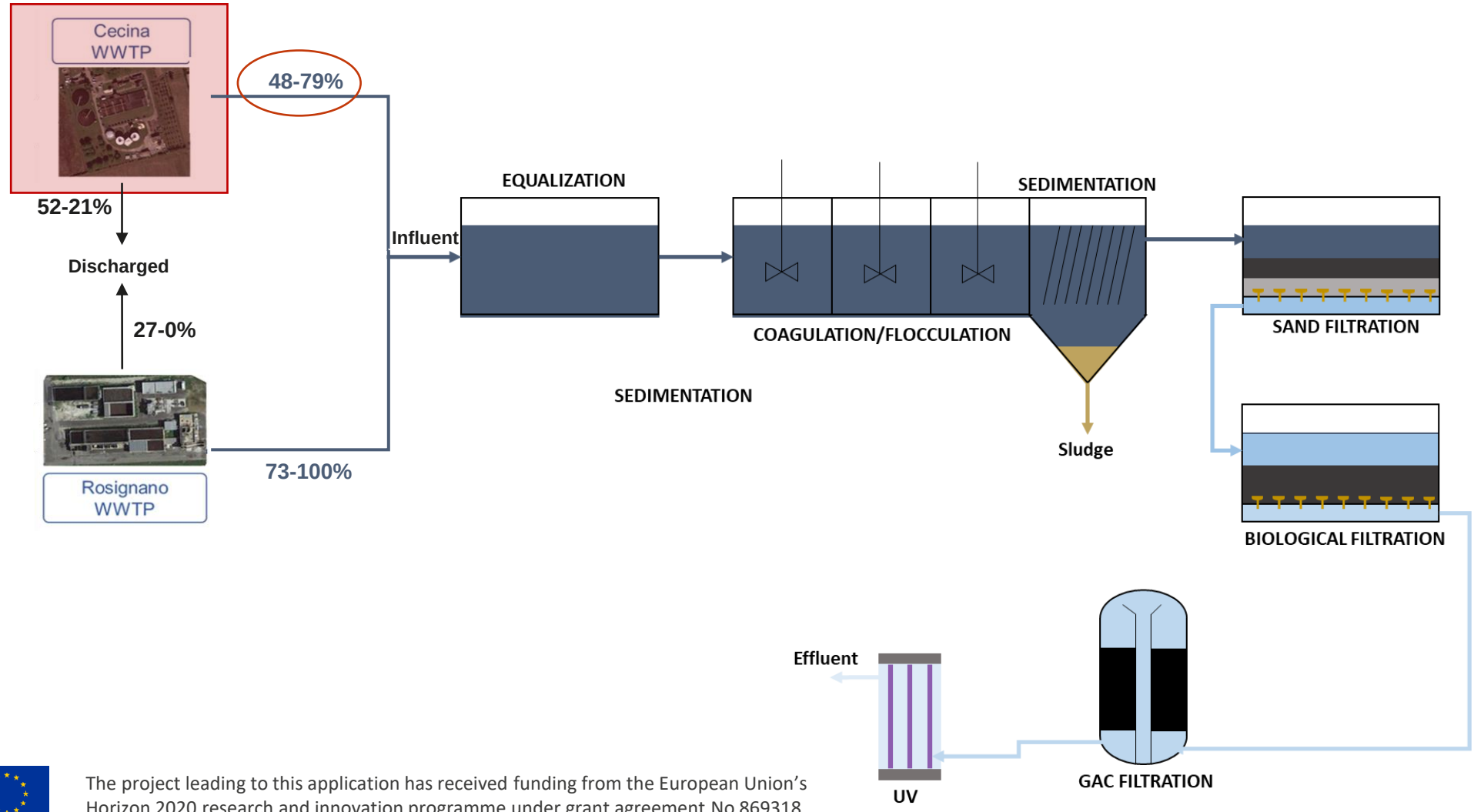


g from
grant a

Smart equalization

Set-point in the equalization tank which activates/regulates the two pumps from Cecina

➡ 11.4 km pipeline



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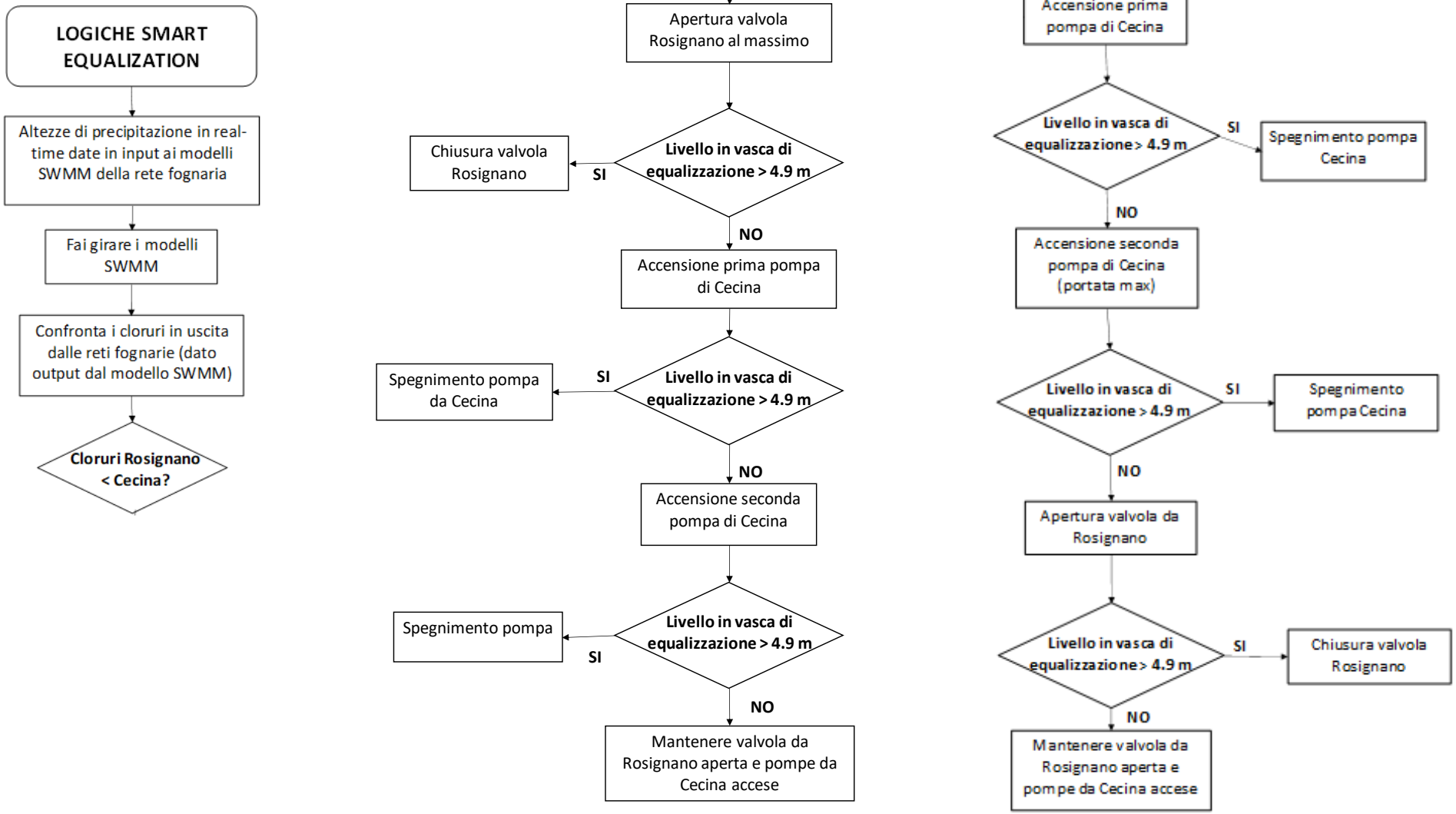
Smart equalization



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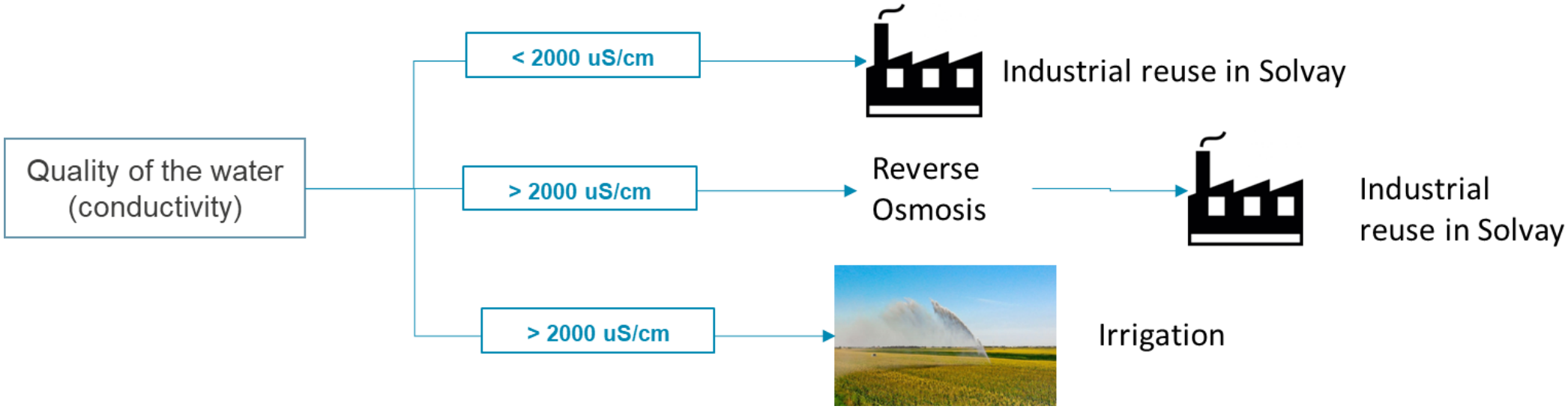
Match-making platform



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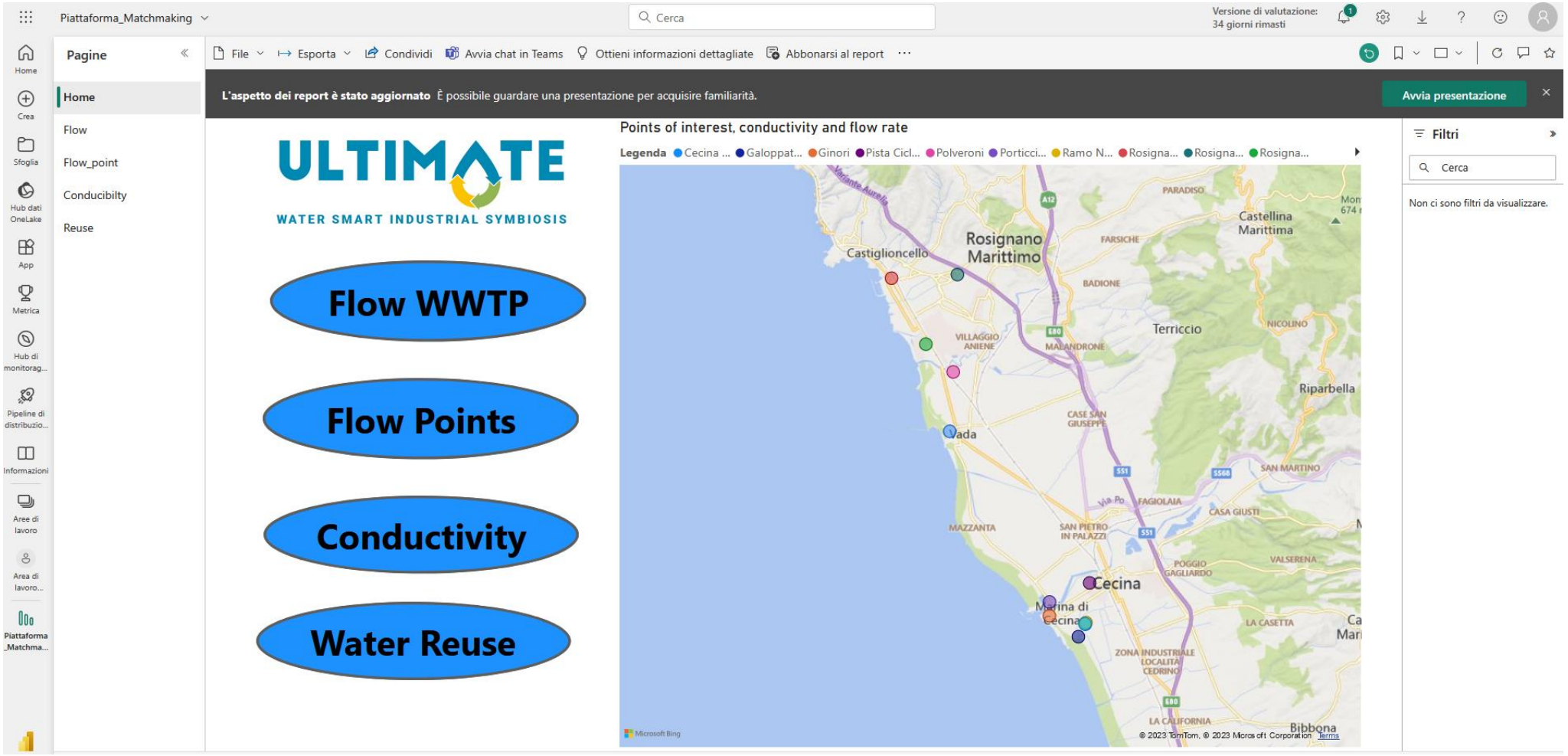
Match-making platform



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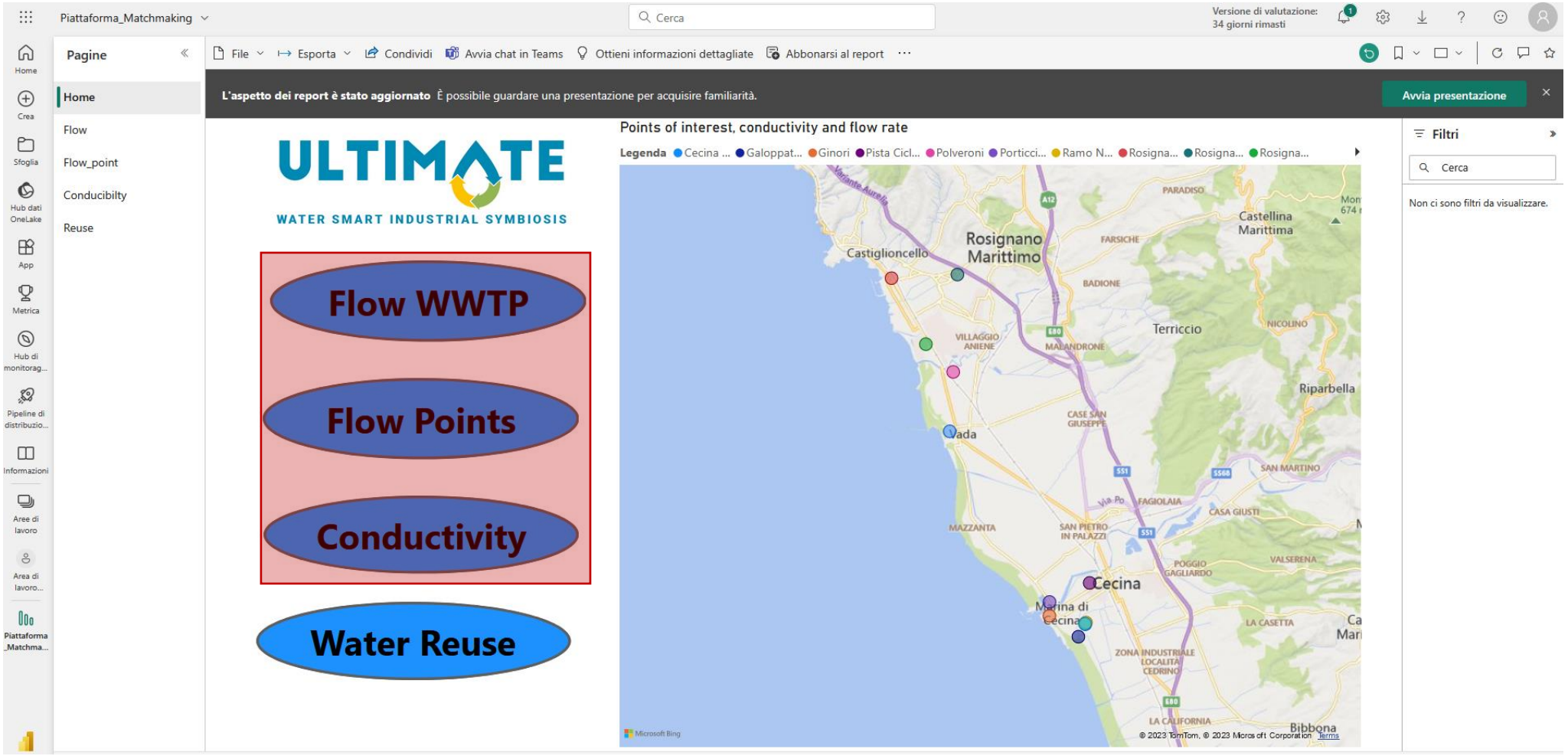
Match-making platform



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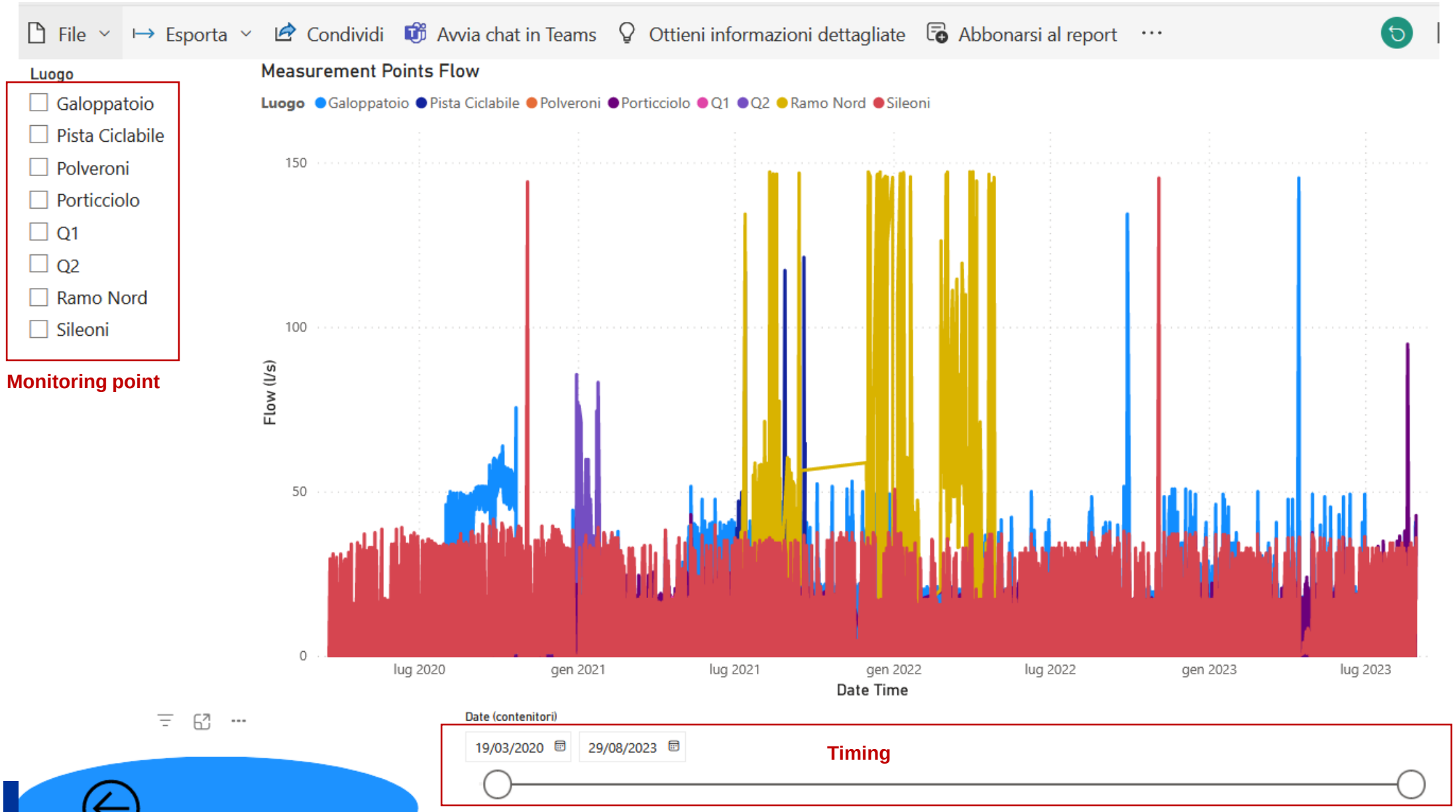
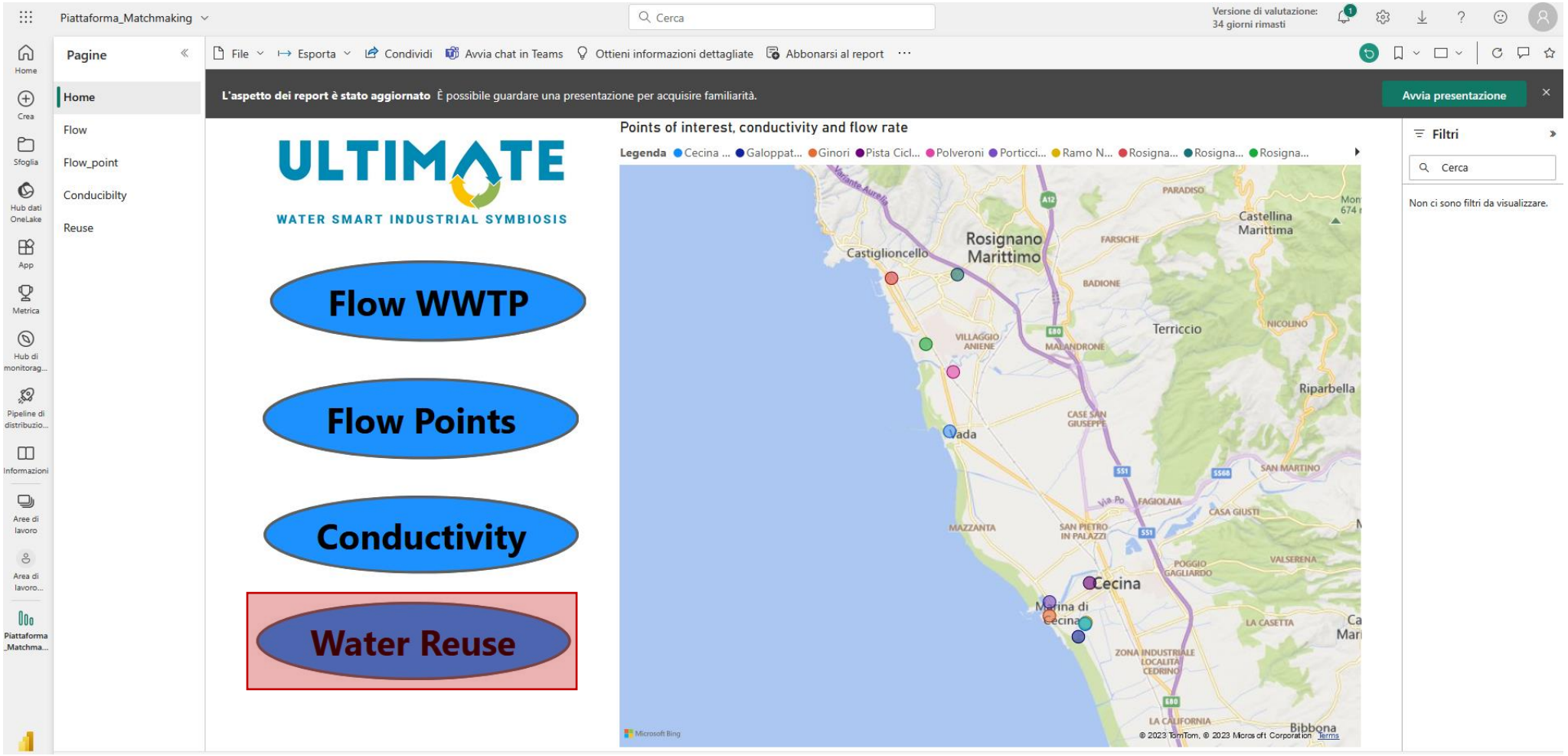
Match-making platform



Horizon 2020 research and innovation programme under grant agreement No 869318

Match-making platform



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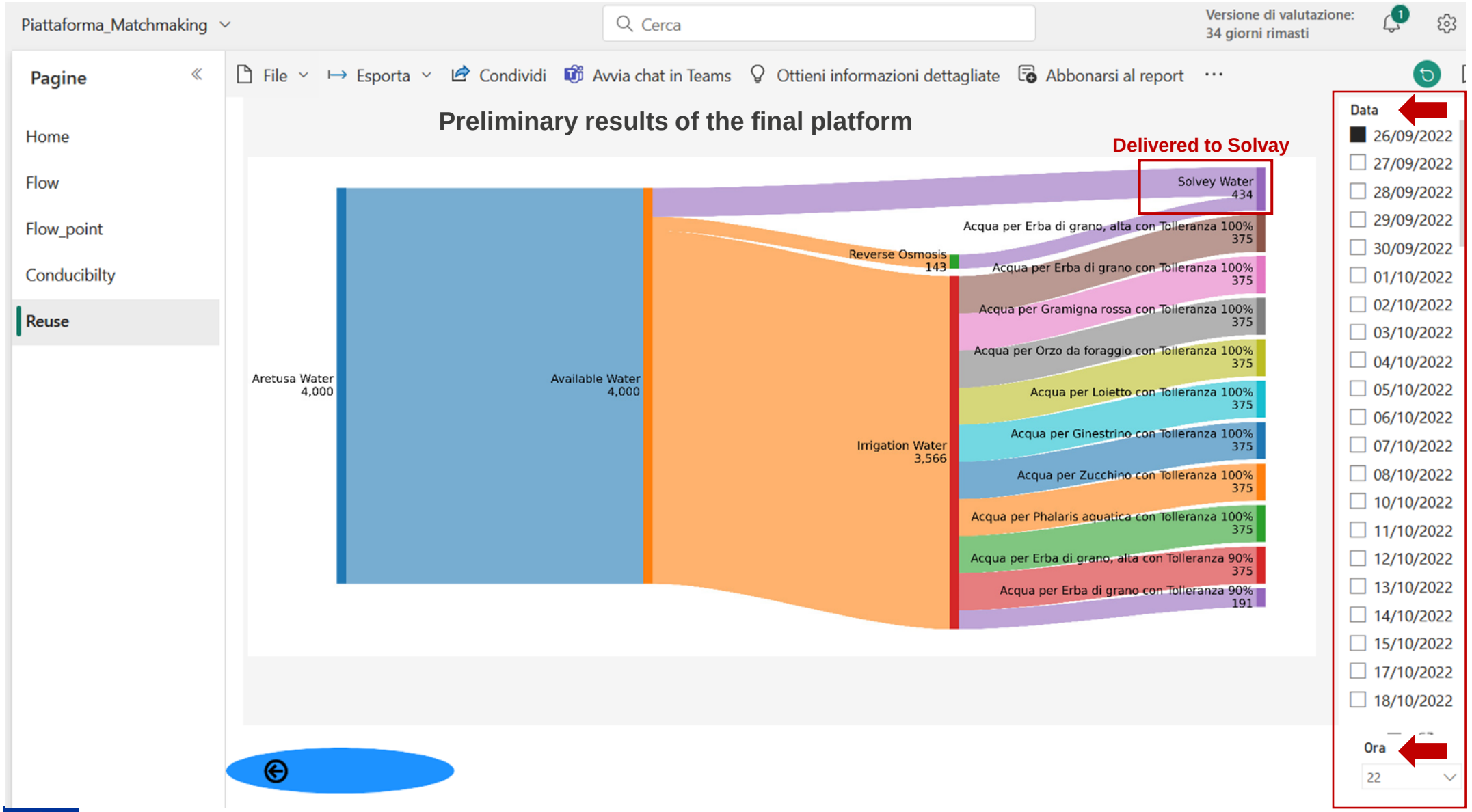
Match-making platform



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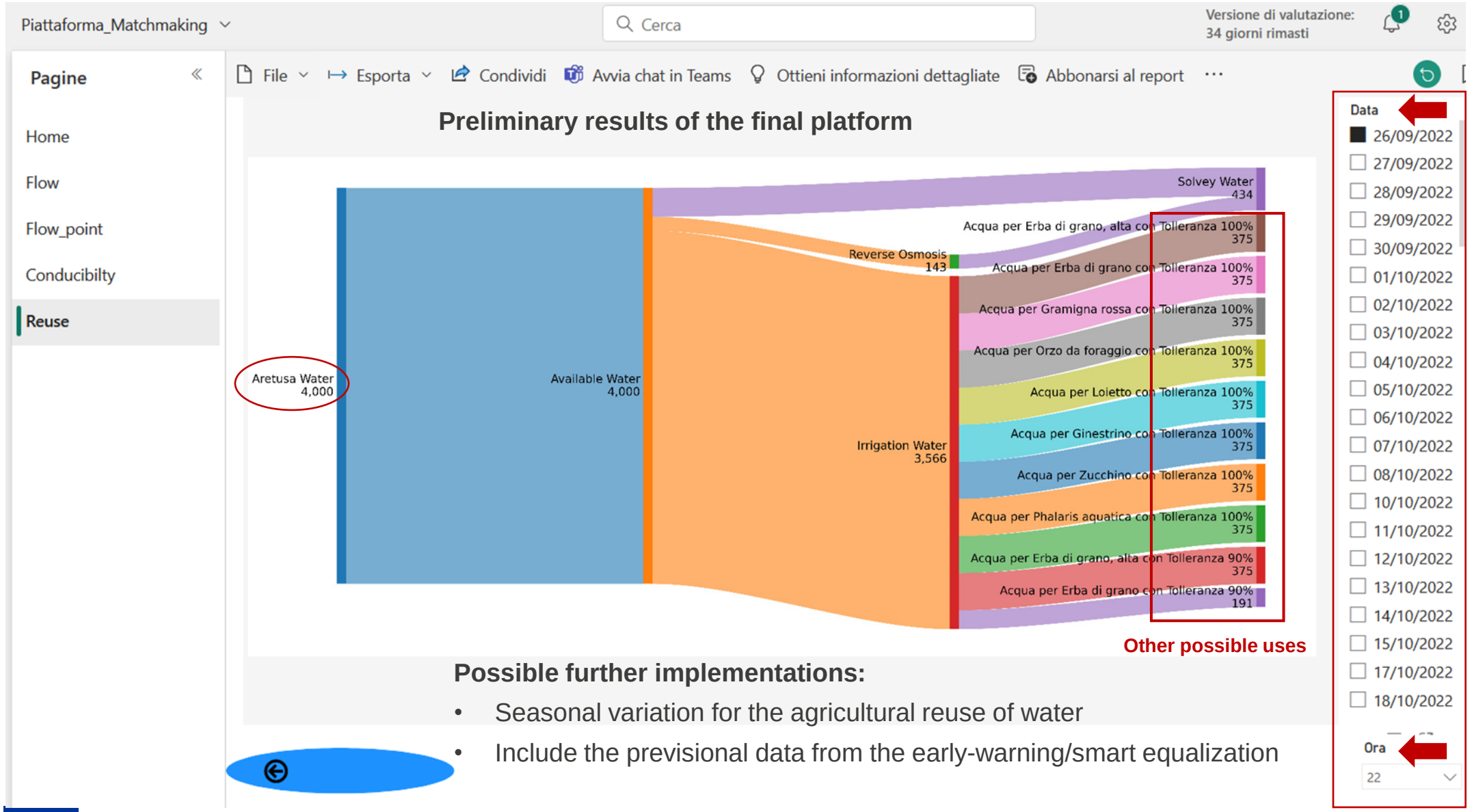

The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

Thank You!

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

The role of membranes in future WRRFs: from prove of concept to process optimization

Ángel Robles
Department of Chemical Engineering
ETSE-UV School of Engineering
Universitat de València

CS meeting on "Digitization, Monitoring and Forecasting in water and wastewater management"
September 26th, 2023

CALAGUA



Joint research unit

- Research Institute of Water and Environmental Engineering
  Prof. José Ferrer

iiama Instituto de Ingeniería del Agua y Medio Ambiente

UNIVERSITAT POLITÈCNICA DE VALÈNCIA

- Department of Chemical Engineering – School of Engineering
  Prof. Aurora Seco

Escola Tècnica Superior d'Enginyeria

VNIVERSITAT DE VALÈNCIA

16	Professors
5	Post-Doc researchers
17	PhD students
2	Technical staff

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Main research areas

- Anaerobic valorization of organic matter
- Nutrient removal and recovery
- Microalgae cultivation
- Priority and emerging pollutants
- Microbiological and biokinetic analysis
- **Membranes for wastewater treatment**
- **Mathematical modelling**
- **Process monitoring, control and optimization**

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Membrane-based pilot plants



AnMBR



MPBR

Anaerobic wastewater treatment with UF membrane technology.

Algae cultivation using the nutrient-rich effluent from an anaerobic MBR. Microalgae separation using UF membranes.

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Membrane-based pilot plants



AnMBR



MPBR

Anaerobic wastewater treatment with UF membrane technology.

Algae cultivation using primary-settled wastewater. Microalgae separation using UF membranes.

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Membrane-based pilot plants



DMF



Tertiary UF

UF-based direct membrane filtration of raw MWW and primary settler supernatant.

UF-based tertiary filtration of the effluent from MWWTP.

AnMBR

LIFE MEMORY Project

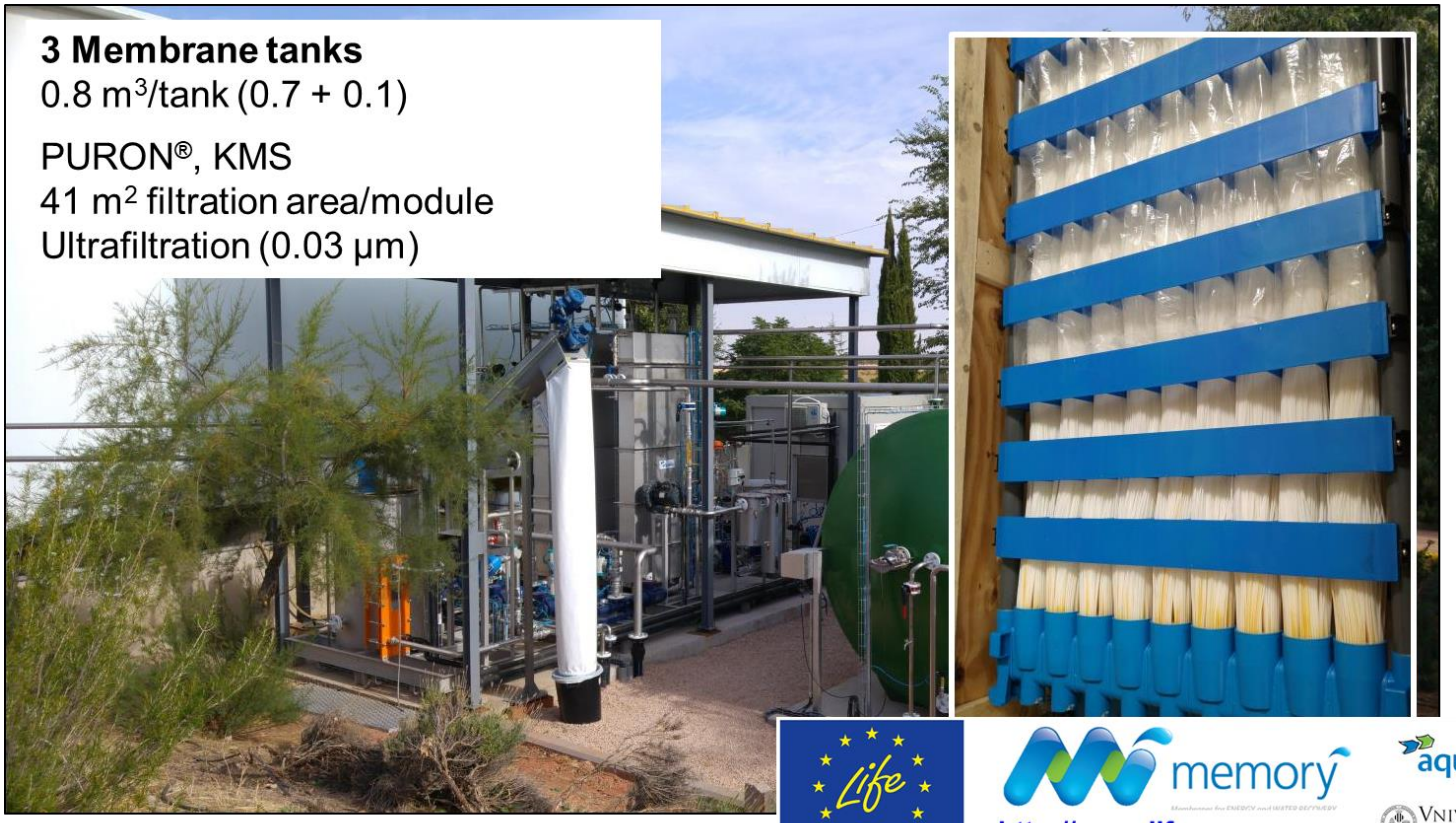
Fed with the effluent from the pre-treatment of the Alcázar de San Juan WWTP (Ciudad Real, Spain)



http://www.life-memory.eu

AnMBR

LIFE MEMORY Project



http://www.life-memory.eu

AnMBR

http://www.life-memory.eu

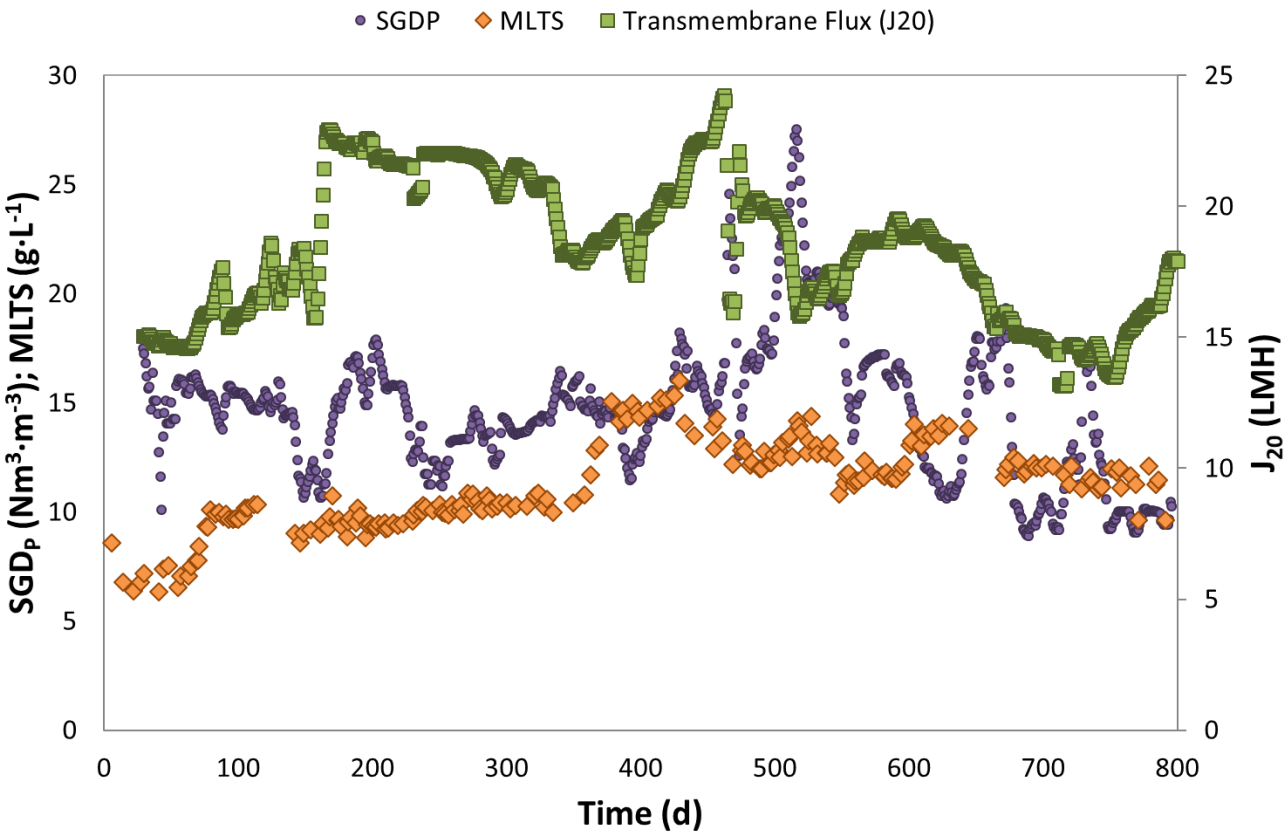
LIFE MEMORY Project

COD removal > 90%

High quality rich-nutrient effluent

COD < 125 mg/L

BOD < 25 mg/L



High energy efficiency

AnMBR

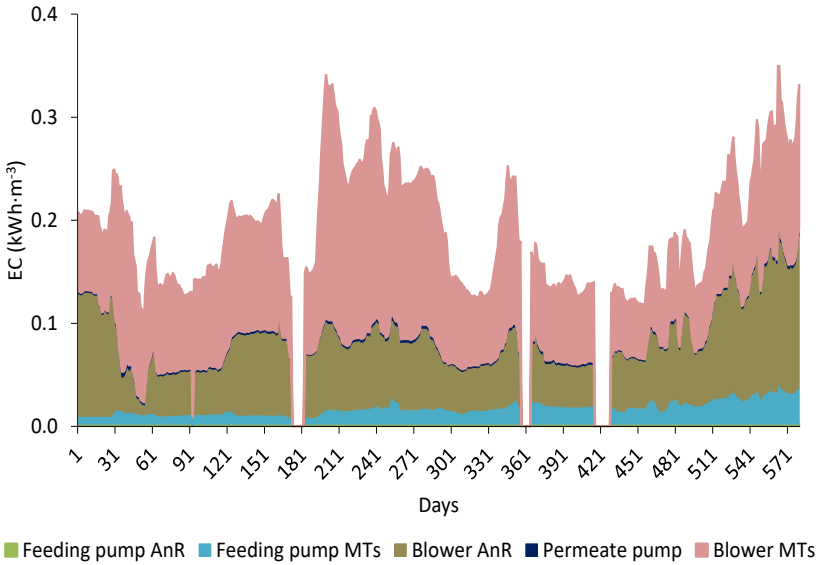
http://www.life-memory.eu

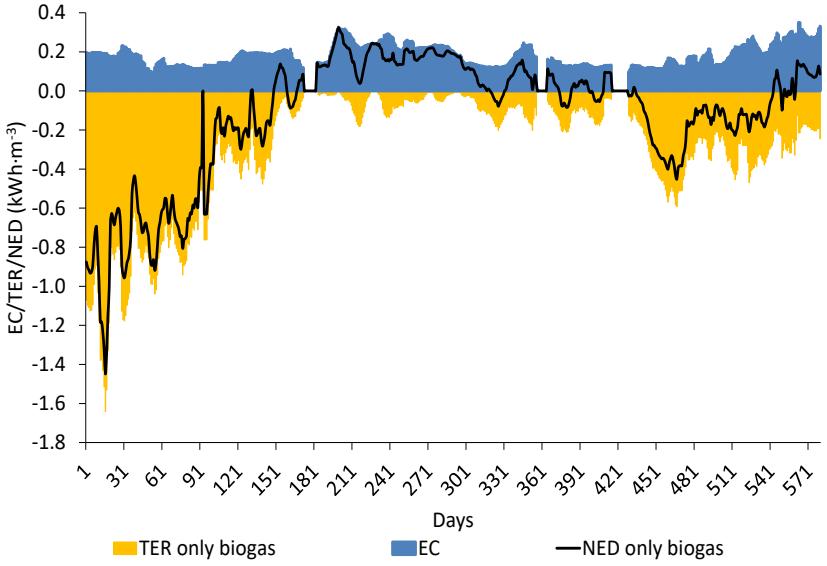
LIFE MEMORY Project

CAS: 0.3 – 0.7 kWh/m^3

EA: 0.3 – 0.8 kWh/m^3

MBR: 0.5 – 1.0 kWh/m^3





Filtration process control

Lodif Biocontrol

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Configurable software to facilitate the implementation of control systems and optimization algorithms in WWTPs.

Developed at pilot plant research level.

Validated and optimized at full scale in a significant number of WWTPs.

Aeration – Nutrient removal – Membrane fouling – Sludge line – …

The software is under continuous development, incorporating improvements detected after WWTP implementations and new algorithms developed at the research level.

Filtration process control

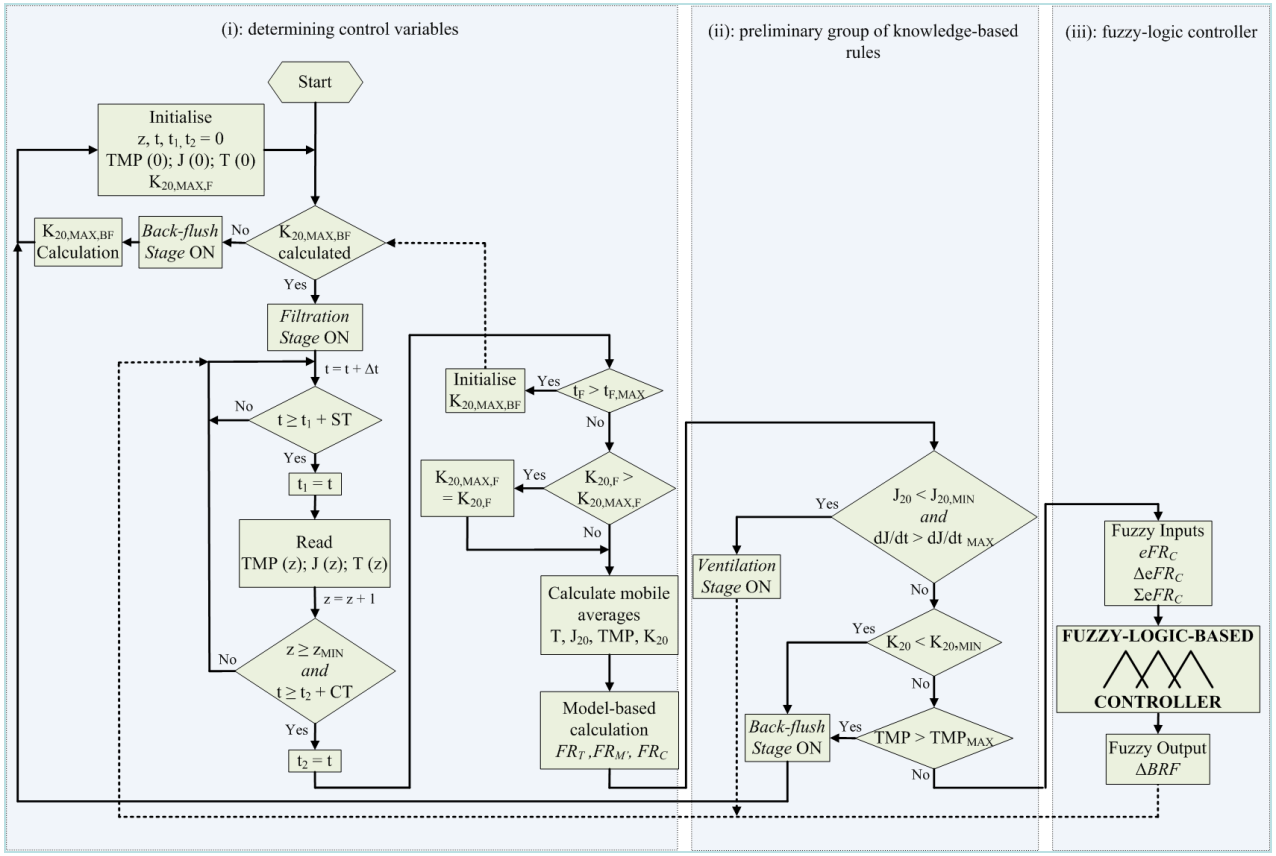
Upper layer controllers

- Knowledge-based controller
  - Sludge recycling flow
  - Back-flushing initiation
  - **Gas sparging for membrane scouring**

- Model-based supervisory controller
  - OPEX minimization
    - Knowledge-based controller set points

Filtration process control

Knowledge-based controller



Knowledge-based controller

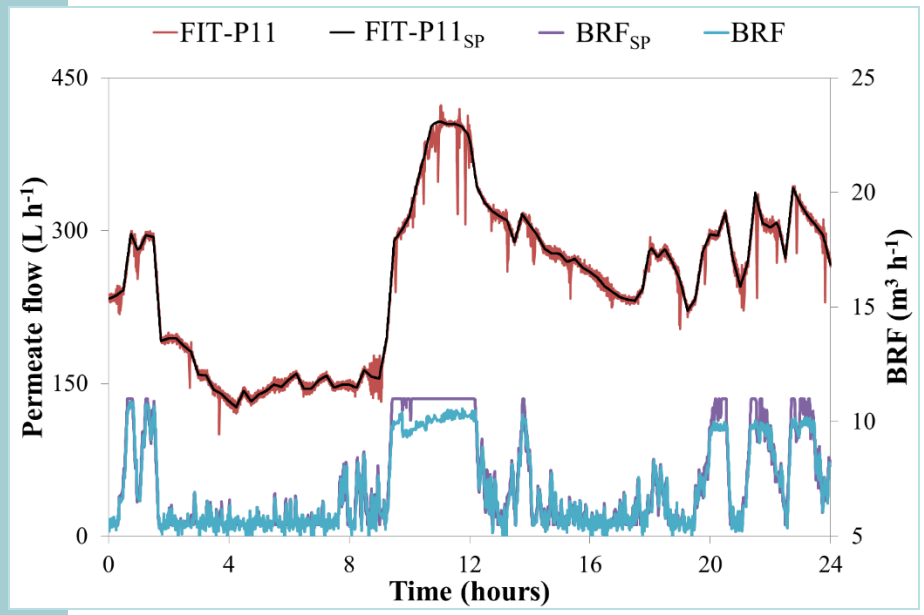
Structure of fuzzy-logic controller

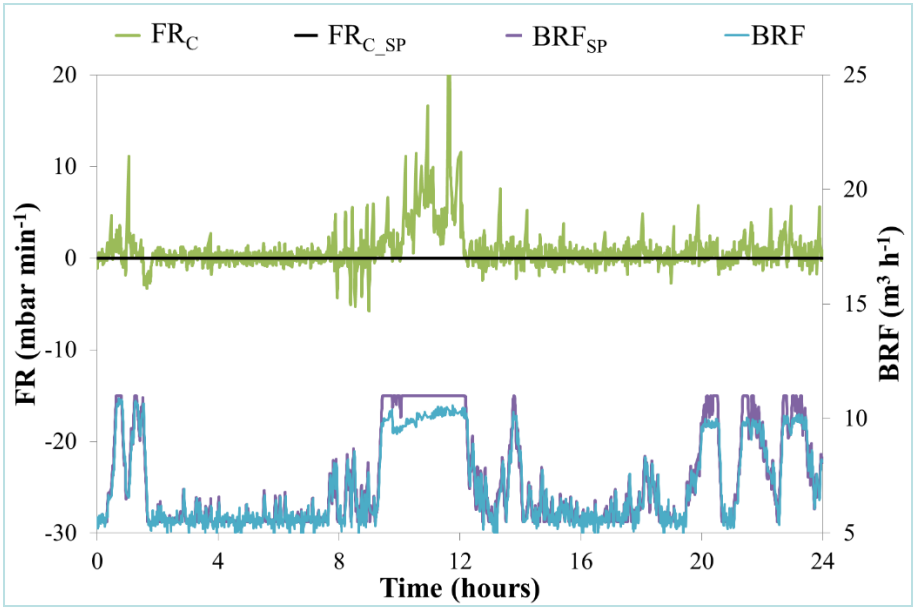
- Output
  - Variation in the set point of the biogas recycling flow
    - $\Delta BRF_{SP}\ (t)$

- Inputs (fouling rate related to cake layer formation)
  - Error
    - $eFR_C\ (t) = FR_C\ (t) - FR_{C\_SP}$
  - Accumulated error
    - $\Sigma eFR_C\ (t) = \Sigma eFR_C\ (t - CT)\ + CT\ \cdot\ eFR_C\ (t)$
  - Error difference (including algebraic factor)
    - $\Delta eFR_C\ (t)\ = eFR_C\ (t) - \frac{eFR_C\ (t)\ \cdot\ eFR_C\ (t-CT)}{|eFR_C\ (t)\ \cdot\ eFR_C\ (t-CT)|}\ \cdot\ eFR_C\ (t\ -\ CT)$

Knowledge-based controller

Performance of fuzzy-logic controller

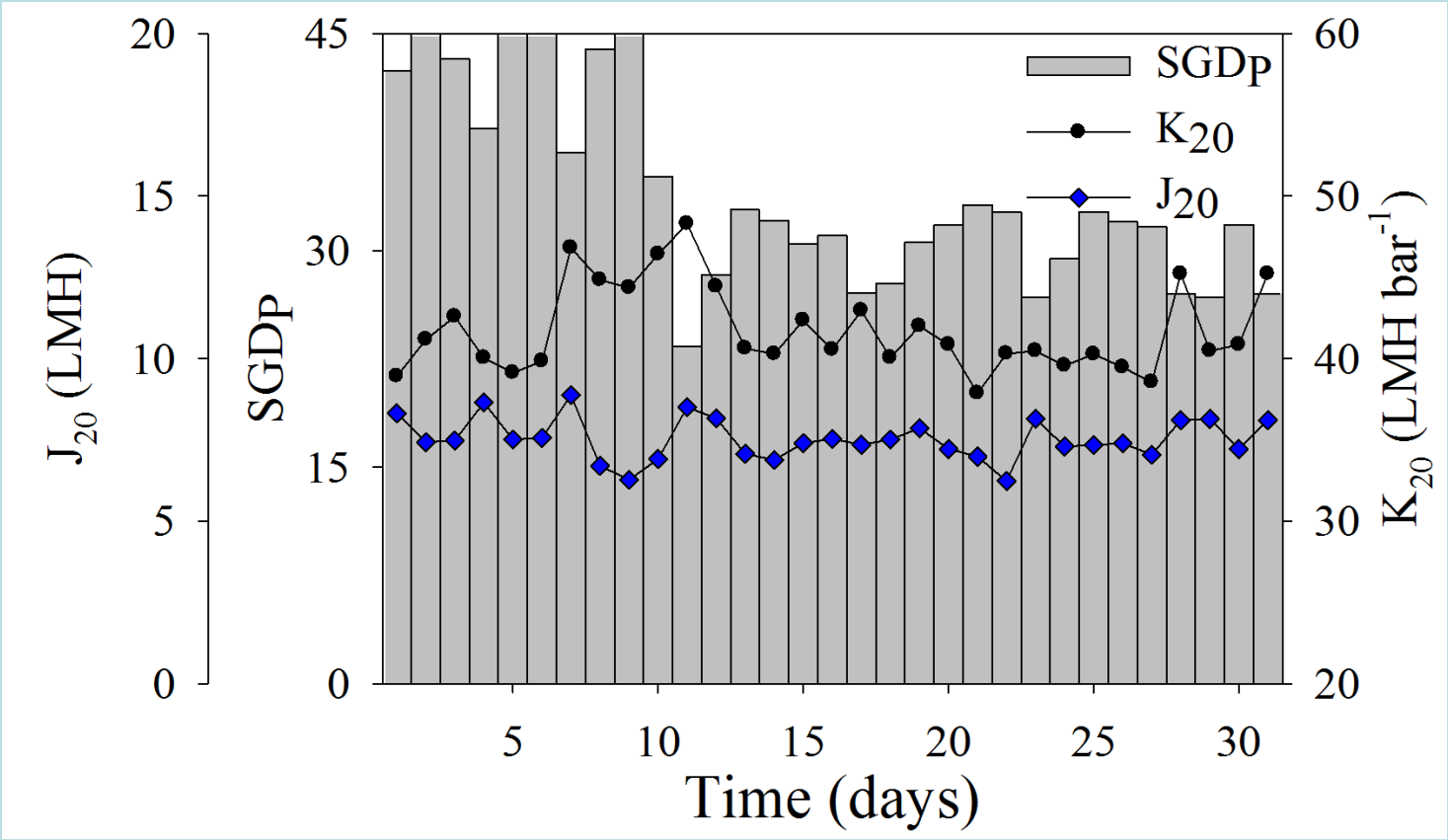




Fouling rate remained close to its set point, when there were no constraints on the gas sparging intensity.

Knowledge-based controller

Overall performance



Energy consumption for membrane scouring of about 0.16 kWh/m³

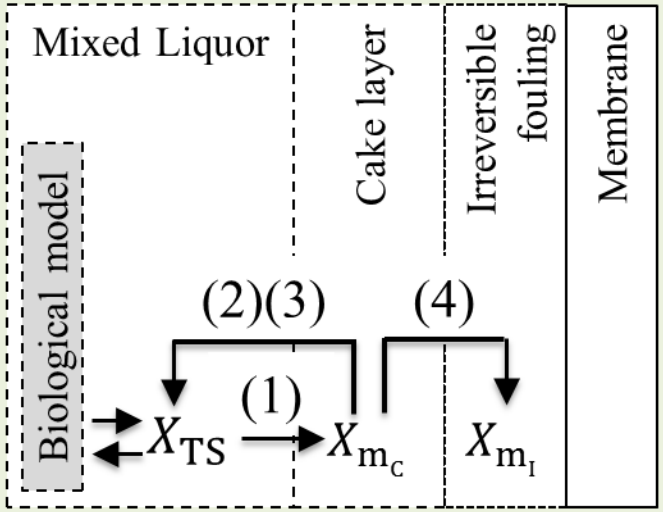
Savings of up to 35%

Model-based supervisory controller

RIS-based filtration model

- $TMP(t) = J \cdot \mu \cdot (R_M + R_C + R_I)$

Filtration model (based on resistance-in-series model)



Model components:

X_{TS}: MLTS concentration (obtained from biological model)

X_{m_C}: dry mass of cake on the membrane surface

X_{m_I}: dry mass of irreversible fouling on the membrane surface

Kinetically governed physical processes :

(1) cake layer build-up during filtration

(2) cake layer removal by membrane scouring with biogas

(3) cake layer removal during back-flushing

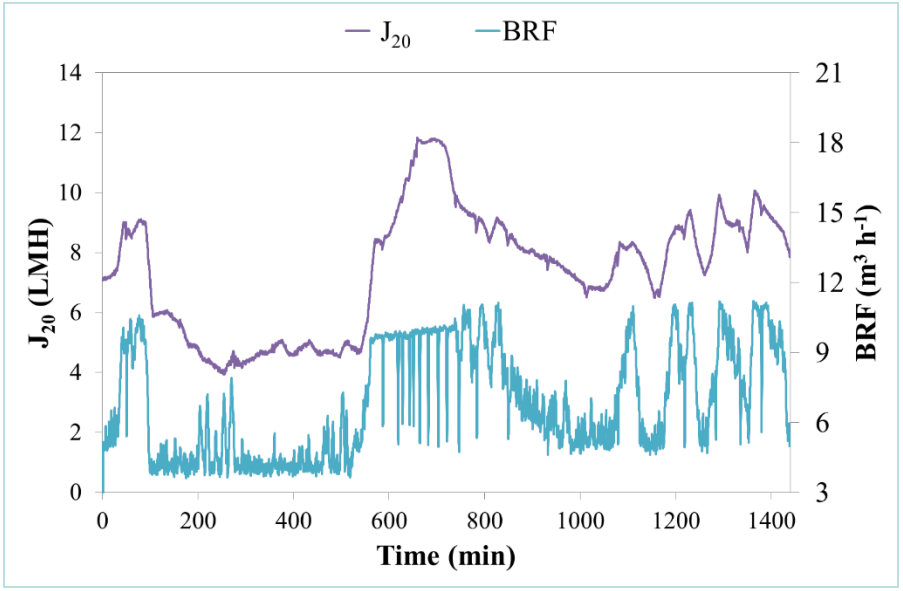
(4) irreversible fouling consolidation

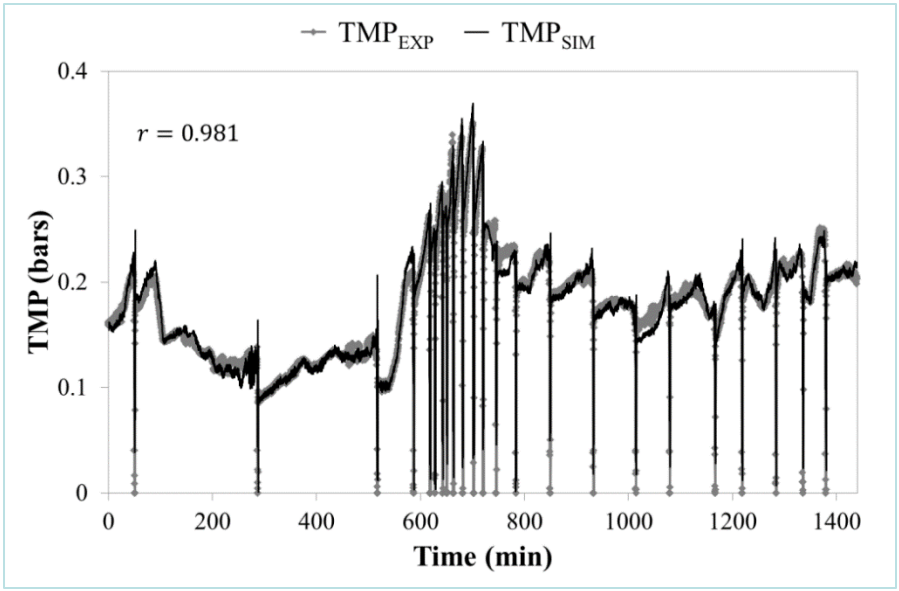
Robles et al. (2013) J. Membrane Sci. 444, 139–147.

Model-based supervisory controller

Filtration model

- Short-term model validation



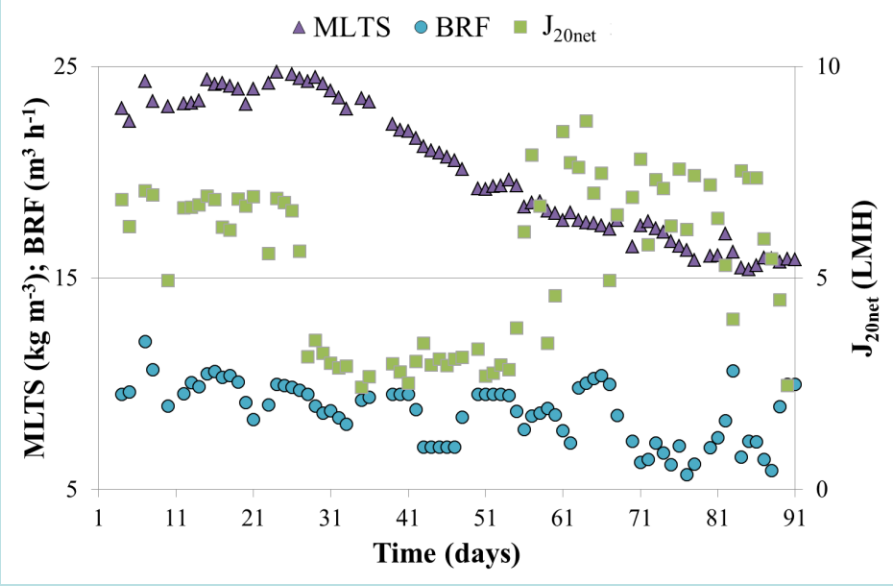


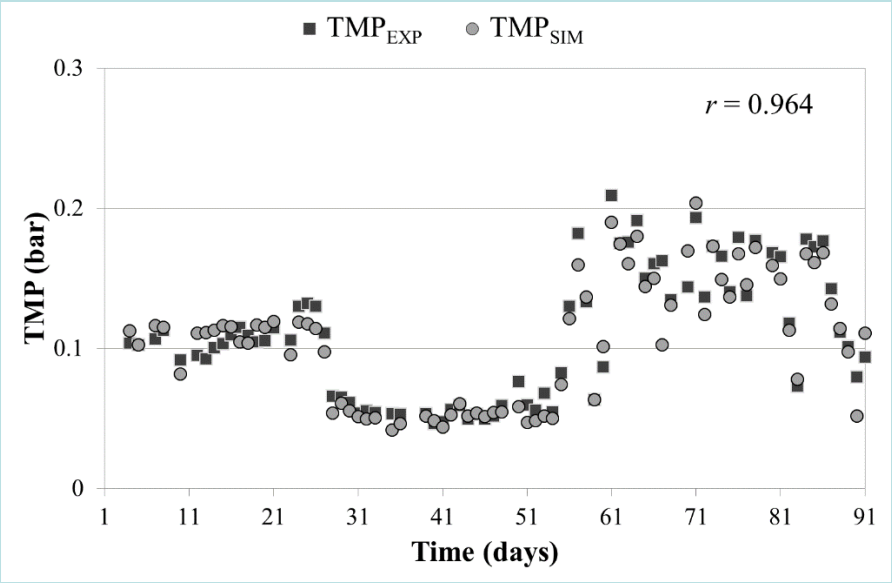
Robles et al. (2013) J. Membrane Sci. 444, 139–147.

Model-based supervisory controller

Filtration process model

- Long-term validation



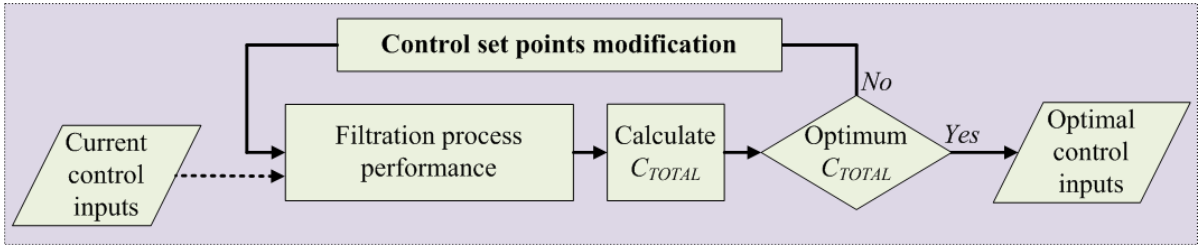


Robles et al. (2013) J. Membrane Sci. 446, 303–309.

Model-based supervisory controller

OPEX optimization

- Knowledge-based controller set points
  - SRF_{SP}
  - TMP_{MAX}
  - $K_{20,MIN}$
  - FR_{C_SP}



Model-based supervisory controller

OPEX optimization

- Membrane scouring by gas sparging (C_B)

$$C_B = \frac{M \cdot R \cdot T_{gas}}{(\alpha - 1) \cdot \eta_{blower}} \left[\left(\frac{P_2}{P_1} \right)^{\frac{\alpha - 1}{\alpha}} - 1 \right] \cdot \frac{E_{COST}}{V_T}$$

- Sludge pumping (C_{SRF})

$$C_{SRF} = q \cdot \rho_{sludge} \cdot g \frac{\left[\left(\frac{(L + L_{eq}) \cdot f \cdot V^2}{D \cdot 2 \cdot g} \right)_{asp} + \left(\frac{(L + L_{eq}) \cdot f \cdot V^2}{D \cdot 2 \cdot g} \right)_{imp} \right] + [z_1 - z_2]}{\eta_{pump}} \cdot \frac{E_{COST}}{V_T}$$

- Permeate pumping (C_{stage})

$$C_{stage} = \frac{q_{stage} \cdot TMP_{stage}}{\eta_{pump}} \cdot \frac{E_{COST}}{V_T}$$

Model-based supervisory controller

OPEX optimization

- Chemical cleaning ($C_{REAGENTS}$)

$$C_{REAGENTS} = \frac{\Delta R_{I,\,filtration}}{\Delta R_{I,MAX}} \cdot \frac{\left(X_{AC} \cdot AC_{COST} + X_{NaOCl} \cdot NaOCl_{COST}\right)}{V_T}$$

- Membrane replacement ($C_{LIFESPAN}$)

$$C_{LIFESPAN} = \frac{\Delta R_{I,\,filtration}}{\Delta R_{I,MAX}} \cdot \frac{M_{COST} \cdot A \,/\, N_{C,MAX}}{V_T}$$

$$OPEX = C_B + C_{SRF} + C_{stage} + C_{REAGENTS} + C_{LIFESPAN}$$

Model-based supervisory controller

4 set points for the knowledge-based controller

- FR_{C_SP}
- TMP_{MAX}
- $K_{20,MIN}$
- SRF_{SP}

A total of 23 parameters need to be adjusted:

REDUCING THE NUMBER OF TUNING PARAMETERS IS ESSENTIAL!

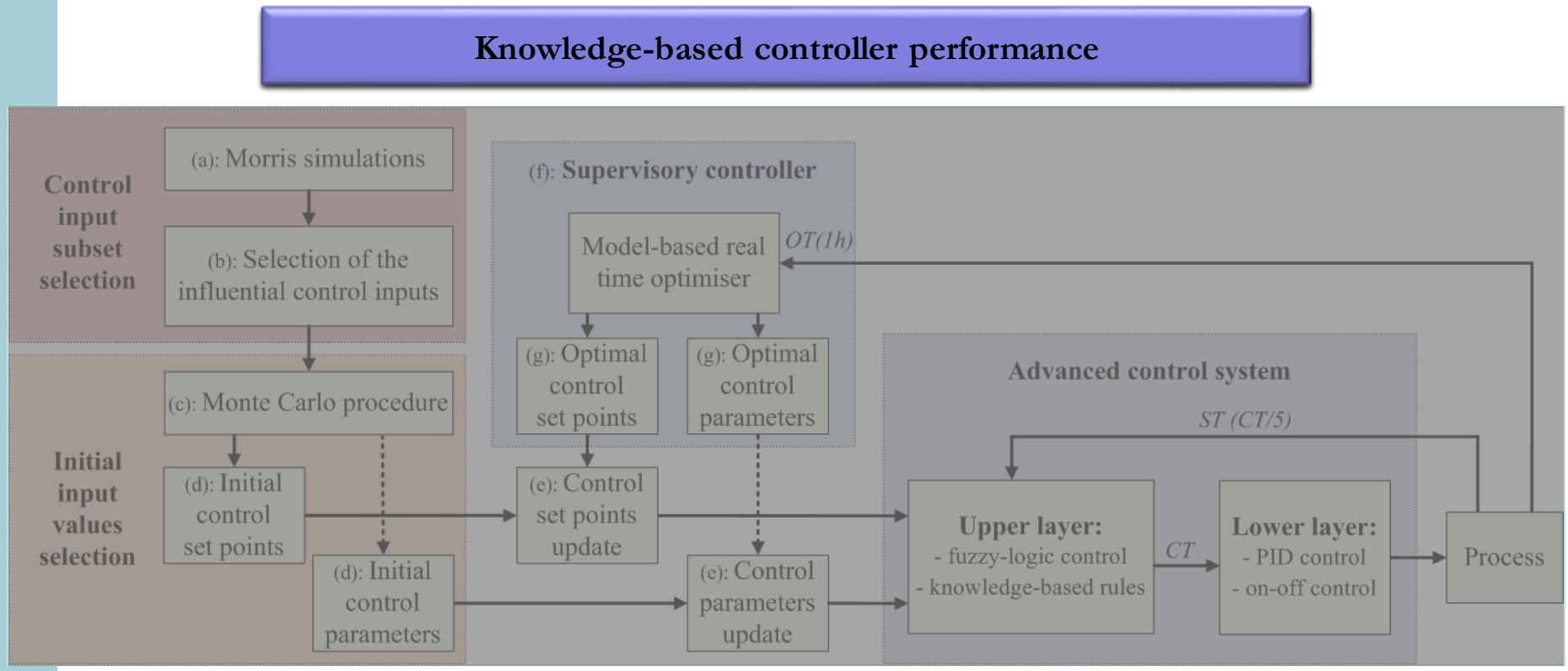
19 values of fuzzy-logic control parameters

- Centre
- Amplitud
- Singleton
- Control time (*CT*)

GLOBAL SENSITIVITY ANALYSIS

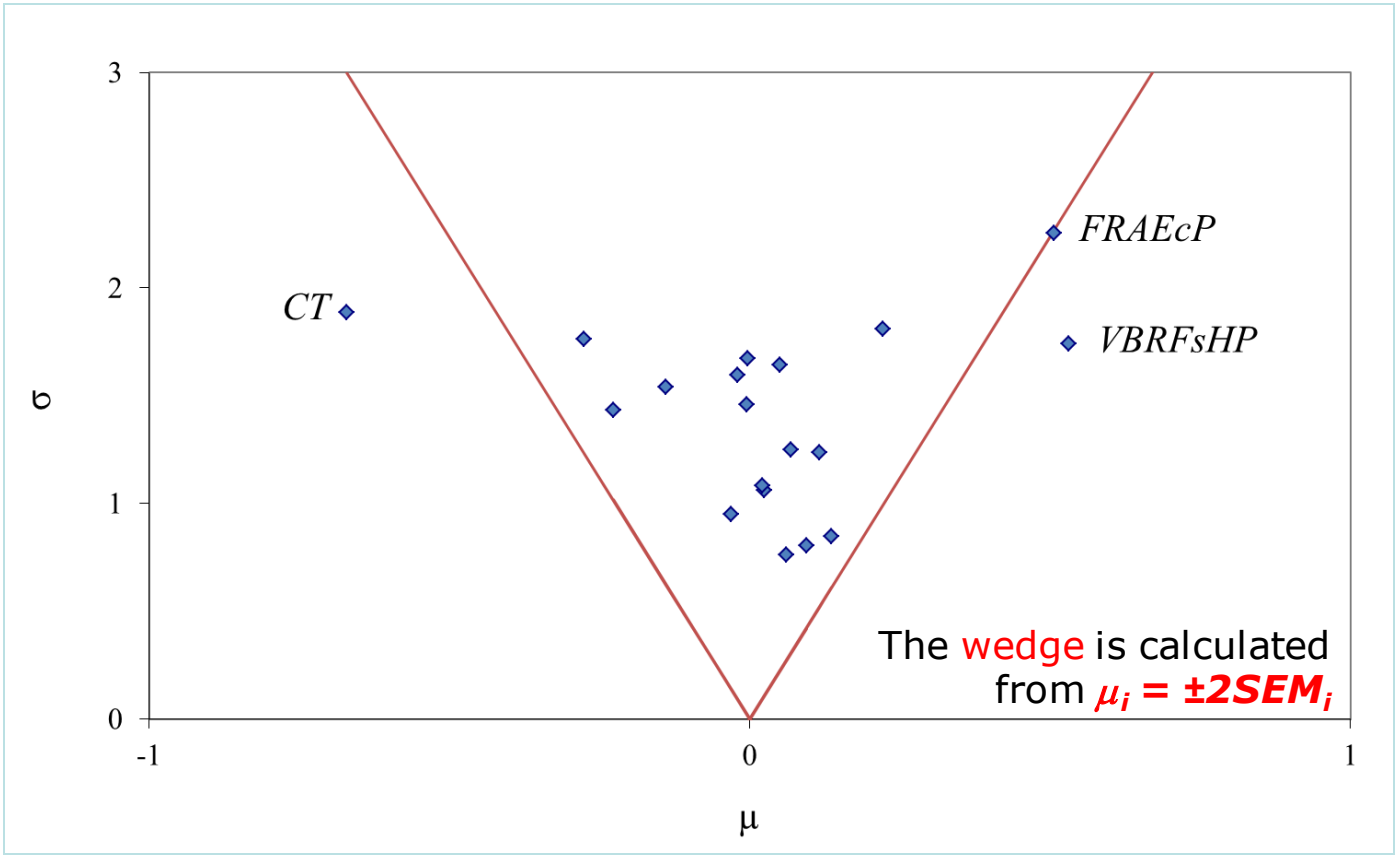
Model-based supervisory controller

Control structure



Model-based supervisory controller

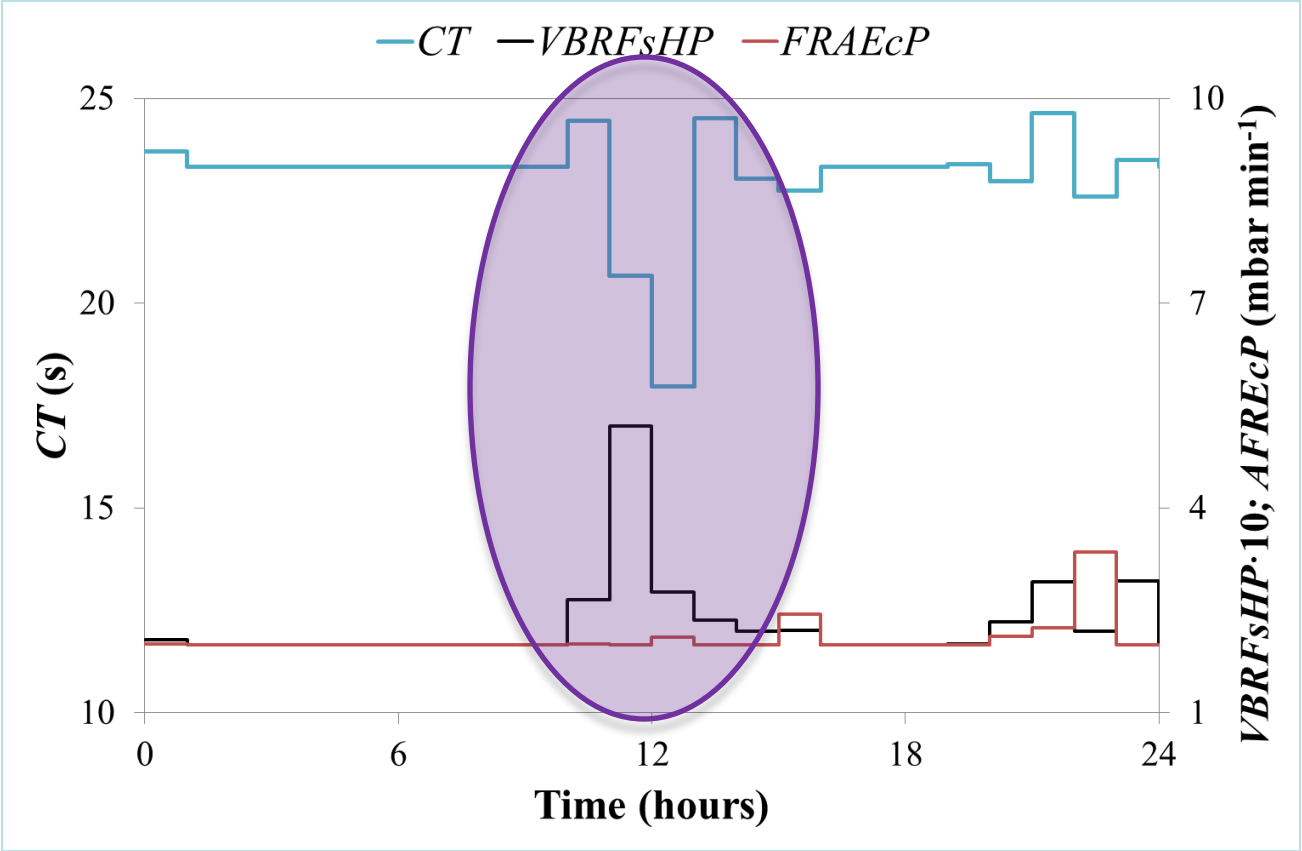
Sensitivity analysis: fuzzy-logic control parameters



Graphical Morris approach for r=80

Model-based supervisory controller

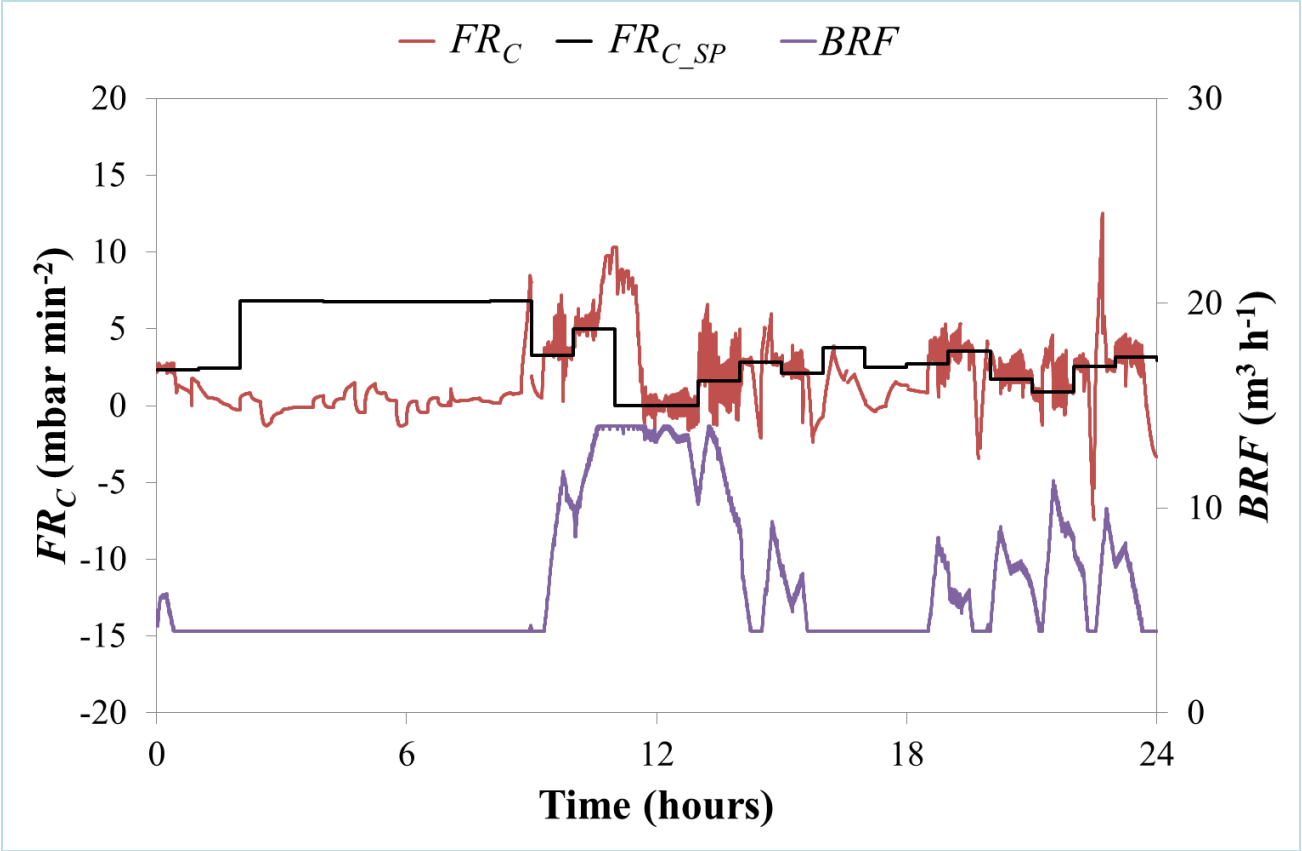
Optimization of fuzzy-logic control parameters



HIGHER VARIATION IN THE PERMEATE FLUX

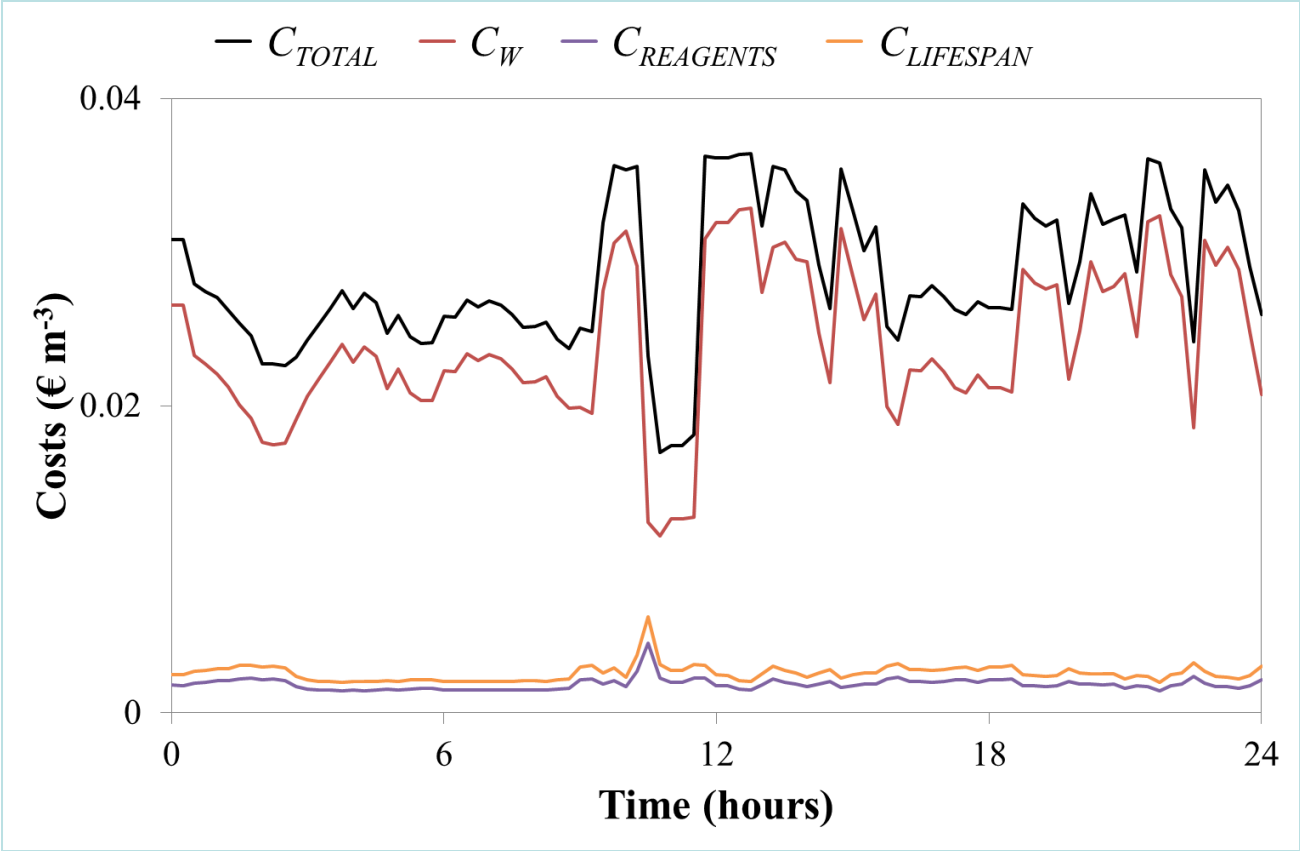
Model-based supervisory controller

Optimization of set points



Model-based supervisory controller

Overall performance: OPEX



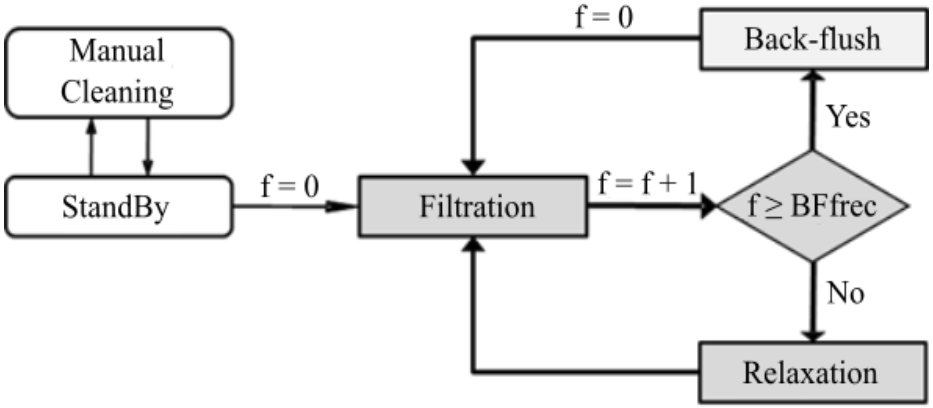
Energy term = €0.138/kWh

OPTIMUM OPERATING STRATEGY:
Operating at transmembrane fluxes around the critical flux.

Model-based optimization strategy

OPEX optimization

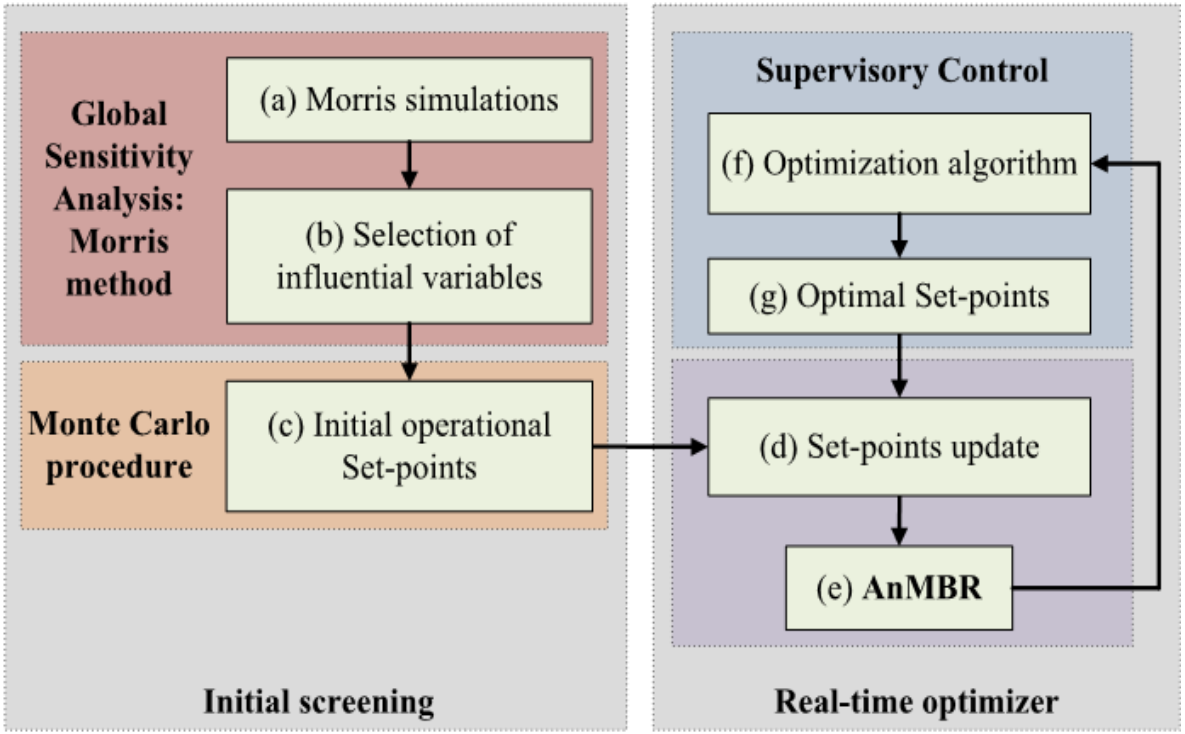
- Inputs
  - Biogas recycling flow (*BRF*)
  - Sludge recycling flow (*SRF*)
  - Duration of the filtration (*F*), relaxation (*R*) and back-flushing (*BF*)
  - Frequency of back-flushing initiation (BF_{freq})
  - Transmembrane flux during back-flushing (J_{BF})
- Output
  - OPEX



Robles et al. (2018) Waste Management 80, 299–309.

Model-based optimization strategy

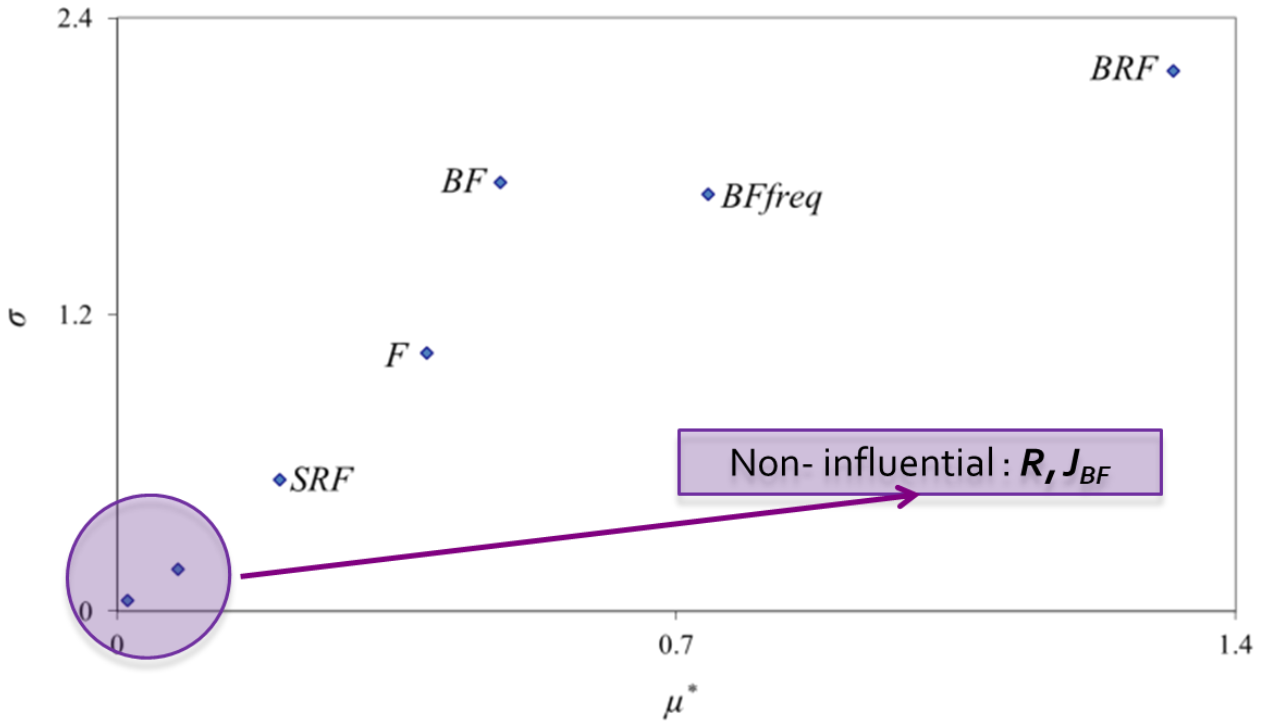
OPEX optimization



Robles et al. (2018) Waste Management 80, 299–309.

Model-based optimization strategy

OPEX optimization

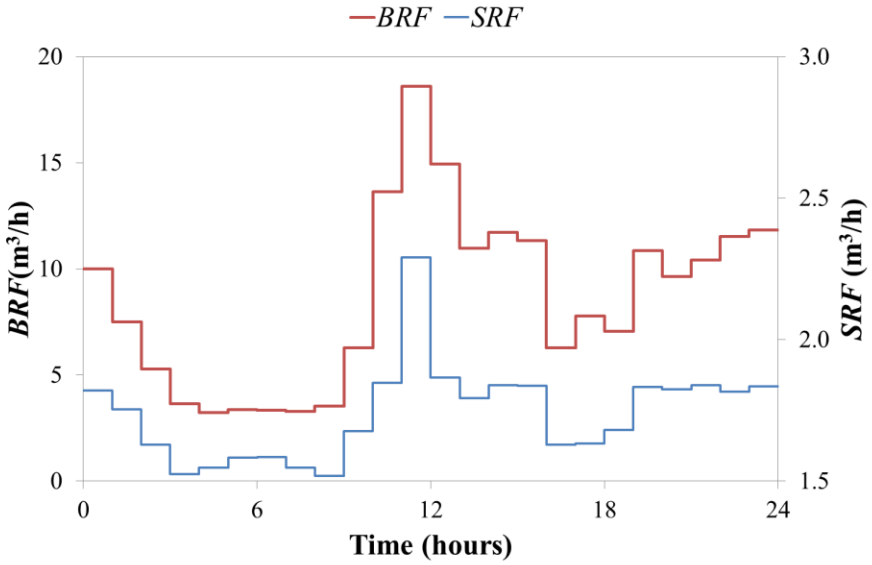


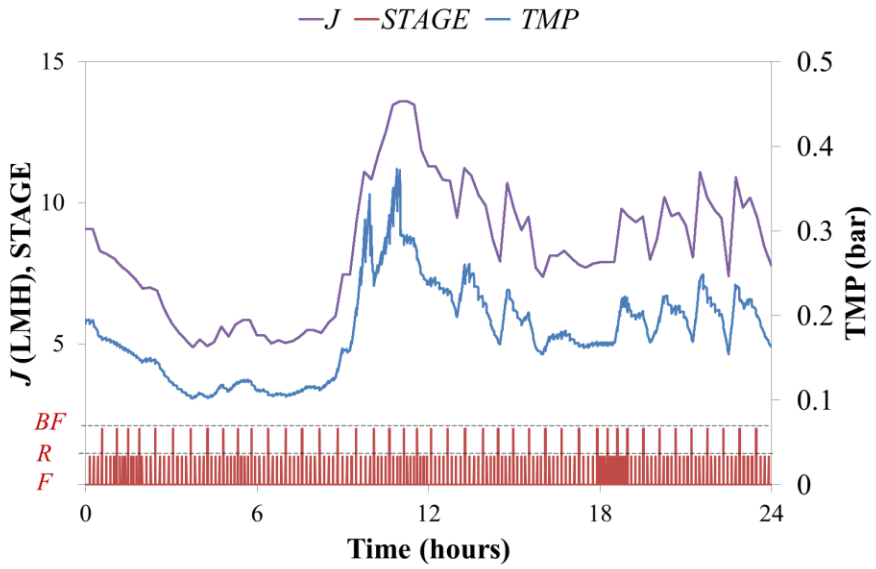
Graphical Morris approach for r_{opt}=40

Robles et al. (2018) Waste Management 80, 299–309.

Model-based optimization strategy

OPEX optimization





Robles et al. (2018) Waste Management 80, 299–309.

The role of membranes in future WRRFs: from prove of concept to process optimization

Ángel Robles
angel.robles@uv.es

CS meeting on "Digitization, Monitoring and Forecasting in water and wastewater management"
September 26th, 2023

VNIVERSITAT DE VALÈNCIA
Cal Agua
Unidad Mixta UV-UPV
UNIVERSITAT POLITÈCNICA DE VALÈNCIA

ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

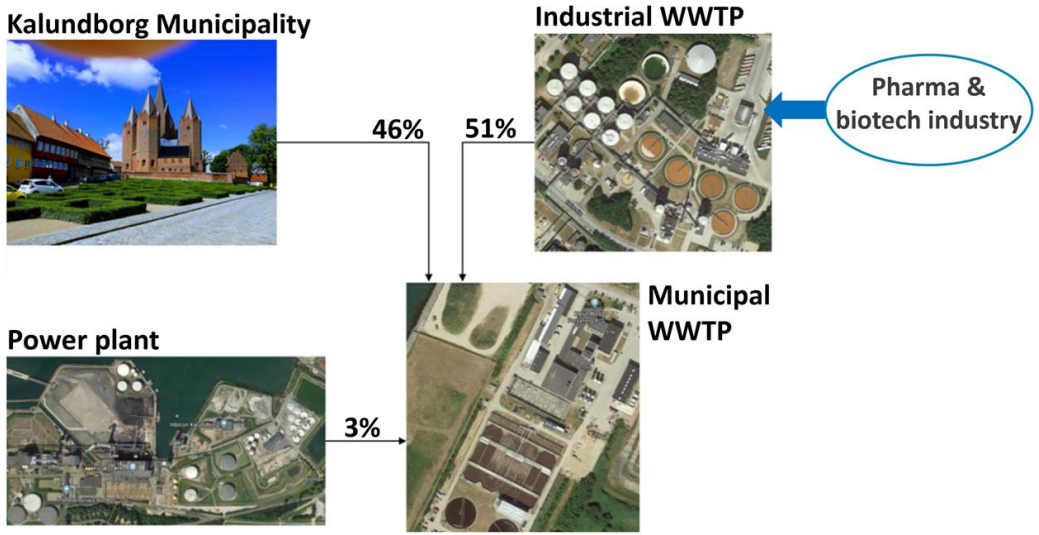
CS9 Kalundborg:

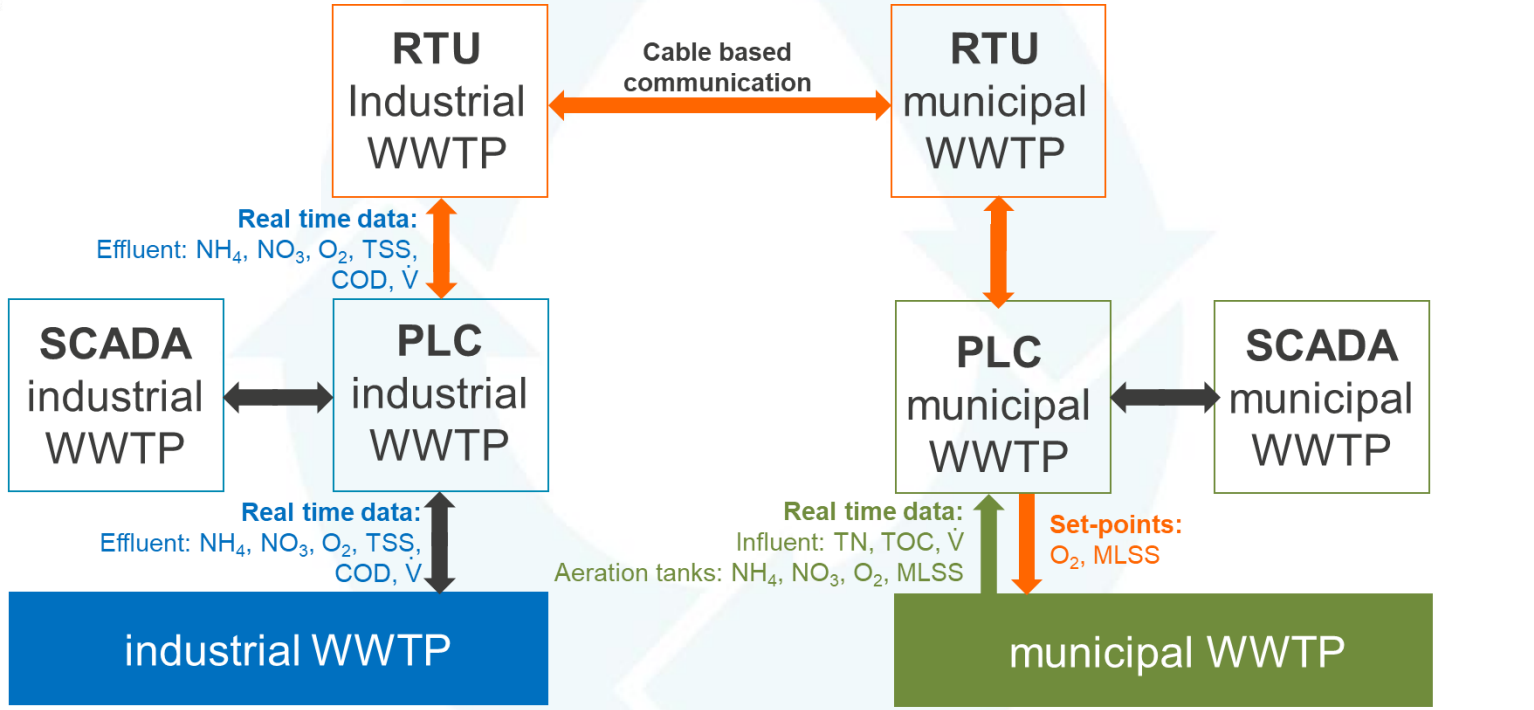
Joint control system for an industrial and a municipal wastewater treatment plant

Jan Schütz, Anne Kleyböcker, Sille Bendix Larsen, Malene Kristensen, Ulf Miehe



Idea – Joint control system for two WWTPs





SCADA	Supervisory Control and Data Acquisition
RTU	Remote Terminal Unit
PLC	Programmable Logic Controller
WWTP	Wastewater Treatment 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

Objectives and approach

Development of an activated sludge model (ASM-Model) for the municipal WWTP in order to test different scenarios regarding:

Reduction of the energy consumption

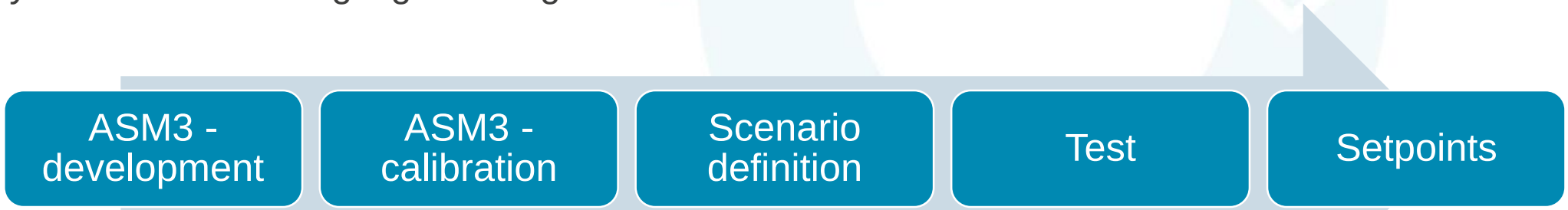
→ Model-based predictive controlled nitrogen elimination
(air supplied as low as possible via predicting TN load to the municipal WWTP)

Reduction of chemicals consumption for phosphorus elimination

→ Implementation of enhanced biological phosphorus removal

Optional: Reduction of direct discharges of untreated wastewater to recipient

→ Hydraulic buffer during high loading situations or stormwater events



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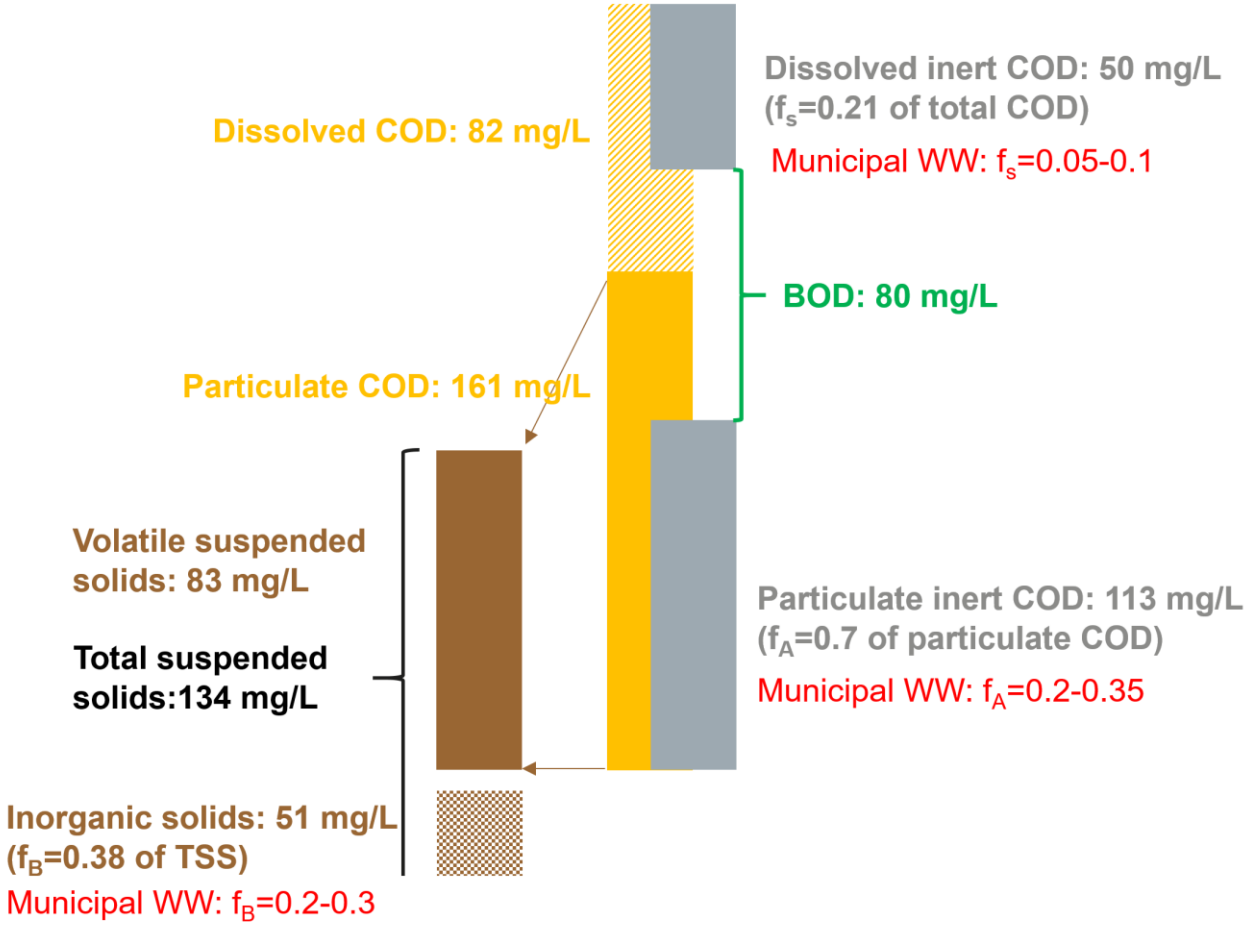
Challenges of the composition of the wastewater



- High fraction of inert COD
- Hight fraction of solids (COD and TSS)
- Low fraction of biodegradable substrate

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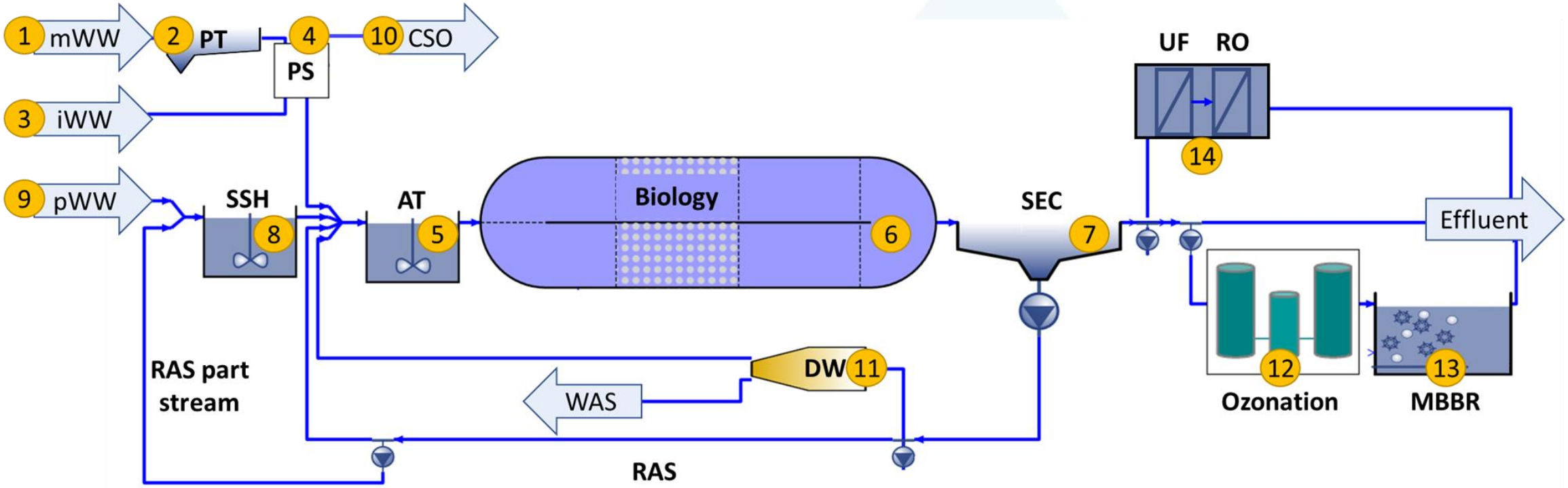
Plant set-up of the mWWTP



mWW	Municipal Wastewater	**PT**	Pre Treatment	**Ozonation**	Ozonation
iWW	Industrial Wastewater	**PS**	Pumping Station	**MBBR**	Moving Bed Biofilm Reactor
pWW	Power Plant Wastewater	**SSH**	Side Stream Hydrolysis	**UF**	Ultra Filtration
CSO	Combined Sewer Overflow	**AT**	Pre Mixing Tanks	**RO**	Reverse Osmosis
WAS	Wasted Activated Sludge	**Biology**	Aeration Tanks		
RAS	Return Activated Sludge	**SEC**	Secondary Clarifiers		
Effluent	Effluent to the recipient				

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

System boundaries for the model of the mWWTP

AT- tank:

V = 2100 m³

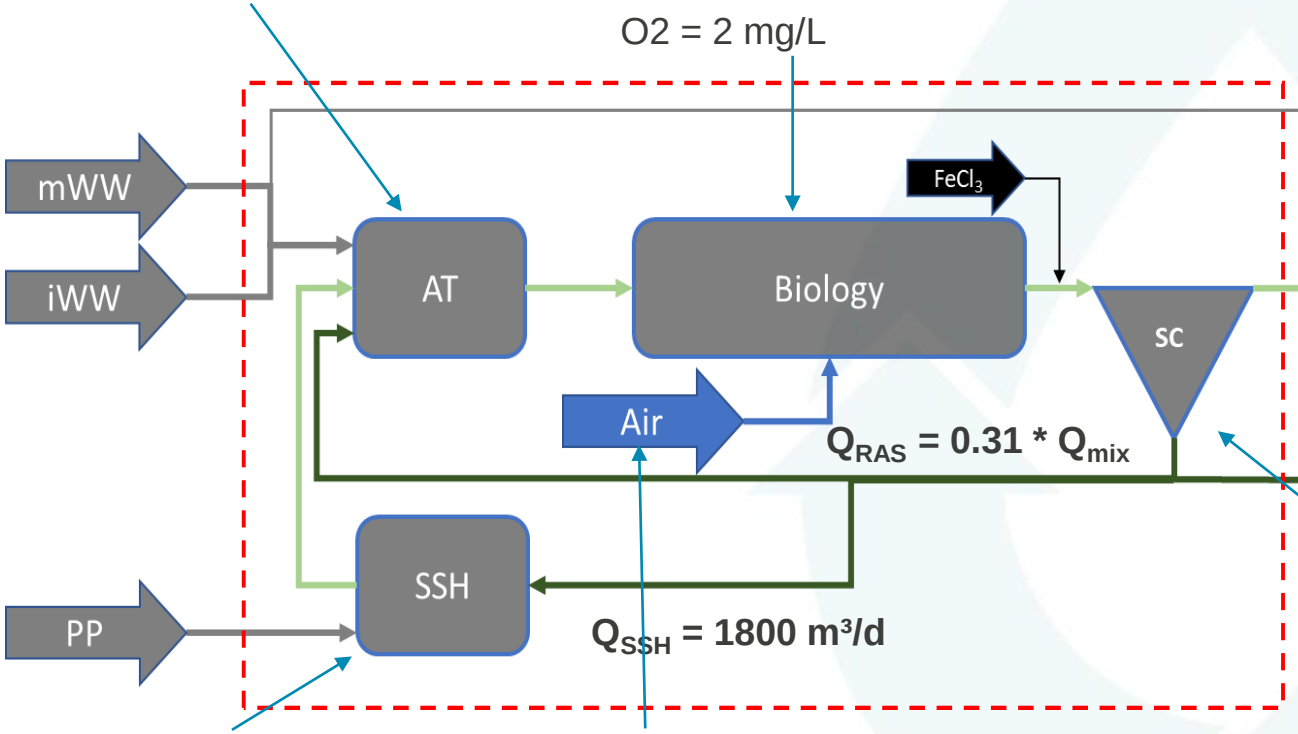
is used for mixing (with air)

4 Aeration ditches in parallel:

V = 14800 m³

MLSS = 5000 mg/L

O2 = 2 mg/L



CSO:

When the mixed WW flow exceeds 2160 m³/h

→ direct discharged

WAS:

Is controlled manually

→ Q_{WAS} = 143 m³/d

SSH for bio P removal:

V = 2200 m³

Aerationsystem:

Maximum capacity: Air = 2200 Nm³/h/tank

Diffusers: Fine tube, total length of 1400 m

Secondary clarifier:

A = 2122 m²; h = 4,1 m

SVI = 105 ml/g

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

Plant set-up of the mWWTP in SIMBA#

via software:

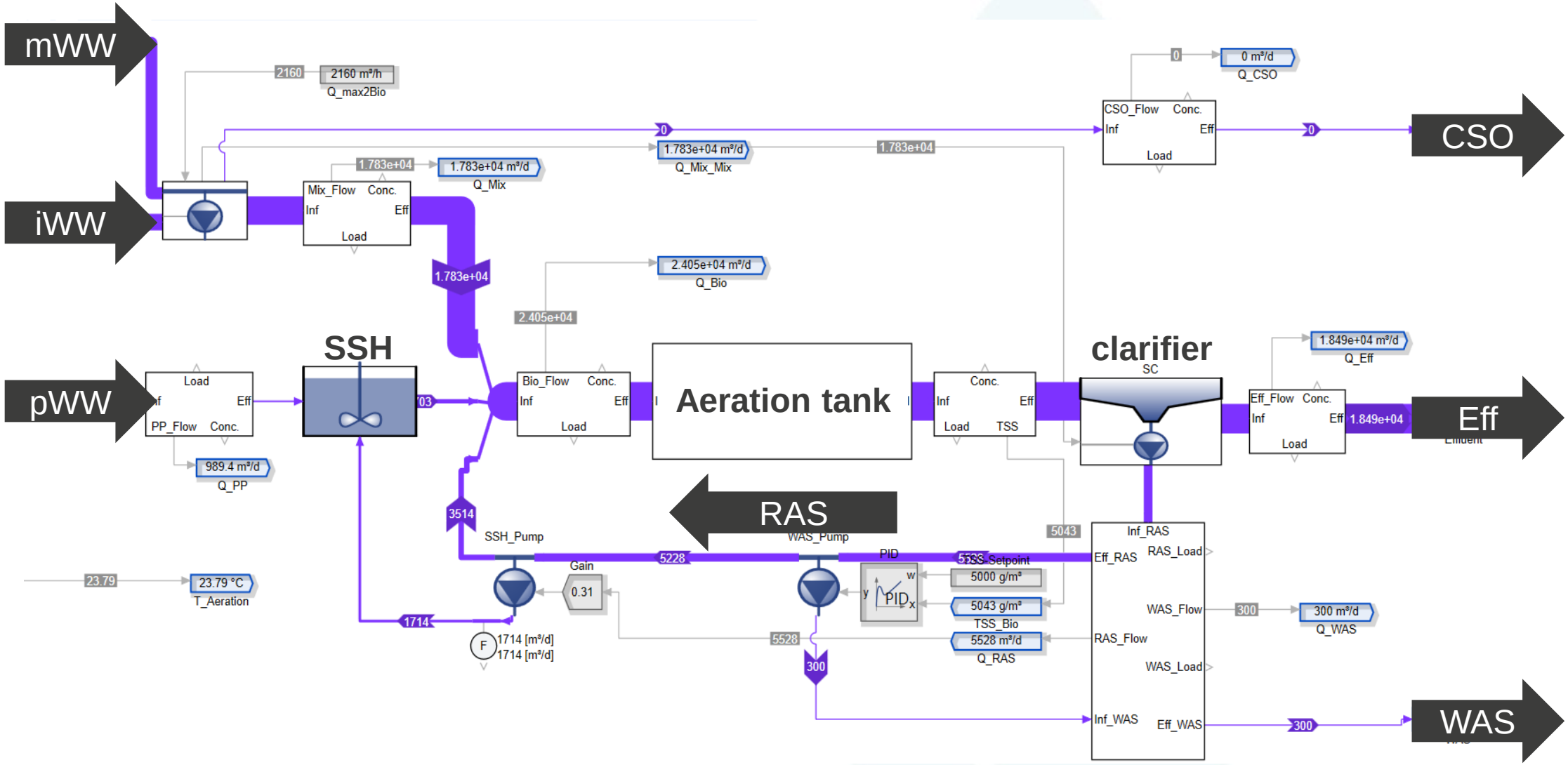


→ Challenge: wastewater results not only from municipality, but also from industry

→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

mWWTP in SIMBA# → flow



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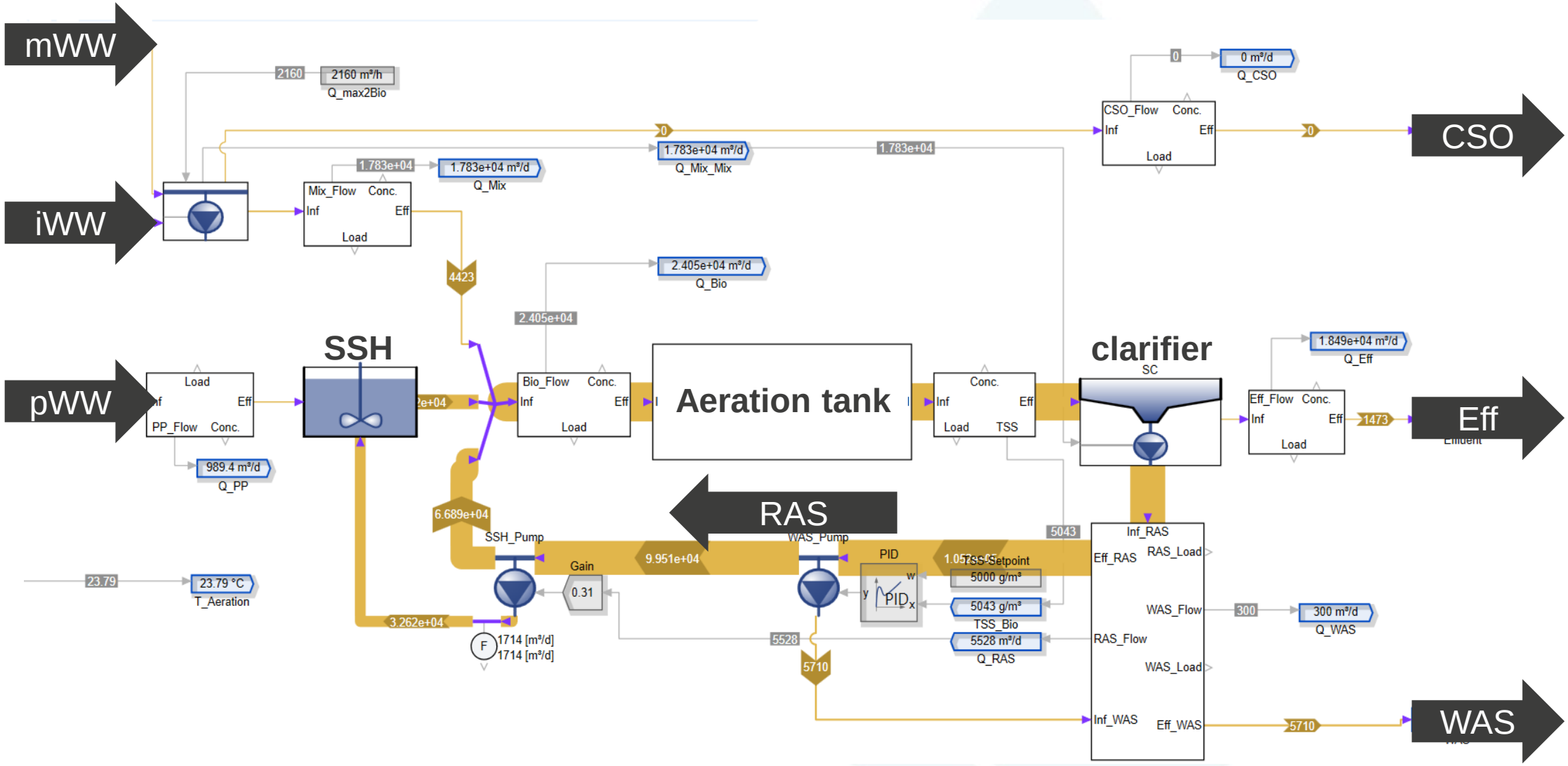
mWWTP in SIMBA# → COD load



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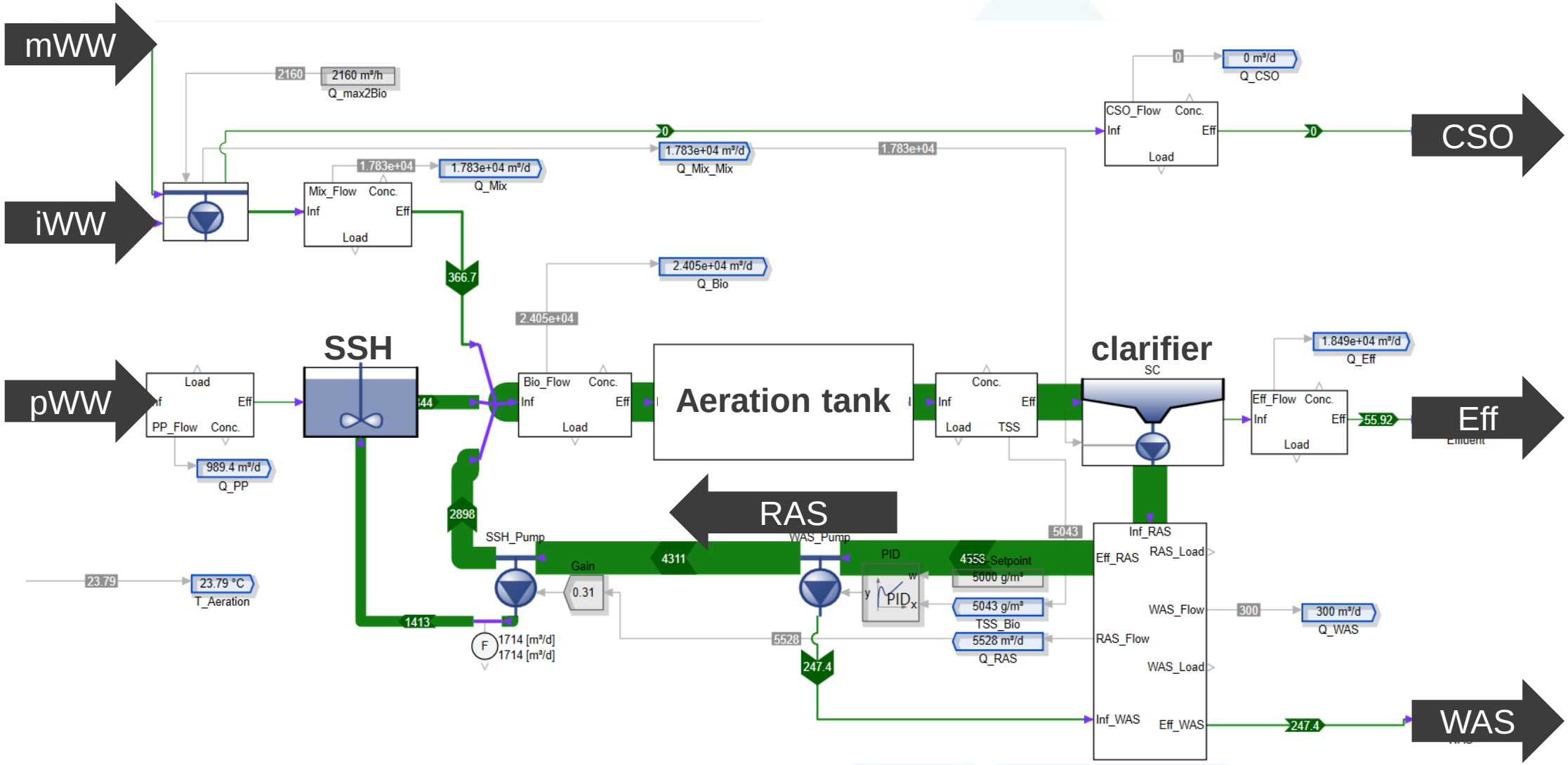
mWWTP in SIMBA# → TN load



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

Calibration of the KCR-Model

Statistical results: Model efficiency

Parameter	R^2	NSE	L	a_j
COD	0,92	0,91	0,91	0,26
TSS	0,74	-0,18	0,31	0,09
TN	0,81	0,68	0,72	0,20
NHx-N	0,64	0,58	0,66	0,19
NOx-N	0,11	-1,44	0,09	0,03
RAS	0,95	0,83	0,84	0,24

> 0,75
< 0,75 >0,25
< 0,25

R^2: coefficient of determination
NSE: Nash–Sutcliffe model efficiency coefficient
L: Likelihood
aj: weighting factor

- → Models are only as good as the quality of the data they rely on.
- → Pre-processing and verification of data is crucial.
- → Due to manual TSS & O_2 control on site, assumptions had to be made to model sludge and aeration control

overall model efficiency

$$E_i = \sum_{j=0}^{n} \alpha_j \times L\left(\frac{\theta_i}{Y_j}\right)$$

E_i = 0,74

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

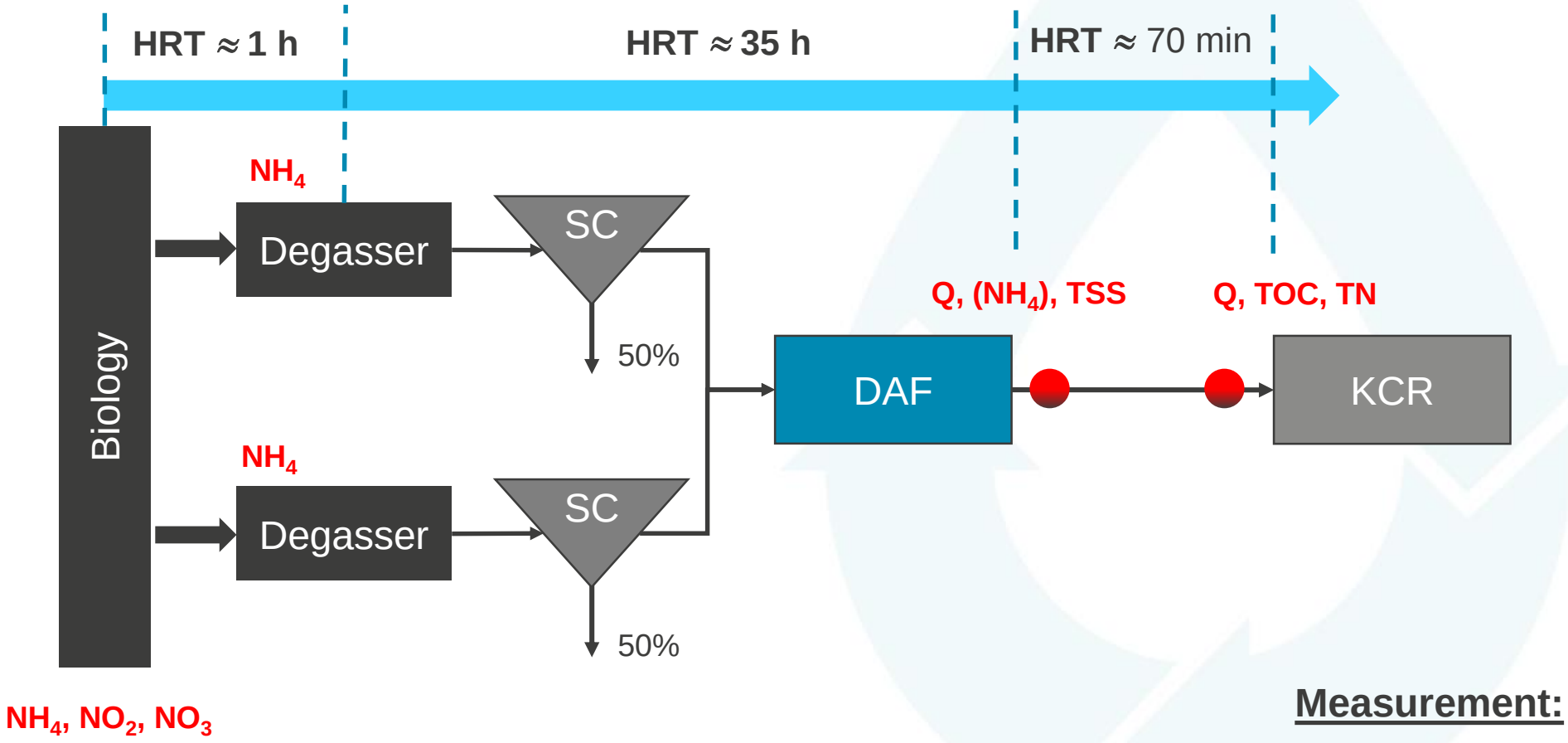
Scenario definition

1. **Model-based predictive controlled nitrogen elimination (air supplied as low as possible via predicting TN load to the municipal WWTP)**
   - Development of a TN prediction equation by statistical analysis - to predict the load of TN from the iWWTP
   - Modelling the effect of TN variations coming from iWWTP on the entire system with different control strategies - **ongoing**

2. **Reduction of direct discharges of untreated wastewater to recipient**
   - Implementation and testing of additional upstream buffer-tank to avoid direct discharges in case of stormwater events

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

TN prediction on hourly basis for NZ effluent → KCR influent



Measurement:

Online

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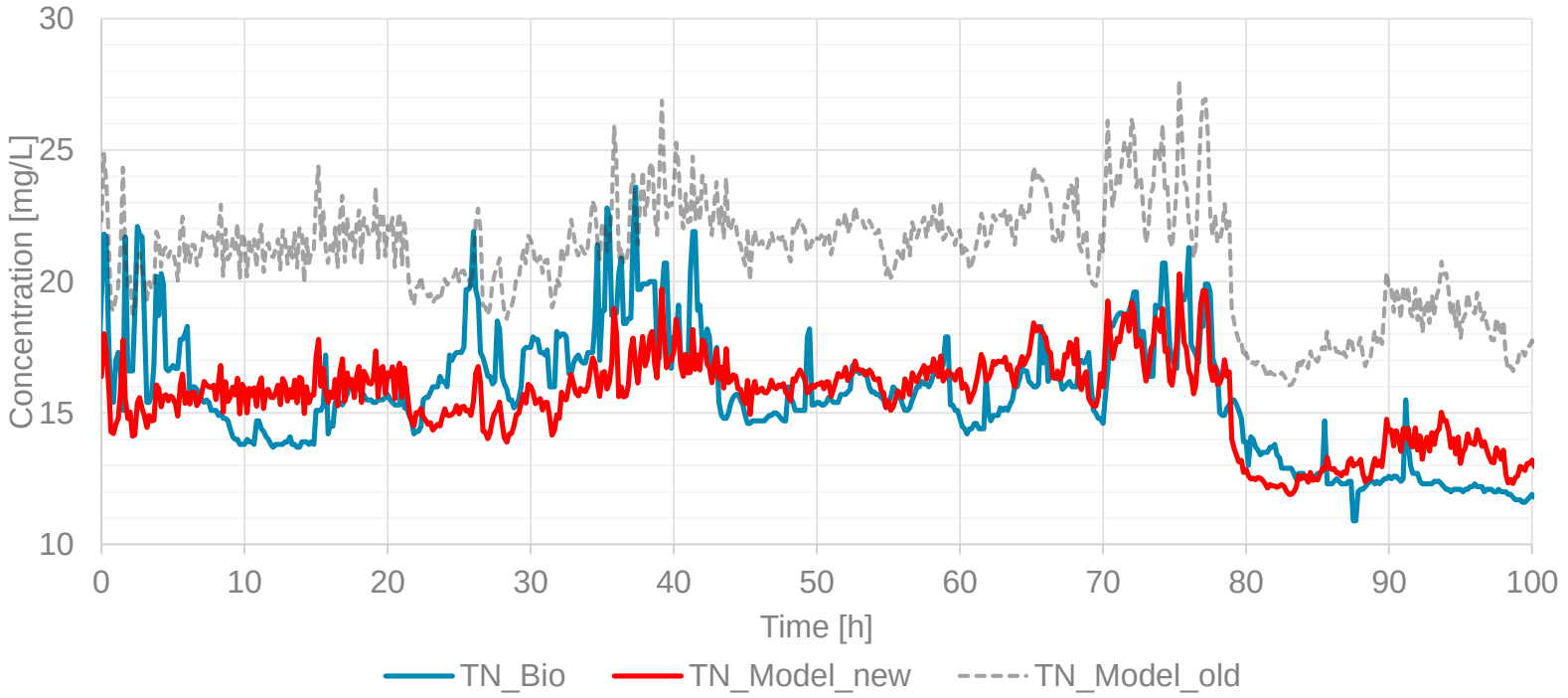
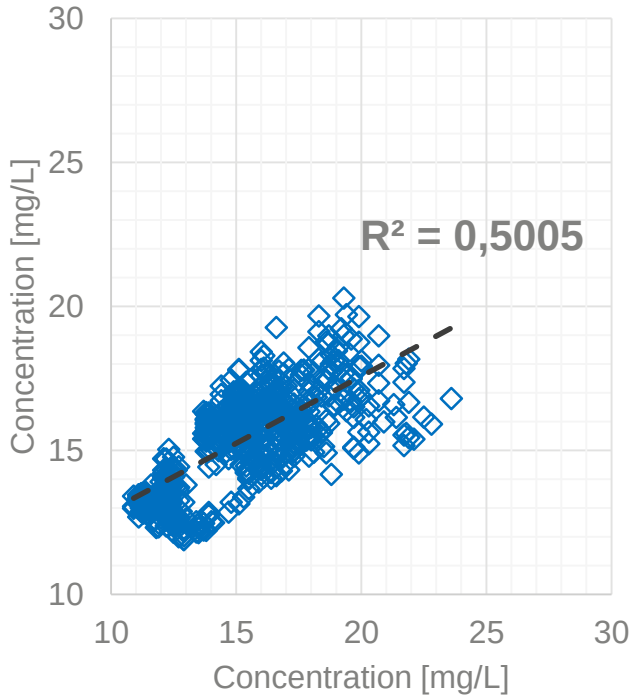
TN prediction on hourly basis for NZ effluent → KCR influent





→ NH_4-N concentration is measured 36h before entering mWWTP

$$TN_{Model_{New}} \approx 1,5 * c_{NH_4-N} + 0,06 * c_{TSS}$$

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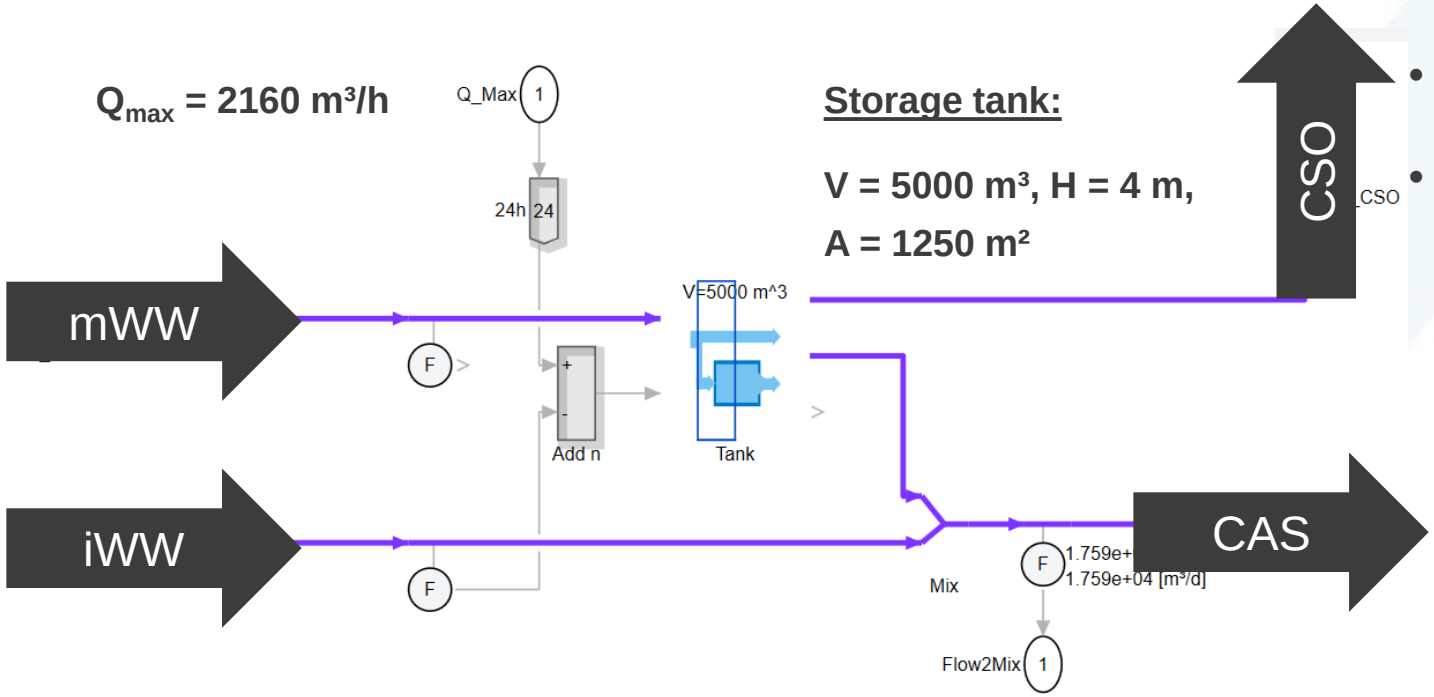
Results Scenario 2: Reduction of overflow-events

Q_{max} = 2160 m³/h



Storage tank:

V = 5000 m³, H = 4 m,
A = 1250 m²

- Maximum Flow is set to 2160 m³/d
- Outflow is calculated by the NZ Flow measurement

$$Q_{OF} = Q_{max} - Q_{NZ}$$

Parameter	without Storage	with Storage	reduction overflow
Q [m³]	283.760	3.077	99%
COD [kg]	73.128	523	99%
TSS [kg]	50.773	379	99%
TN [kg]	5.315	44	99%
TP [kg]	1.229	12	99%

→ Significant reduction of overflow to the recipient: reduction by 99 % of wastewater volume and pollutant loads

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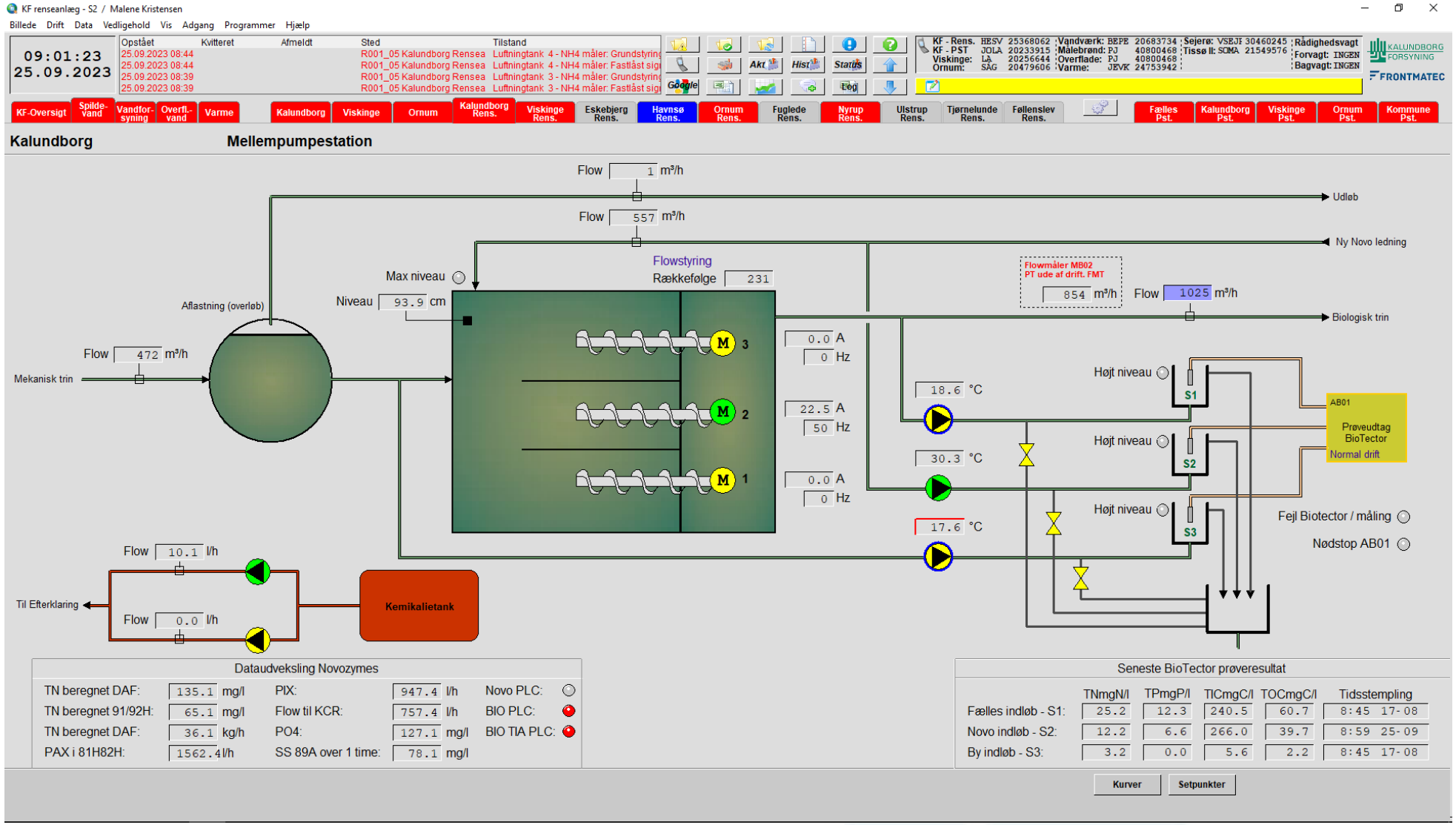
Pictures of joint control system: current implementation



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Pictures of joint control system: current implementation







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Conclusions

- Pre-processing and verification of data is crucial.
- **NH_4-N measurement in degassing tank is suitable as predictive indicator** for TN calculation together with TSS content in the effluent of the iWWTP
- The **high overall model efficiency of 74%** indicates that the model is suitable to investigate different scenarios for set-point definition
- Implementation of upstream **buffer tank (5000 m³) leads to significant reduction (99%) of overflow** to the recipient

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Outlook

1. Modelling of variations in TN load with different control strategies → define further set-points

2. Implement joint control system

3. Test of the joint control system

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B-WaterSmart

Digitalisation, Monitoring and Forecasting in water and wastewater management

The Short-term Demand Forecasting Tool & the Regional Demand-Supply Matching GIS Tool

26 September 2023

Katharina Gimbel & Marcel Juschak
IWW Zentrum Wasser

b-watersmart.eu

Outline

(Short) Introduction on B-WaterSmart and the Living Lab East Frisia

The Regional Demand-Supply Matching GIS Tool

The Short-Term Demand Forecasting Tool

The B-WaterSmart project & Living Lab East Frisia

(Short) Introduction on B-WaterSmart

Coastal areas in Europe facing challenges:

- water scarcity and increasing water demands due to climate change and economic and population growth.

- This can lead to overexploitation of resources, quality deterioration and regional imbalances in the availability of water resources.

B-WaterSmart:

- European research project building a water-smart society and economy

➔ develops and demonstrates smart technologies and circular economy approaches.

- Sister Project to ULTIMATE

(Short) Introduction on B-WaterSmart

Living Labs:

- In cooperation with various interest groups, innovative solutions are co-developed and tested at six sites, called Living Labs, spread across Europe.
- In order to implement those solutions more strongly in the practice of the water sector, technical and digital solutions as well as new business models are jointly developed by the project partners.

- Living Labs: Alicante in Spain, Bodø in Norway, Flanders in Belgium, Lisbon in Portugal, East Frisia in Germany and Venice in Italy develop and demonstrate solutions together with research partners and local technology providers.

- different structures and challenges

Tools and technologies:

- In total 18 technologies and 16 software tools in development



Living Lab East Frisia



Climate Change

- Salt water intrusion / change in groundwater recharge
- Rising peak load
- New water demands (cooling water / irrigation)

Demographic Change

- Rising population and per capita consumption

Applied tools and technologies

- Technologies: Pilot plant for combined treatment of vapour condensate & milk/whey permeate for reuse in dairy industry
- Tools: Regional Demand-Supply Matching GIS Tool, Short-Term Demand Forecasting Tool, Urban Water Optioneering Tool (application)

The Regional Demand-Supply Matching GIS Tool

The Regional Demand-Supply Matching GIS Tool

Motivation

- Raising water needs: often drinking water quality is not necessary for use
- Tap unused water resources instead
- show possible alternative resources

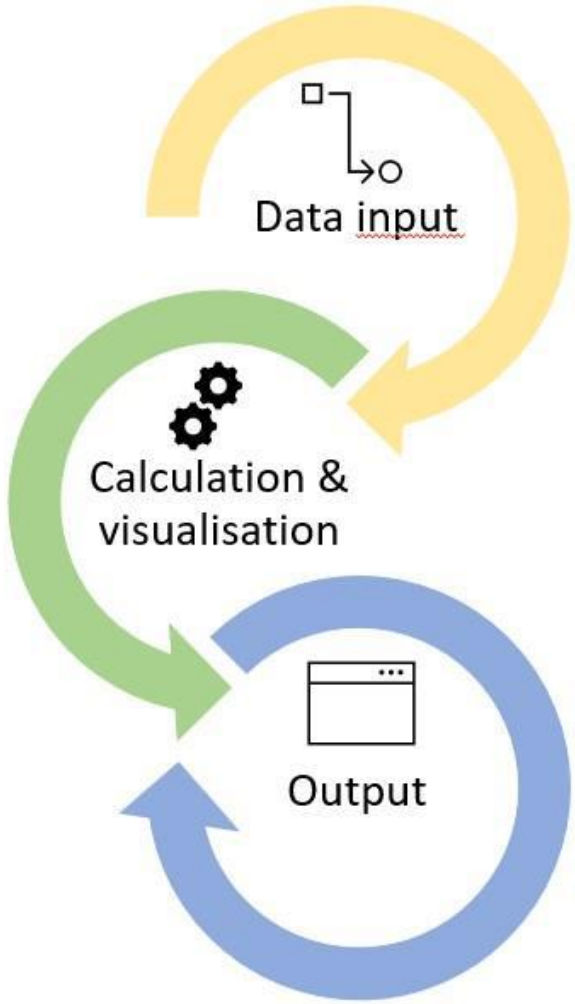
Idea

- use of open data and open GIS platform to match demands and alternative sources of supply on a regional scale
- Pooling and analysis of water-related data in terms of supply/availability, consumption and transfer
- **integrate results of UWOT model** runs (different **water use szenarios**)
- Shows possible **alternative water resources**, e.g. potential for rainwater harvesting and water reuse

Publicly available data

User owned data

UWOT data



Publicly available data

- **Administrative information** (state borders, federal states, counties,...)
- **Land use** information (land use, nature reserves,...)
- Drinking water information - **water consumption** and water extraction (water consumption per capita, total water consumption, extraction rates,...)
- Resource-side information (groundwater bodies, surface waters, chemical status,...)
- Alternative resources (precipitation, water-reuse (wastewater treatment plants),...)

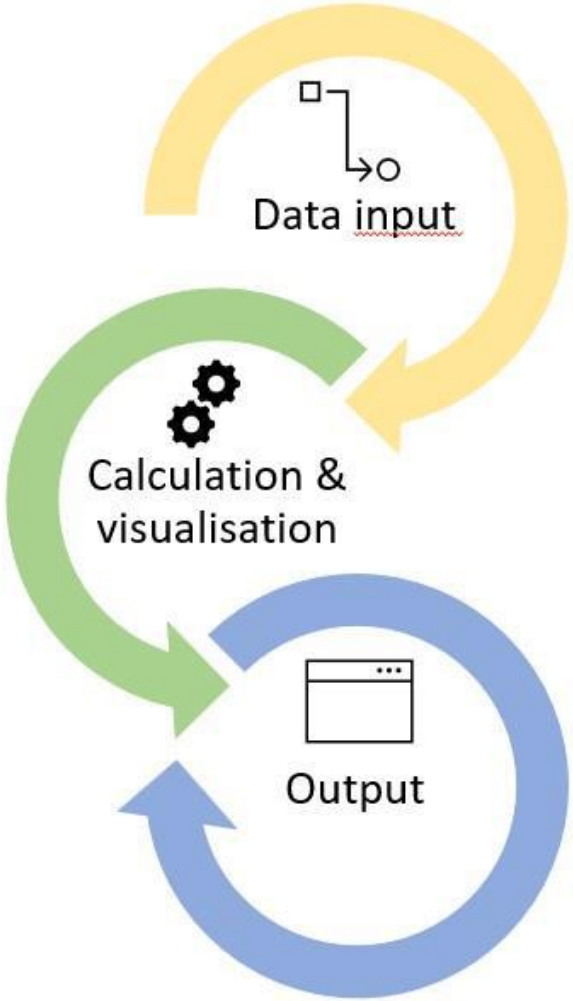
Publicly available data

User owned data

UWOT data

Internal calculation

Visualisation



Query result:

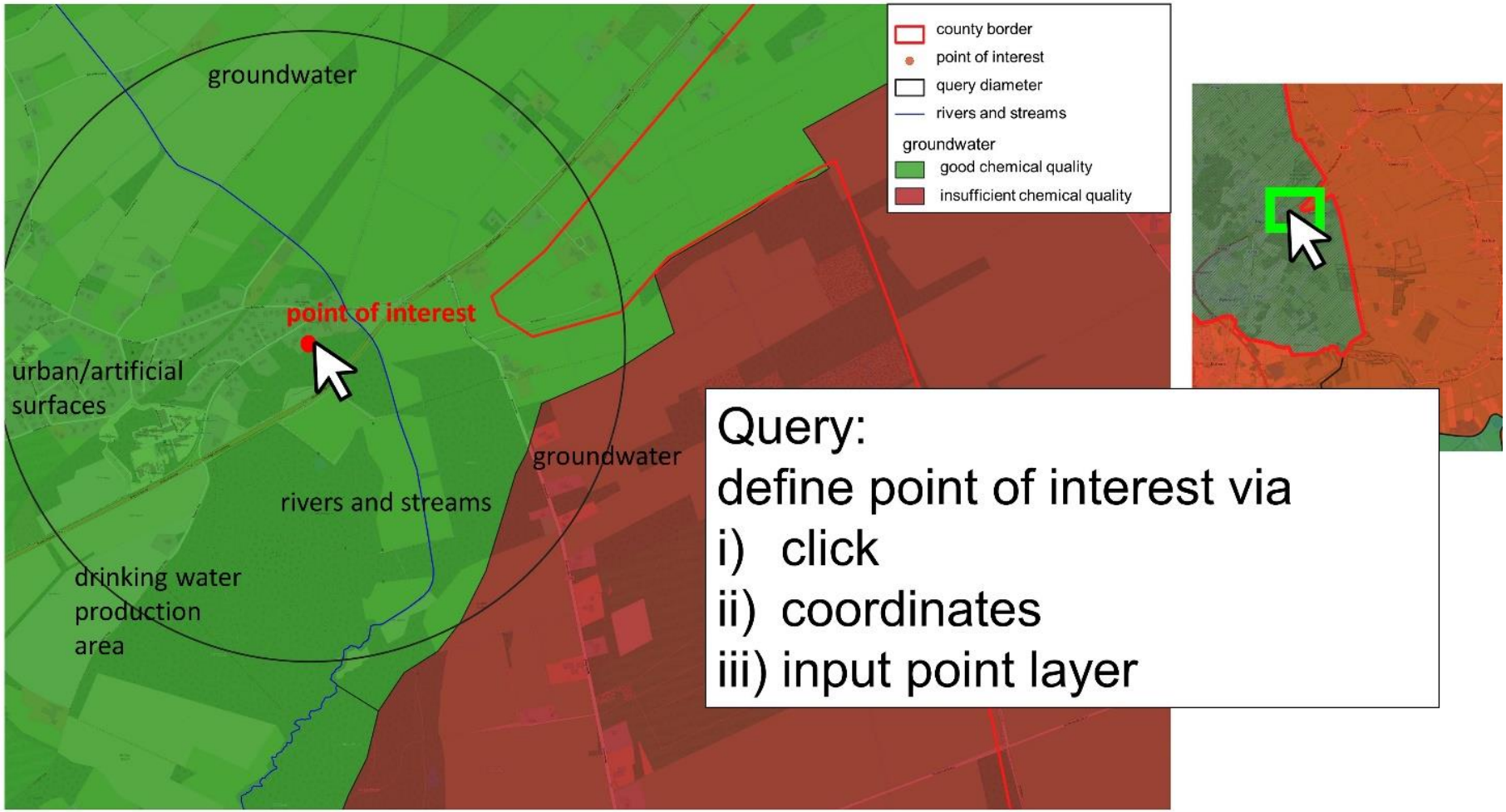
Data results

Distances

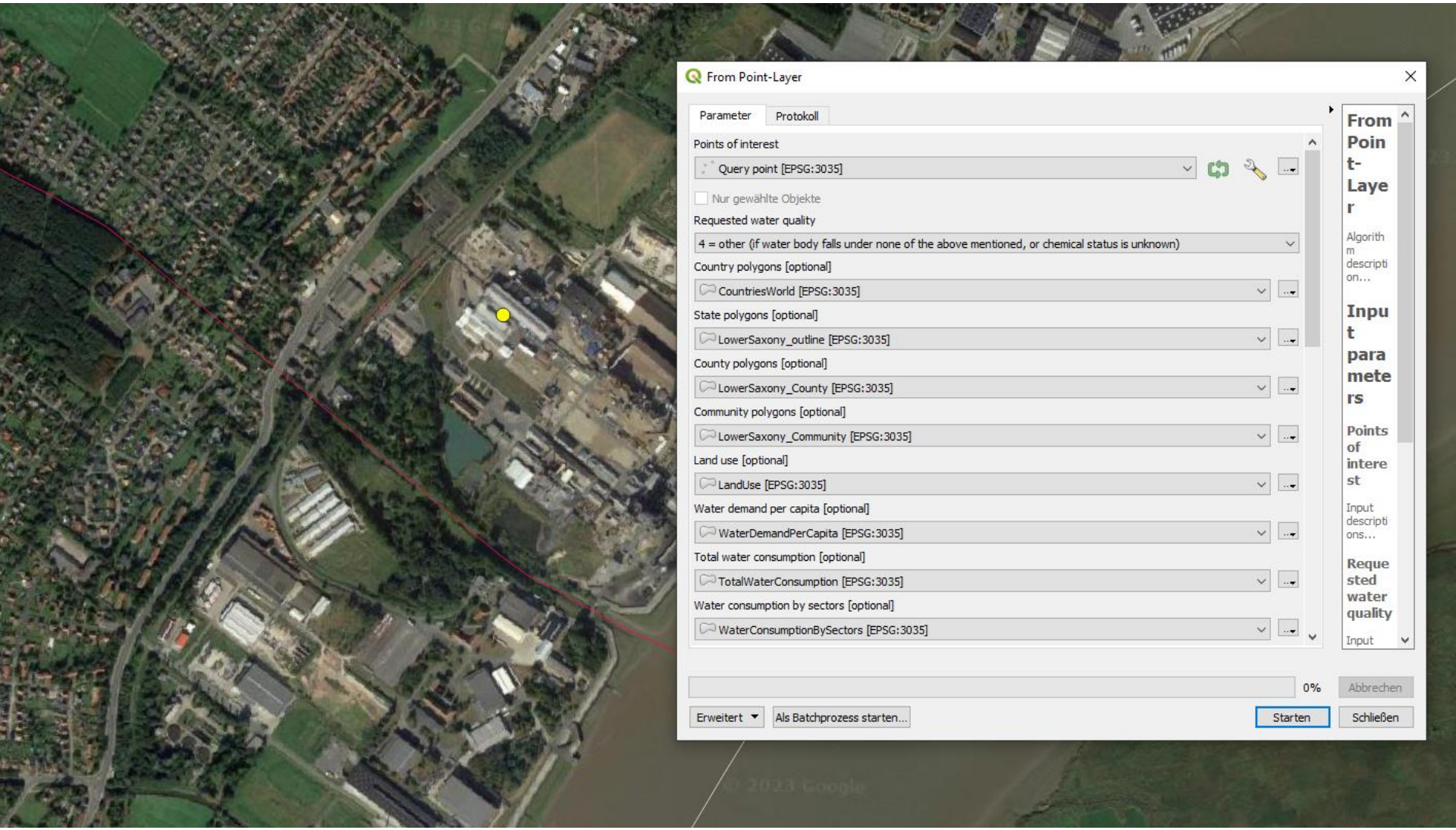
Estimated cost range (high – medium – low)

Precipitation

The Regional Demand-Supply Matching GIS Tool



The Regional Demand-Supply Matching GIS Tool



B-WaterSmart

The Short-Term Demand Forecasting Tool

Marcel Juschak

Short-Term Water Demand Forecasting Tool

Motivation

- Growing peak loads due to increasingly extreme weather (e.g. droughts)
- Risk of local water shortages
- Water demand forecasts help anticipate peak loads and enable water distribution in an efficient manner.
- Forecasts often only exist on a very high level (e. g. for the whole network).
- Complex network structures make the identification of the individual water consumption of households, industrial and agricultural users difficult and thus, the provision of water demand forecasts for smaller supply areas difficult.

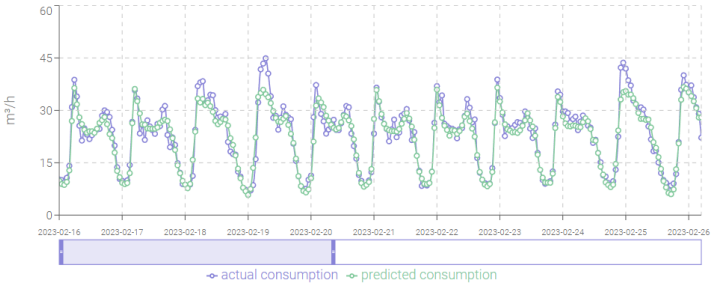
Short-term water demand forecasting tool

- Generates 24-hour water demand forecasts based on smart meter data
- Different spatial resolutions (e.g. per household or group of households)
- Produces a better knowledge base that helps manage the water supply system efficiently and sustainably

Short-Term Water Demand Forecasting Tool

Collect data

- Smart meter installation
- Measurement of water consumption (or flow) over a period of at least 1 year (preferably 3 years)
- Optionally, capture any additional data that the tool should take into account, for example:
  - Weather (temperature, precipitation, …)
  - Local events that impact water consumption

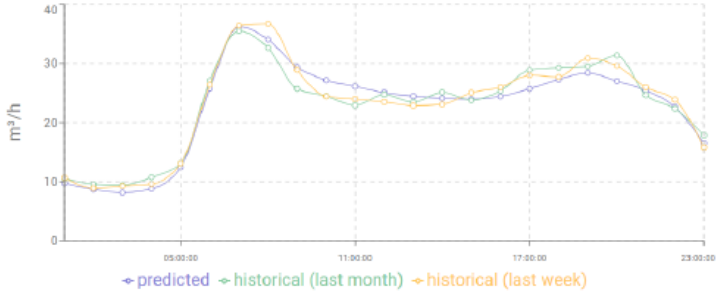


Install the tool

- Connect data streams to tool
- Use the tool‘s optional UI or build a custom UI in your own existing platform
- Alternatively, use the tool headless (i.e. without UI)

Generate value

- Create water demand forecasts manually or automatically
- Take action based on forecasts manually or automatically



Short-Term Water Demand Forecasting Tool

Forecast generation

- Machine learning algorithms
- Learn primarily from water consumption time series data
- Can optionally integrate additional information, like weather
- Six algorithms to choose based on
  - computational resources (some algorithms require a lot of computation)
  - what works best for the given data

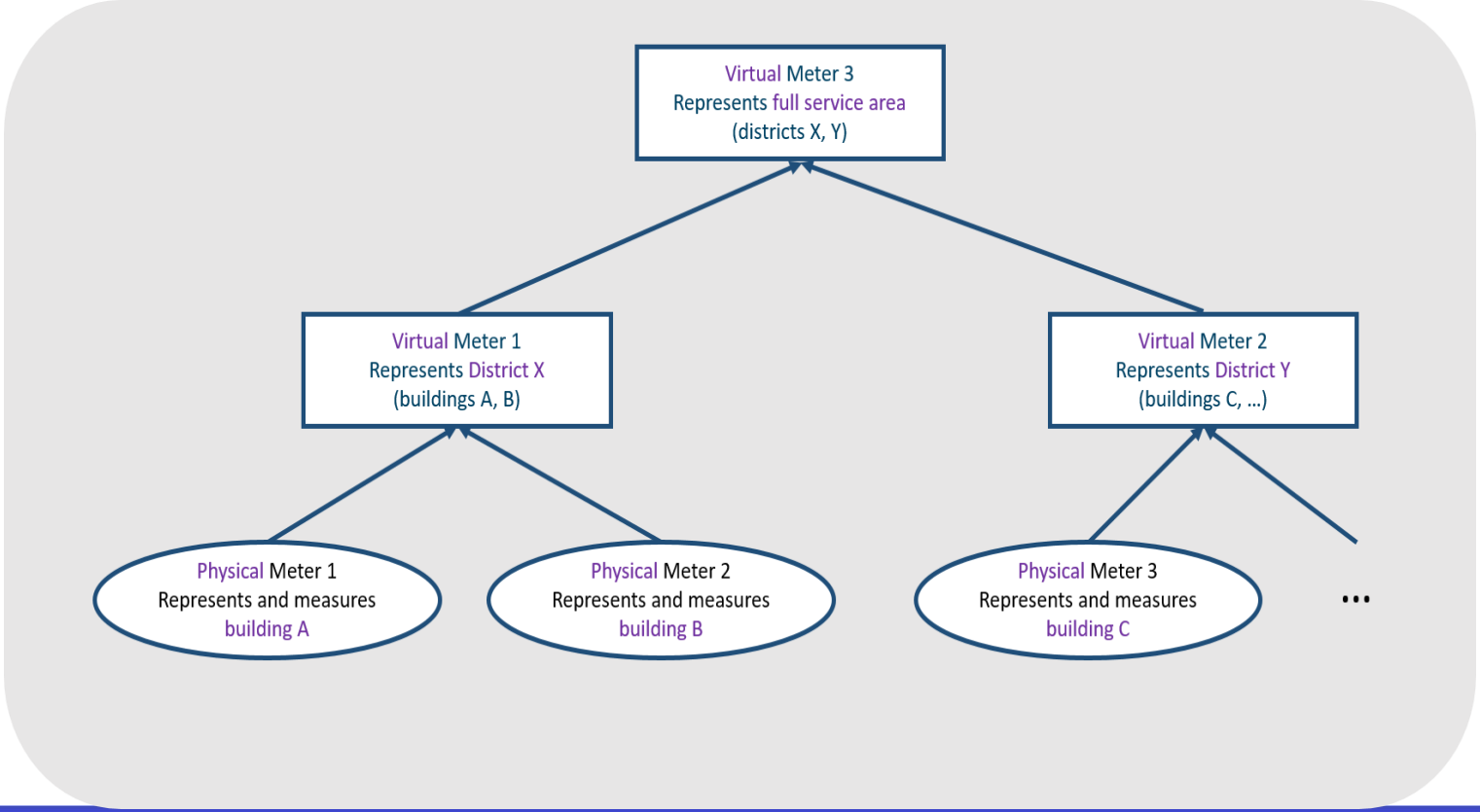
Algorithms

- Variety of algorithms that have different strengths
- Statistical
  - Arima, Triple Exponential Smoothing, Prophet
  - Efficient and effective for data with strong seasonal trends
- Deep Learning / Neural Network based
  - N-Beats, Temporal Fusion Transformer
  - Inefficient, but highest potential to learn complex patterns
- Classical machine learning
  - XGBoost
  - Both efficient and high potential to learn complex patterns
- Hyperparameter‘s can be automatically optimized and chosen (BOHB)

Short-Term Water Demand Forecasting Tool

Spatial resolution

- Forecasts for different spatial resolutions possible
- The smallest spatial resolution is a forecast per smartmeter
- A smart meter can represent a household or a district
- Smart meters can be aggreated to represent larger areas
- A forecast can be generated for a smart meter or a group of smart meters („virtual meter“)

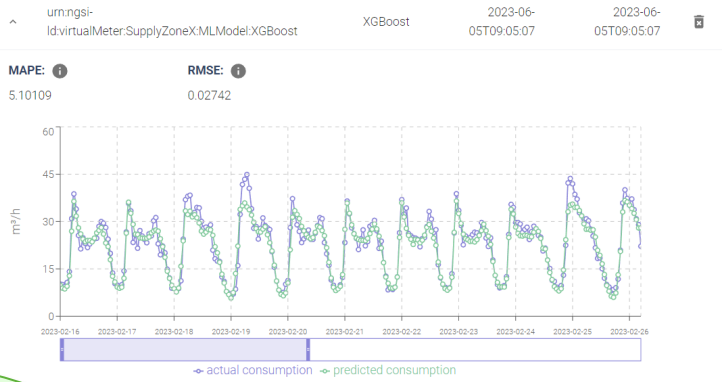


Short-Term Water Demand Forecasting Tool



Smart Meters in Lohne installed

Continuous measurements
in three city districts



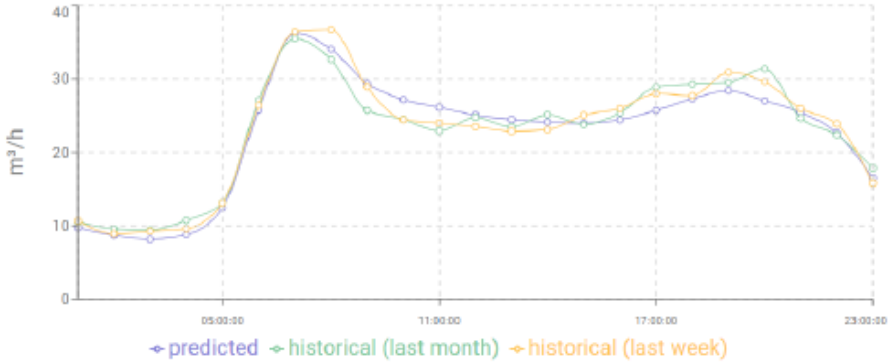


Development of the Short-Term Demand Forecasting Tool



Including **context factors**
for demand forecasting

Predicting future water demands
based on machine learning approaches



B-WaterSmart

More Information…

…can be found in the following sources:

www.b-watersmart.eu
www.mp.watereurope.eu

https://mp.watereurope.eu/d/Product/35

https://github.com/iwwtech/bws-short-term-forecasting-ui
https://github.com/iwwtech/bws-short-term-forecasting

…or mail us:

k.gimbel@iww-online.de
m.juschack@iww-online.de



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ULTIMATE
WATER SMART INDUSTRIAL SYMBIOSIS

CS meeting: Water recovery and reuse on June 11th, 2024

GoToMeeting link: Haga clic aquí para unirse a la reunión

13:00h **Welcoming**
Andrea Naves (Eurecat)

13:05h **CS1 Tarragona**: Increasing reclaimed water availability of the petrochemical complex of Tarragona
Andrea Naves (Eurecat)

13:20h **CS2 Greenhouse areas in the Netherlands**: Optimising water reclamation from agro-food industries in N. Prinsenland
Tavishi Guleria (KWR)

13:35h **CS3 Rosignano:** 20 years of municipal water reuse in chemical industries: governance, technology and future perspectives.
Chiara Giansanti (ARETUSA)

13:50h **CS9 Kalundborg:** Novel membrane treatment for biotech or biotech + municipal WWTP effluent for water reuse in Kalundborg
Jeannette Jährig (KWB)

14:05h ***Break***

14:15h **CS9 Kalundborg LCA**
Fabian Kraus (KWB)

14:30h **CS3 and CS9 Microbial Risk Assessment**
Wolfgang Seis (KWB)

14:45h **Discussion: water recovery and reuse**
Speakers, ULTIMATE partners, B-Watersmart: Kristina Wencki (IWW)

- What is the main challenge/barrier to replicate your technology (technological, economical, legal, environmental, social) and why?
- What might help to tackle this challenge?
- From your perspective, how can EU policy support you to make your business case a success?

15:00h **End**

ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

Water recovery and reuse workshop

Andrea Naves (Eurecat)

June, 11th 2024



ULTIMATE-Membrane technologies 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

Key Ultimate information

Call	2017 - H2020 – Greening the economy in line with the Sustainable Development Goals (SDGS) - H2020-SC5-2018-2019-2020
Topic	CE-SC5-04-2019 - Building a water-smart economy and society
Budget	**TOTAL:** Budget 16.614.814€
Duration	51 months (01/06/2020 – 31/10/2024)
Partners	27 (12 private companies; 8 non-profit/private centers; 7 public centers) from 11 countries
Coordinator	KWR WATER (NL)

Web del proyecto: https://ultimatewater.eu/

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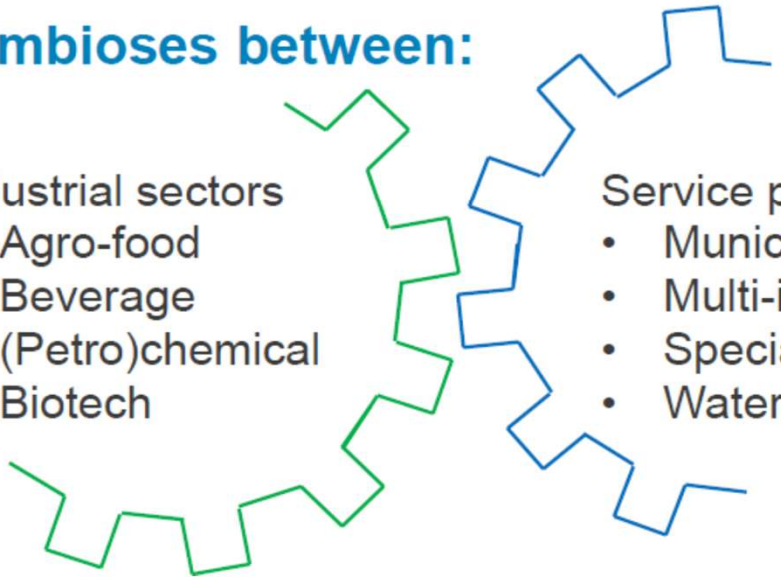
Ultimate (June 2020 – May 2024):

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

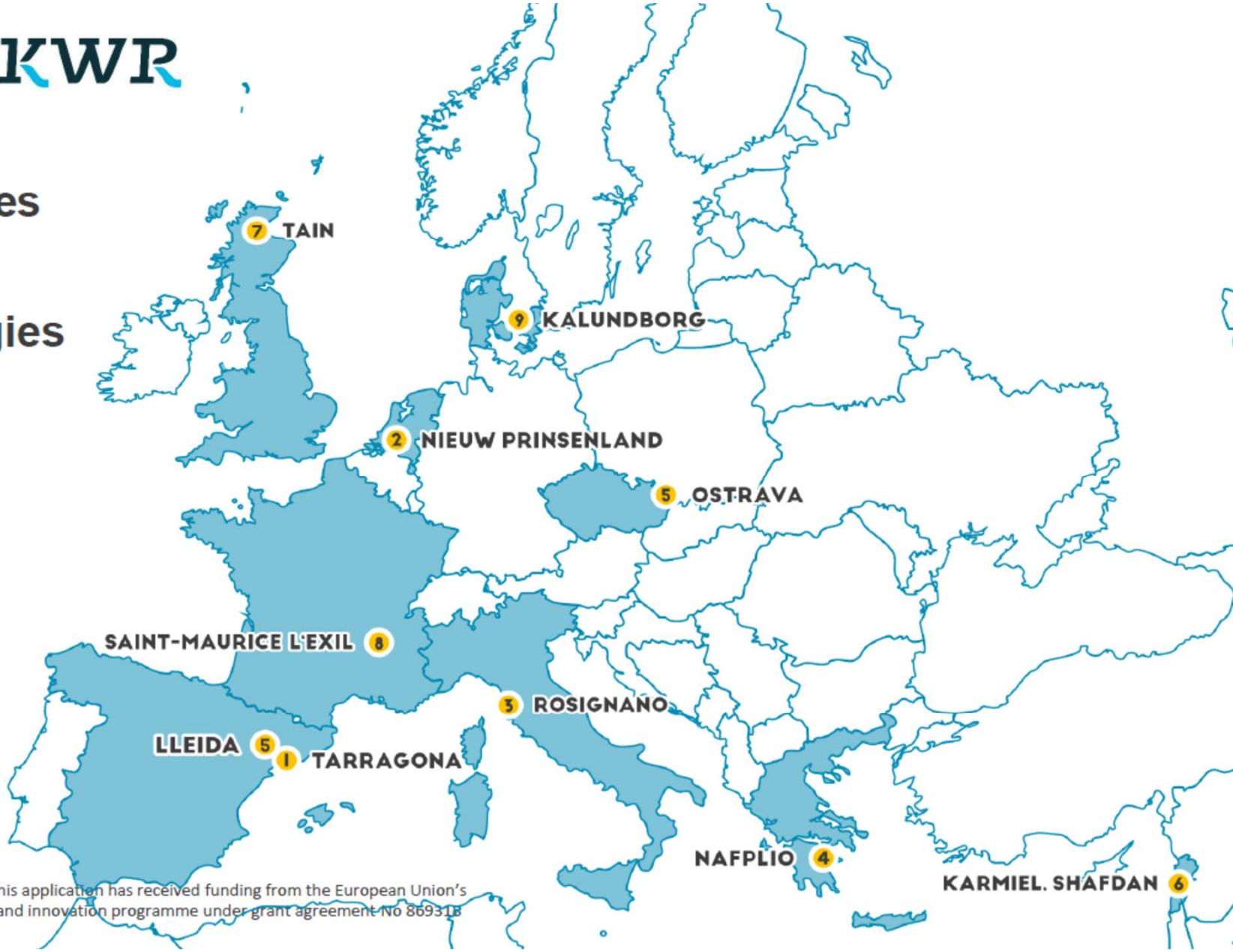
Service providers
- Municipal utility
- Multi-industry utility
- Specialized SME
- Water services provider

Coordinator: KWR

9 Case Studies

27 Partners

37 Technologies



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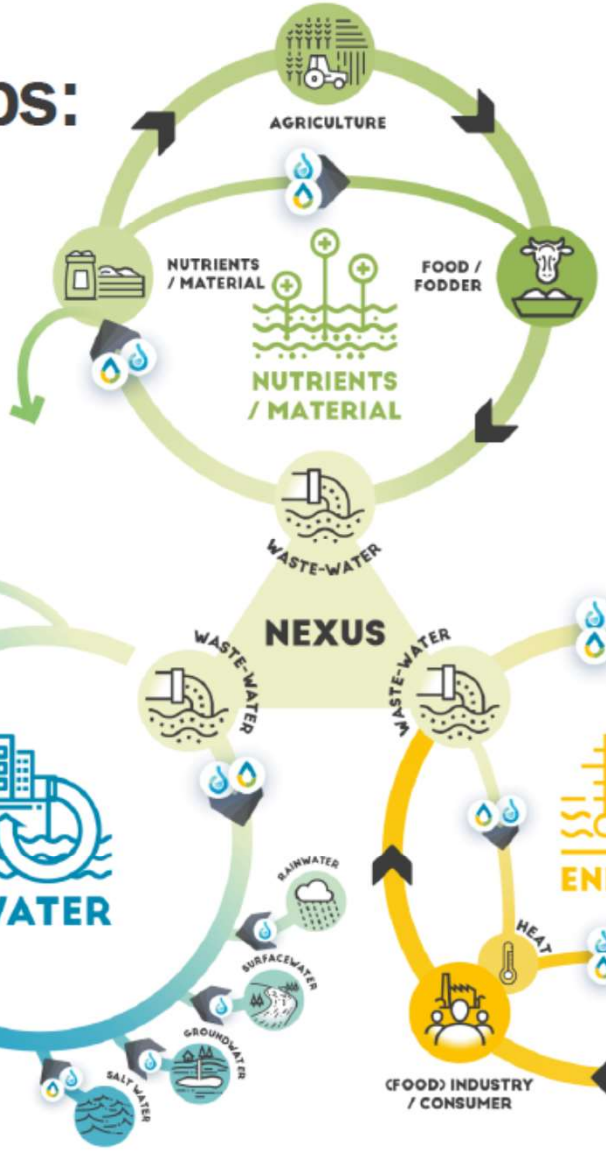
3 Cross-cutting Technology Groups: 9 Topics





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



A. Kleyböcker

KOMPETENZZENTRUM Wasser Berlin

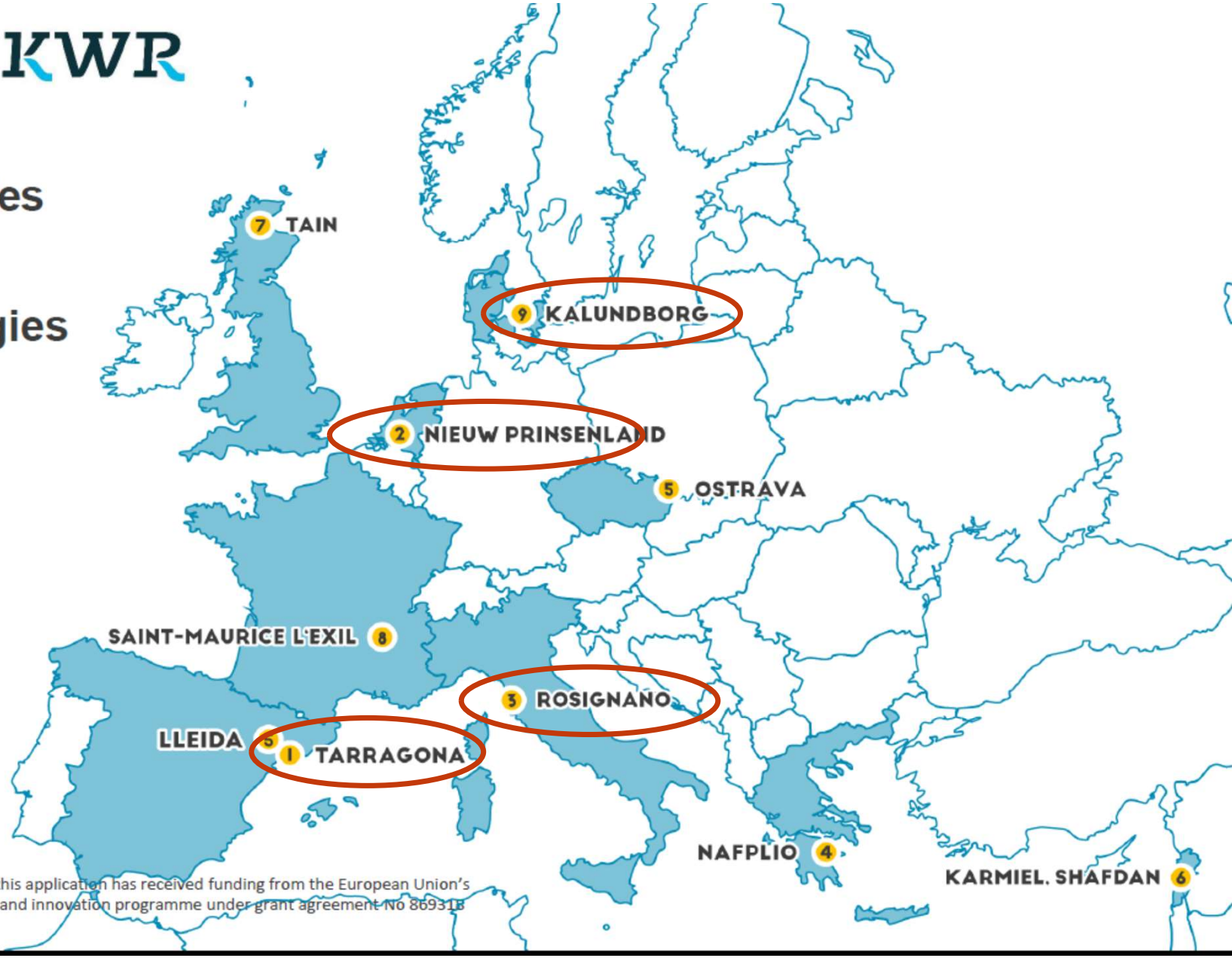
- Biogas technologies
- Heat recovery
- Digitalization

Coordinator: KWR

9 Case Studies

27 Partners

37 Technologies



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Agenda

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15:00h	**End**

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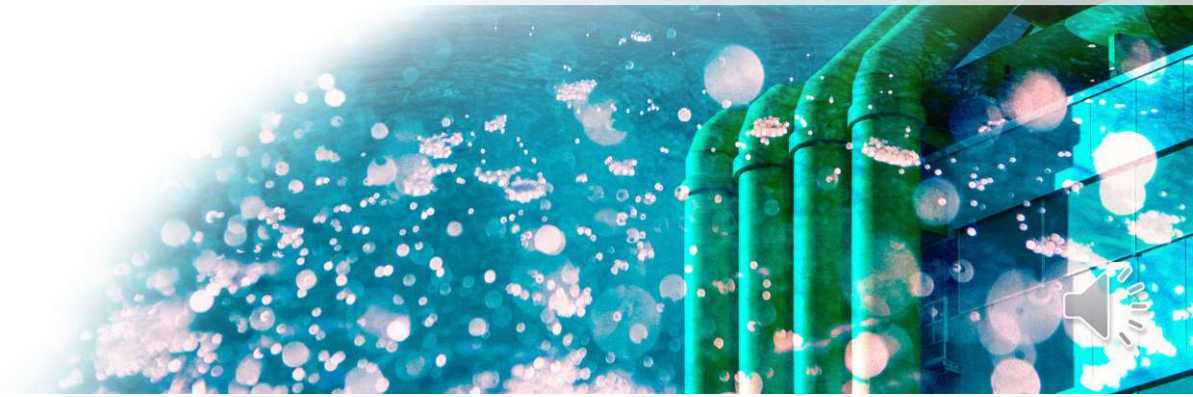
ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

Increasing reclaimed water availability of the petrochemical complex of Tarragona (CS1)

D. Montserrat, J. Cabello (AITASA)

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.

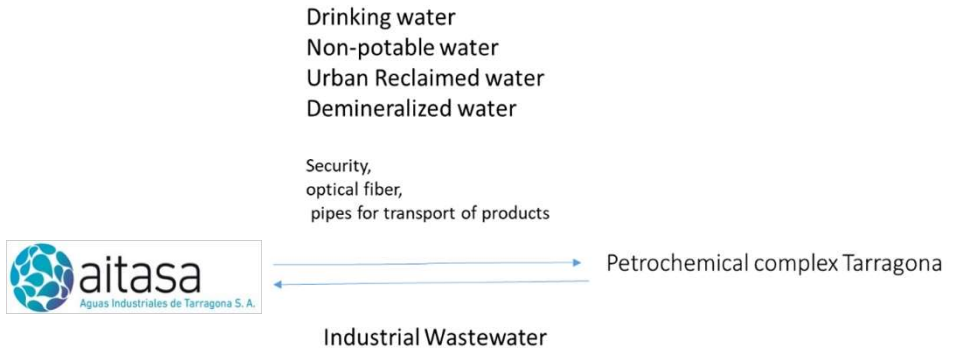
More than 30 companies operate in the petrochemical complex focusing on production of chlorine, alkaline salts, oxygen gas, fertilizers, insecticides, fuels, plastics and synthetic essences.

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 Aguas Industriales de Tarragona S. A.





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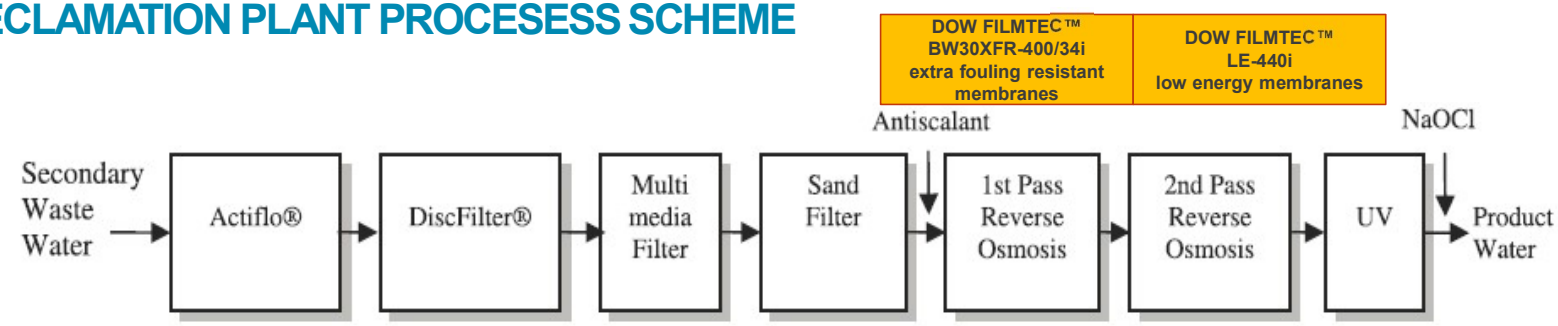
Camp de Tarragona Advanced Water Reclamation Plant

WATER RECLAMATION PLANT PROCESESS SCHEME



RECLAIMED WATER QUALITY

Since 2012, AITASA operates the Water Reclamation Plant (WRP) of Camp de Tarragona producing reclaimed water for boilers and cooling towers of the industry. Reclaimed water has to fulfil with Spanish Royal Decree 1620/2007 that includes the water requirements to be reused in the industry.

Parameter	Requirement	Units
Legionella	Absence	CFU/1 L
Nematode eggs	<1	Eggs/10 L
Escherichia Coli	Absence	CFU/100 mL
Suspended solids	<5	mg/L
Turbidity	<1	TNU

Additionally, some restrictions are established (by the industries) for the reclaimed water at the outlet of the WRP to be reused in cooling towers.

Parameter	Requirement	Units
Ammonium	< 0.8	mg/L
Ortho-PO_4	<3	mg/L
BOD_5	<4	mg/L
TOC	< 15	mg/L
Conductivity	20-40	µS/cm

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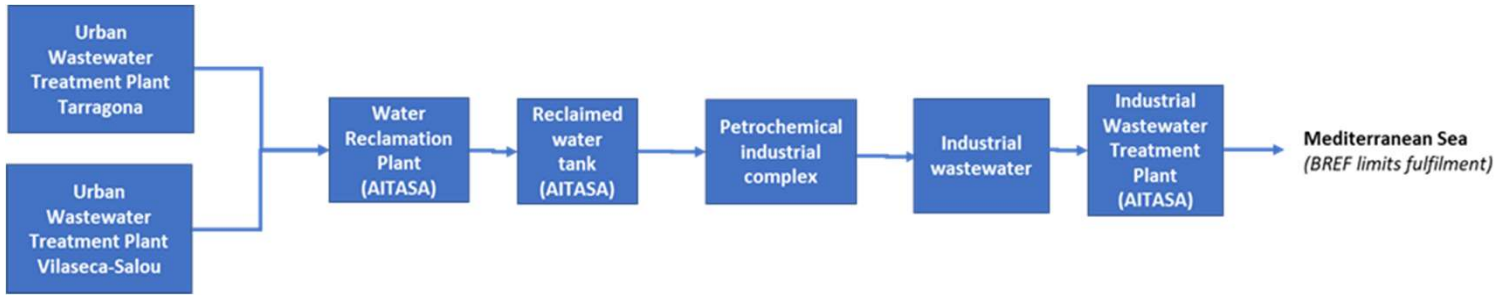
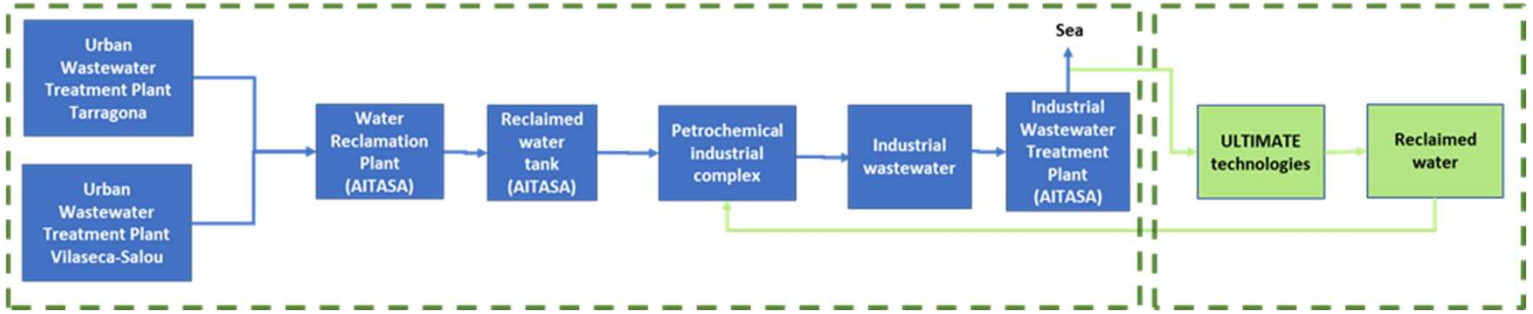
Increase reclaimed water production capacity

Phase 1:19,000 m^3/day (current)→ **Phase 2:** 29,000 m^3/day

Option 1: to increase reclaimed water production capacity in the current Water Reclamation Plant



Option 2: to produce reclaimed water treating the outlet of the Industrial Wastewater Treatment Plant→ ULTIMATE Project (Case Study 1)



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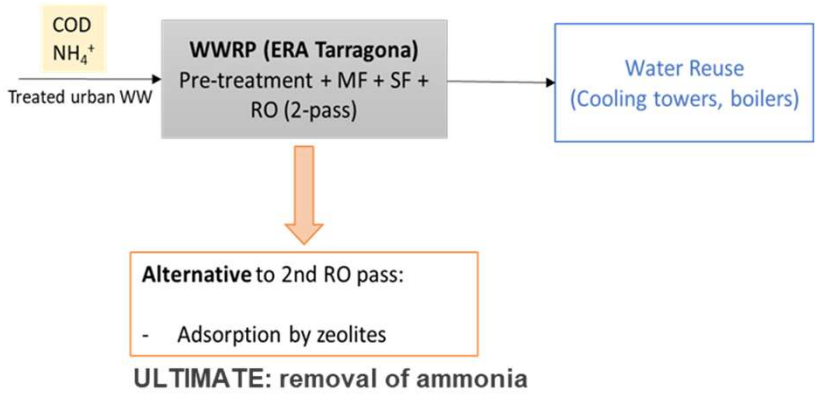
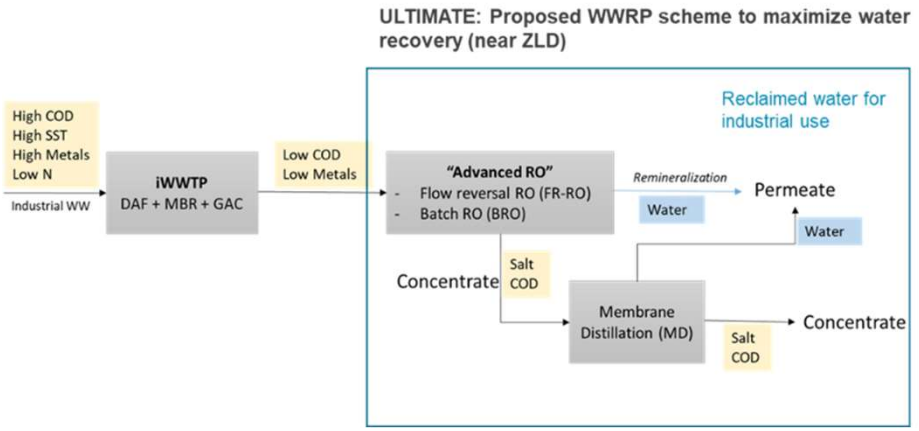
CS1: Objectives of the Ultimate solutions

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

→ **Water Reclamation Plant**:
- → Increase water recovery of the current WWRP with nZLD technologies
- → Remove the ammonium with low-cost technology (zeolite adsorption)



→ **Industrial Wastewater Treatment Plant**:
- → Defining a novel tertiary treatment with nZLD technologies (reverse osmosis and membrane distillation) to obtain reclaimed water



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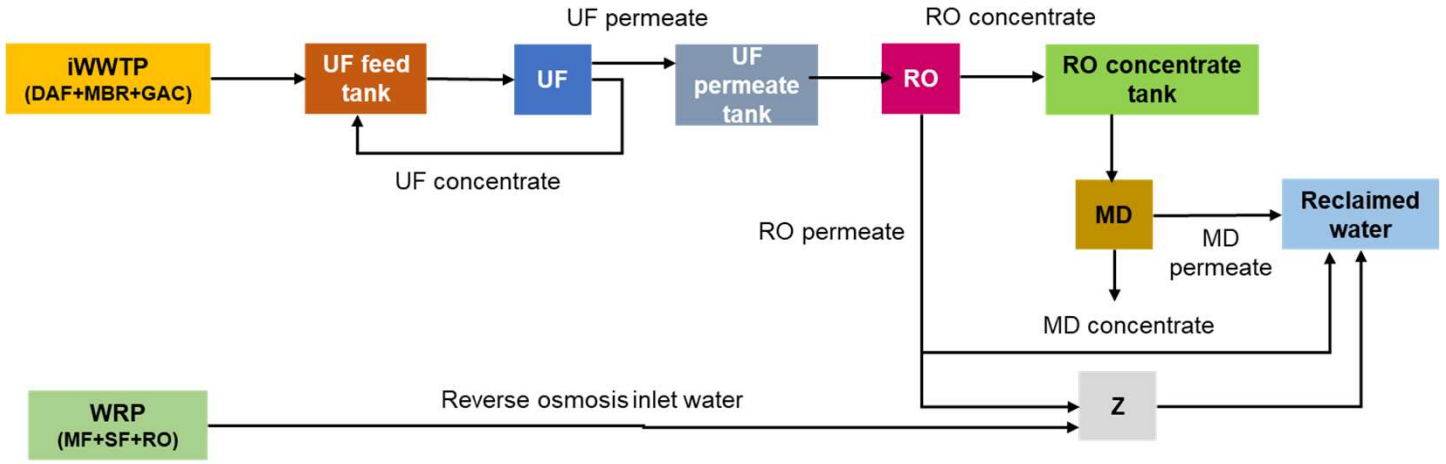
CS1 Pilot Plant

Process	Treatment capacity
Cartridge filter (pre-treatment)	12 m^3/day
Ultrafiltration	40-60 m^3/day
Reverse Osmosis	12 m^3/day
Membrane Distillation	1 m^3/day
Zeolite adsorption	1 m^3/day



40 ft. maritim container and tanks



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Industrial Wastewater Treatment 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

Industrial Wastewater Treatment Plant Water

iWWTP outlet

Parameter	Units	08/05/2023	08/06/2023	07/07/2023	02/08/2023	15/09/2023	17/10/2023	23/01/2024	MIN	MAX	AVERAGE	STANDARD DEVIATION
pH		8,3	7,6	7,5	7,6	7,7	7,8	7,3	7,3	8,3	7,7	0,3
Conductivity	uS/cm	13400	12000	18800	24300	17800	16200	14620	12000	24300	16731	4101
Suspended solids	mg/L	2,4	8	3,1	11	56	22	43,4	2,4	56,0	20,8	21,1
TDS	mg/L		8000	13000	16000	12000	11000		8000,0	16000,0	12000,0	2915
Turbidity	NTU	1,1	11	0,68	4,3	1,3	7,8		0,7	11,0	4,4	4,2
COD	mg/L	8,5	63	16	22	16	11	425	8,5	425,0	80,2	153,1
TOC	mg/L	9	64	17	23	17	14	28,5	9,0	64,0	24,6	18
Oils and greases	mg/L		<5	<5	<5	<5	<5		<5	<5	<5	0,0
Ammonium	mg/L	<0,05	0,14	2,5	7,4	2,4	0,32	8,3	0,1	8,3	3,5	3,5
TIC	mg/L	70,1	76,3	83	87,9	81,7	69,8	98,6	69,8	98,6	81,1	10,2
Carbonate	mg/L	<6	<6	<6	<6	<6	<6		<6	<6	<6	0,0
Bicarbonate	mg/L	390	450	420	410	380	330		330,0	450,0	396,7	40,8
Chloride	mg/L	2400	5200	5900	3800	5400	4100	4280	2400	5900	4440	1179
Bromide	mg/L		24	31	26	2,8	2,4		2,4	31,0	17,2	13,6
Sulfate	mg/L	1100	2000	1600	1600	1400	1300	1430	1100	2000	1490	284
Total P	mg/L		1	2,2	1,1	3,5	1,2	2,59	1,0	3,5	1,9	1,0
Phosphate	mg/L		2,8	2,7	2,5	10	3,3	<2,0	2,5	10,0	4,3	3,4
Total N	mg/L		22	14	12	3,7	3,3	10,3	3,3	22,0	10,9	7,0
Nitrite	mg/L		1,9	3,7	2,8	4,4	0,09		0,1	4,4	2,6	1,7
Nitrate	mg/L		32	32	8,4	8,8	43	4	4,0	43,0	21,4	16,3
Calcium	mg/L	170	230	220	230	>200	>200	174	170,0	230,0	204,8	103
Magnesium	mg/L	43	110	59	68	71	70	44,9	43,0	110,0	66,6	22,4
Barium	mg/L		0,09	0,08	0,09	0,06	0,067		0,1	0,1	0,1	0,0
Sodium	mg/L		>1000	3200	3400	>200	>200	3260	3200,0	3400,0	3286,7	1801
Potassium	mg/L		58	33	26	33	46	36,3	26,0	58,0	38,7	11,5
E.Coli	nmp/100 mL	4,1	<1	0	0	7	3		0,0	7,0	2,8	2,9
Langelier Saturation Index (20ºC)		1,3	0,77	0,61	0,7	0,72	0,77					
Tendency		Scaling	Scaling	Scaling	Scaling	Scaling	Scaling					

Potential risk of scaling and organic fouling

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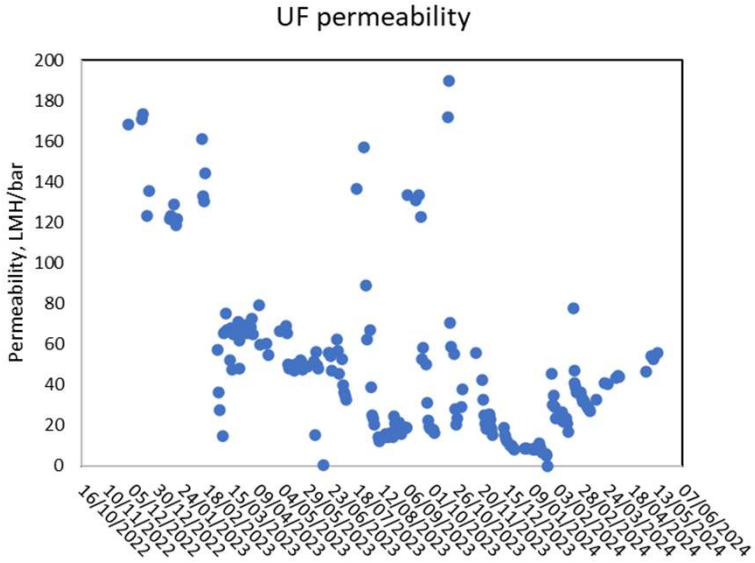
Ultrafiltration

- Feed: iWWT outlet
- No coagulant added
- Discontinuous operation
- Flushing with permeate and NaOH



2 membranes, Memos ME-C100-08-2995-6.2
Surface=6,2 m^2/membrane



Ultrafiltration KPI	Membrane technical specifications	Value (aver.)
Inlet flow rate, m3/h		40
Inlet pressure, bar		1,3
Permeate flow rate, m3/h		0,7
Permeability, LMH/bar		48,2
TMP, bar	8 (max.)	0,7
Cross-flow velocity, m/s	2--5	2,7
Temperature, ºC	40	26,7
Recovery rate, %		60,1
Permeate turbidity, NTU		0,4
Permeate TSS, mg/L		4
Energy consumption, kWh/m3 permeate		0,9

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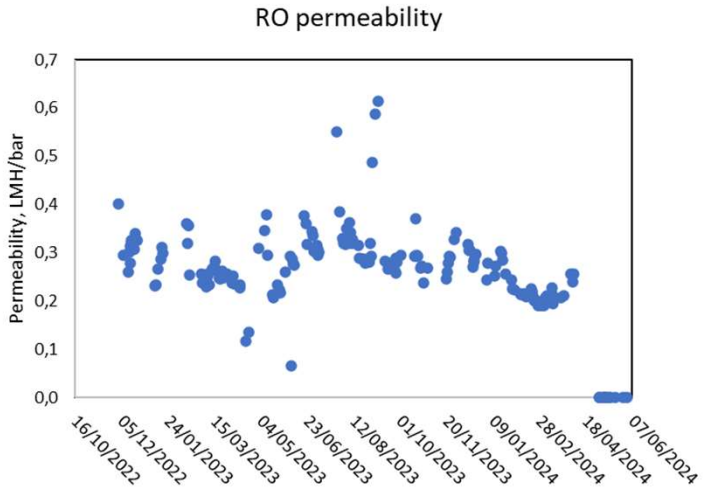
Reverse Osmosis (1-pass)

- Feed: ultrafiltration permeate
- Antiscaling dosing (no biocide dosing)
- Discontinuous operation
- Flushing with permeate and NaOH



2 membranes Nitto, SWC5-LD
Surface=37,2 m^2/membrane



RO 1-pass KPI	Membrane technical specifications	Value (1-pass)	Value (2-pass)
Inlet flow rate, m3/h		0,98	1,0
Inlet pressure, bar	82,7 (max.)	33,5	27,8
Permeate flow rate, m3/h	19,3 (max.)	0,7	0,8
Concentrate flow rate, m3/h	2,7 (min.)	8,8	13,7
TMP, bar		3,7	13,9
Recovery rate, %		68	75,6
Inlet turbidity, NTU	1 (max)	0,4	0,4
Permeate conductivity, uS/cm		152	<10
Salt passage, %		1,2	
Antiscaling consumption, L/m3 permeate		6,4	

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Ultrafiltration + 2-pass Reverse Osmosis

A reverse osmosis 2- pass is required to obtain reclaimed water quality permeate

RECLAIMED WATER

Parameter	Unit	Limit	UF permeate	1-pass RO permeate	2-pass RO permeate
Conductivity	uS/cm	20-40	15318	333	<10
Ammonium	mg/L	0,8	2,2	0,3	0,1
Suspended solids	mg/L	5	<2	1,3	<2
Turbidity	NTU	1	0,61	0,4	0,4
TOC	mg/L	15	15,8	1,5	1,1
E. Coli	nmp/100 mL	0	0	0	0

UF and RO concentrate does not fulfil with BREF limits (discharge limits)

BREF LIMITS (DISCHARGE LIMITS)

Parameter	Unit	Limit	iWWTP outlet	UF inlet	UF concentrate	RO concentrate
TOC	mg/l	33	24,6	17,0	21,3	33,7
COD	mg/l	100	80,2	51,8	231	55,5
Suspended solids	mg/l	25	20,8	12,9	6,3	3,5
N total	mg/l	25	10,9	11,3	11,6	19,2
P total	mg/l	3	1,9	1,7	1,3	8,8

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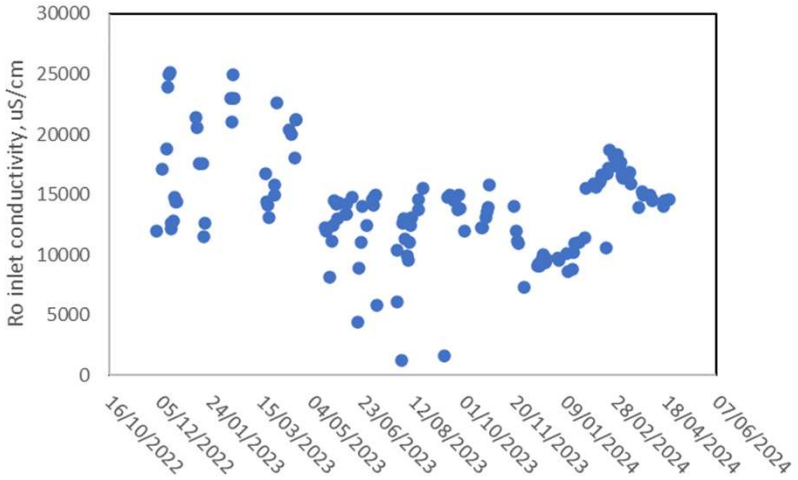
Ultrafiltration + 2-pass Reverse Osmosis

RO rejection (aver.) = 98,8%

With 2-pass RO, permeate conductivity < 10 μS/cm

(limit 40 μS/cm)

Month	Recovery, %			Total recovery, %
	UF	1-pass RO	2-pass RO	
may-23	0,69	0,67	0,75	0,35
jun-23	0,66	0,66	0,75	0,33
jul-23	0,76	0,67	0,75	0,38
aug-23	0,26	0,70	0,75	0,14
sep-23	0,41	0,70	0,75	0,21
oct-23	0,61	0,74	0,75	0,34
nov-23	0,41	0,74	0,75	0,23
dec-23	0,19	0,74	0,75	0,10
jan-24	0,16	0,73	0,75	0,09
feb-24	0,48	0,75	0,75	0,27
march-24	0,58	0,76	0,75	0,33



ULTIMATE objective recovery > 20%

AITASA objective recovery > 50%

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Ultrafiltration + 2-pass Reverse Osmosis

Critical Raw Material were analyzed in RO concentrate

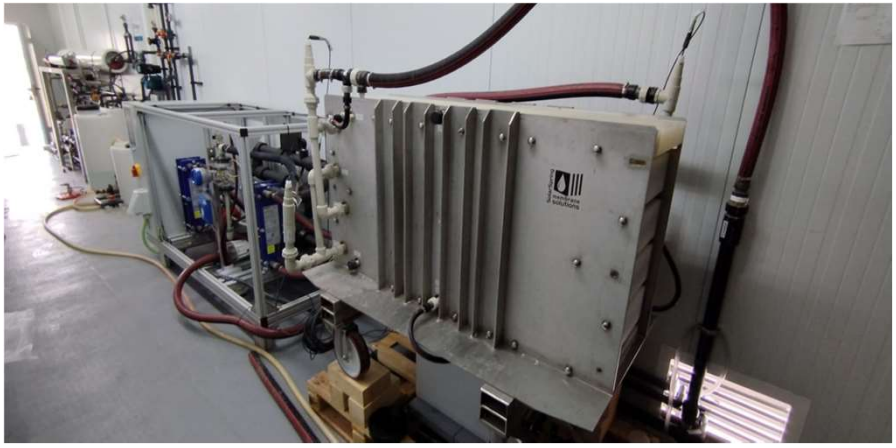
Significant amounts of strontium and lithium were found

Metal	Units	Concentrate RO	BREF LIMITS
Lithium (Li)	ug/l	105	
Beryllium (Be)	ug/l		
Boron (B)	ug/l	468,7	
Aluminium (Al)	ug/l	74,4	
Scandium (Sc)	ug/l		
Titanium (Ti)	ug/l	1,1	
Vanadium (V)	ug/l	6,1	
Manganese (Mn)	ug/l	52	
Cobalt (Co)	ug/l	1,1	
Nickel (Ni)	ug/l	21	50
Copper (Cu)	ug/l	2,1	50
Gallium (Ga)	ug/l		
Arsenic (As)	ug/l	3,2	
Strontium (Sr)	ug/l	5671,1	
Niobium (Nb)	ug/l		
Antimony (Sb)	ug/l	1,5	
Tantalum (Ta)	ug/l		
Tungsten (W)	ug/l	1,3	
Bismuth (Bi)	ug/l		
Magnesium (Mg)	mg/l	71,4	
Phosphorus (P)	mg/l	4,3	
Chromium (Cr)	ug/l	0	25
Zinc (Zn)	ug/l	220,4	300
Cadmium (Cd)	ug/l		8
Mercury (Hg)	ug/l		1
Lead (Pb)	ug/l		30

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

Membrane distillation

- Feed: reverse osmosis concentrate
- No antiscaling dosing
- Discontinuous operation
- Feed= RO concentrate



GORE membrane with a pore size of 0,2µm, PTFE membrane and PP backing.
Surface=11 m^2/membrane
AGMD configuration

RECLAIMED WATER

Parameter	Unit	Limit	MD permeate
Conductivity	uS/cm	20-40	174
Ammonium	mg/L	0,8	1,5
Suspended solids	mg/L	5	0,2
Turbidity	NTU	1	1,8
TOC	mg/L	15	53
E. Coli	nmp/100 mL	0	0

Membrane distillation does not allow to obtain reclaimed water quality permeate

Membrane distillation concentrate does not fulfil with discharge limits

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

Main conclusions

- Industrial Wastewater Treatment Plant outlet water has high conductivity (high variability) and scaling tendency, according Langelier Saturation Index
- Scaling effect was mainly observed in ultrafiltration membrane. Permeability was recovered with CIP cleaning
- Ultrafiltration + 2-pass reverse osmosis system allows to obtain reclaimed water quality permeate
- To achieve a global water recovery > 20% in UF+2-pass RO system, it is needed ultrafiltration recovery > 40% and 2-pass reverse osmosis (1-pass and 2-pass) > 75%
- UF and RO concentrate do not fulfil with discharge limits→ Potential legal risk if solution is scaled-up
- Significant concentration of lithium and strontium were found in RO concentrate
- Membrane Distillation permeate does not fulfil with reclaimed water limits and its concentrate does not fulfil with discharge limits

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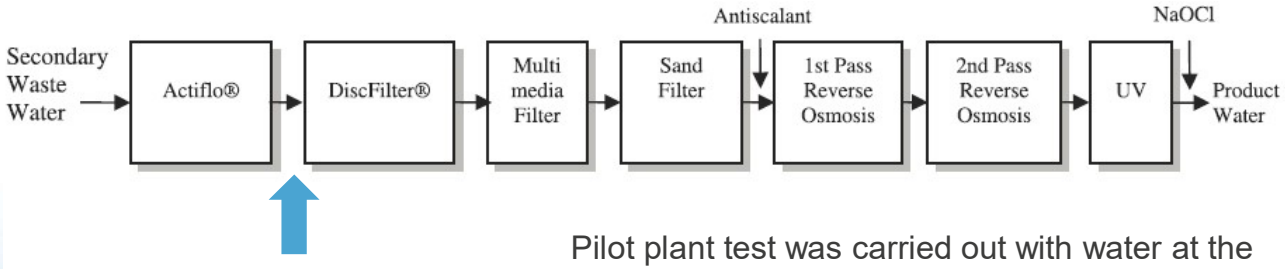
Water Reclamation Plant

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

Adsorption on zeolites

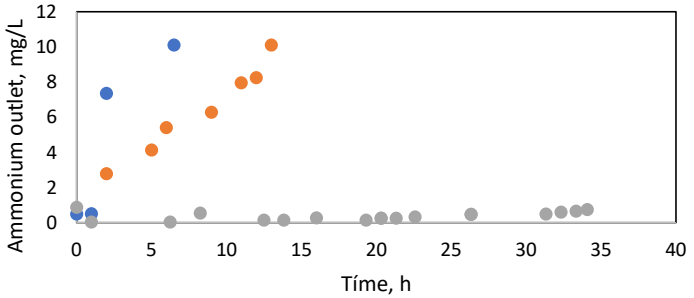




Natural zeolite Zn Aqua
(Clinoptilolite, 82-86%)
Particle size= 0,5-1 mm

Pilot plant test was carried out with water at the outlet of Actiflo process (RO 1-pass does not have NH4 because HClO is added before sand filters inlet to remove it)

Break-through curves



Parameter	Test 1	Test 3	Test 4
Zeolite mass, kg	14,3	14,3	140
Observations (zeolite)	New	Used in test 1	New
NH4 inlet, mg/L (average)	64,7	30,4	41,3
Inlet flow rate, m3/h	0,15	0,15	0,25
Linear velocity, m/h	5,5	5,5	2,3
EBCT, min	6,81	6,81	40
Breakthroug time, h	1,04		34
Adsorption capacity, mg NH4/g zeolite	0,71		2,51

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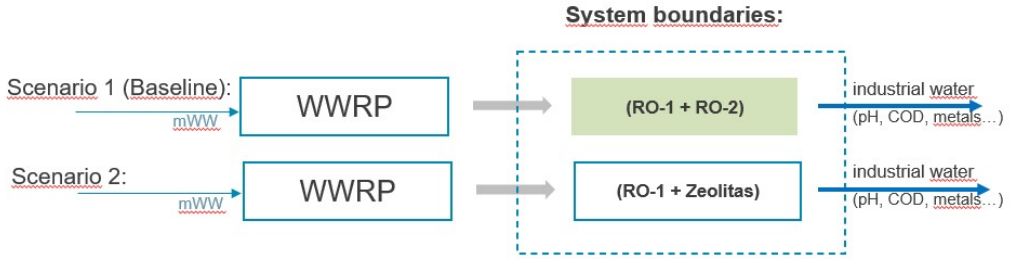
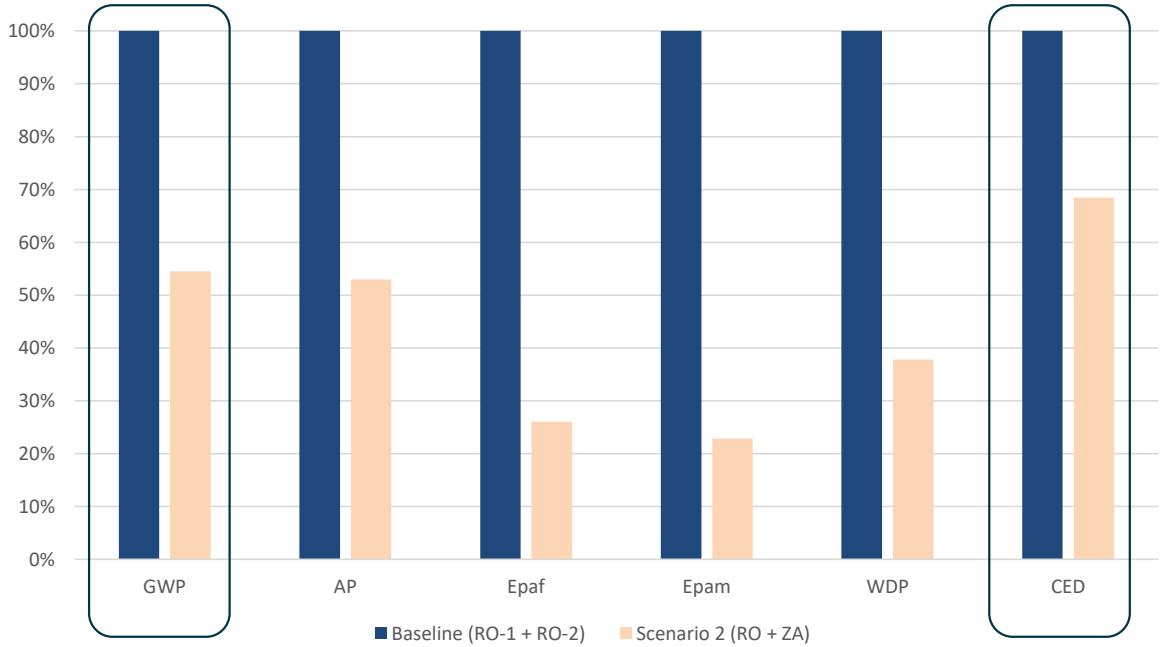
Adsorption on zeolites LCA





The substitution of the second step of osmosis with zeolite adsorption has resulted in an **45% reduction** in environmental impact in terms of kg of CO_2 equivalents

In terms of energy consumption, the baseline scenario demands more energy than scenario 2, which uses zeolites. This results in a **32% reduction in the cumulative energy demand** for the entire 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

Main conclusions

- Ammonium adsorption capacity on zeolite is quite low, and it is even lower after regeneration with NaCl 10%
- Ammonium removal by adsorption on zeolites seems to be a low-cost alternative in comparison with the second pass of the reverse osmosis in terms of energy consumption (6% less energy consumption)

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ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

Thank you!

Andrea Naves (Eurecat)

June, 11th 2024



ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

KWR

ULTIMATE CS2: Nieuw Prinsenland

Tavishi Guleria, Joep van den Broeke, Ides Platteau, Timon Rijnaarts, Emile Cornelissen, Gerard van den Berg

11th June 2024



KWR Coöperatieve Tuinbouw Water Zuivering De Vlot

GHENT UNIVERSITY

Glastuinbouw Nederland

NIEUW PRINSENLAND

Greenhouse Horticulture

- Netherlands is the second largest exporter of agriculture products in the world
  - **10 € billion** in flowers
  - **7.4 € billion** worth of vegetables
  - Mostly grown in **Greenhouse horticulture**
- High resource efficiency and production rates – **advanced sector!**
- **Challenges** – water scarcity (alternative sources), restrictions in concentrate disposal, strict legislation for effluent quality



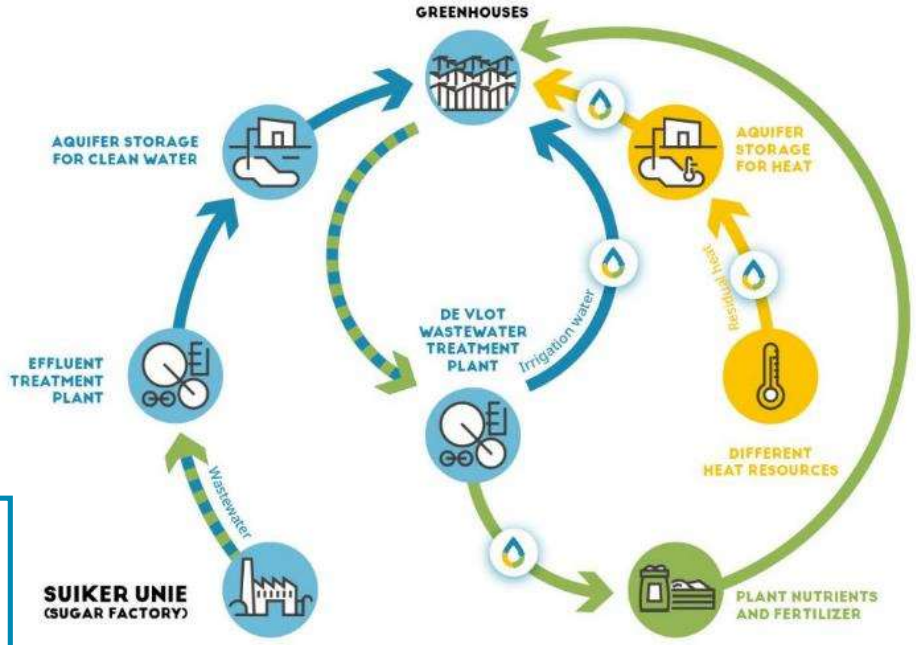




The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

ULTIMATE CS2

- **Cooperative** system for 60 greenhouses (160 ha) with a collective treatment (60 m^3/h)
- Current situation: treated water is discharged into the sewer
- The horticulture industry aims to reach **zero liquid discharge**
- Proposed circular water system with to produce **fit-for-purpose irrigation water**



Objectives:

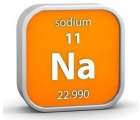
- Produce **high quality irrigation water** for reuse from greenhouse wastewater
- Evaluate **technology performance at pilot scale**

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 CS2: Objectives

- **Minimal liquid discharge** minimizes the volume of discharged wastewater, increasing the volume of water that may be reused

- **Na^+ concentration** (main focus), plant pathogens, crop protection agents



"The effects of sodium in plants are similar to those of exposure to drought"

- **(Capacitive) Electrodialysis**

Ions	Na^+ (mg/L)	Cl^- (mg/L)	EC (mS/cm)	pH
Effluent	162,09	271,21	2,5	7,3

S. no.	EC (mS/cm at 25 °C)	Na^+ (mmol/l)	Na^+ (mg/l)	Cl^- (mmol/l)	Cl^- (mg/l)
1	<0.2	<0.1	<2.3	<0.1	<3.5
2	<0.5	<1.5	<35	<1.5	<53
3	0.5–1	1.5–3	35–69	1.5–3	53–107
4	1–1.5	3–4.5	69–104	3–4.5	107–160

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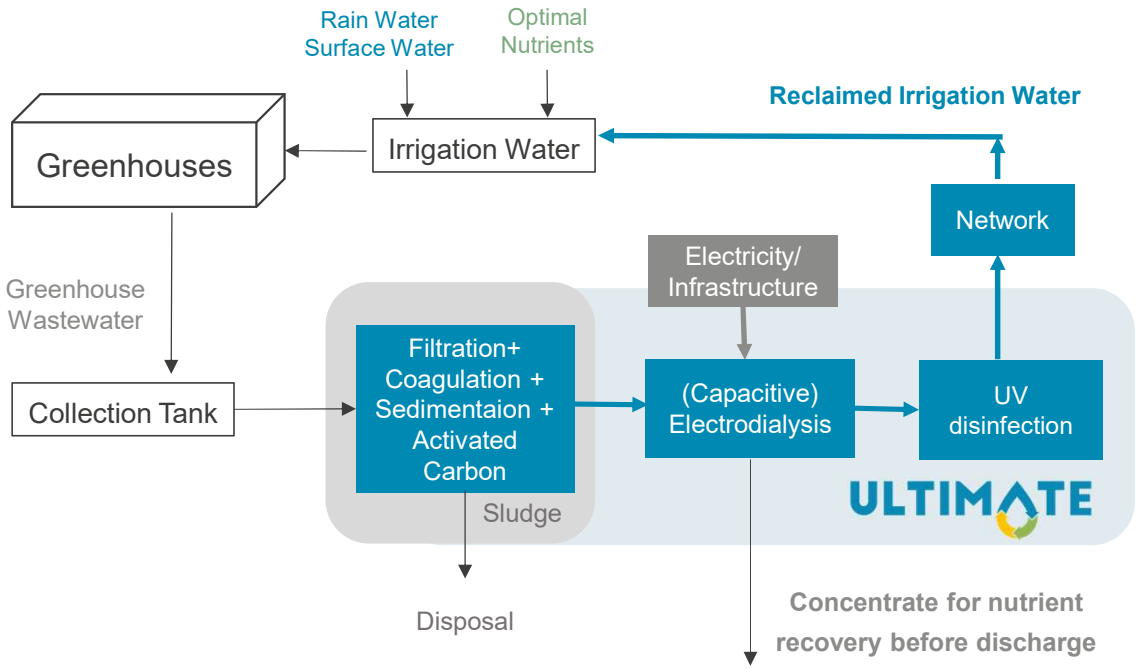
CS2 Proposed Flow Scheme



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(Capacitive) Electrodialysis

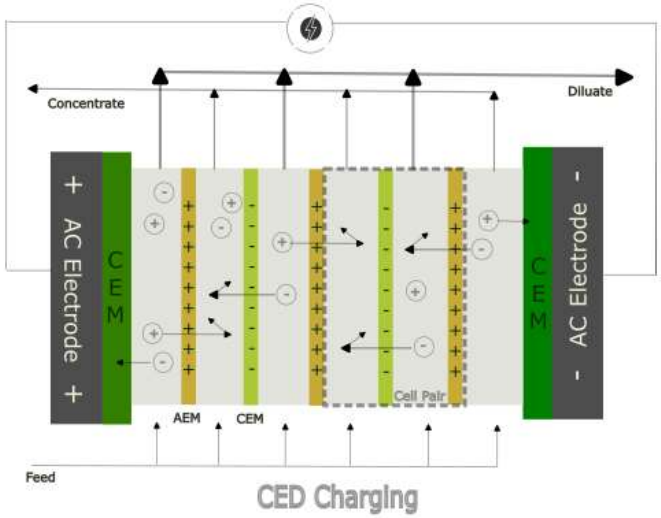
Electrodialysis (ED) is a membrane-based process involving transport of ions through membranes using an applied electric field

Why ED?

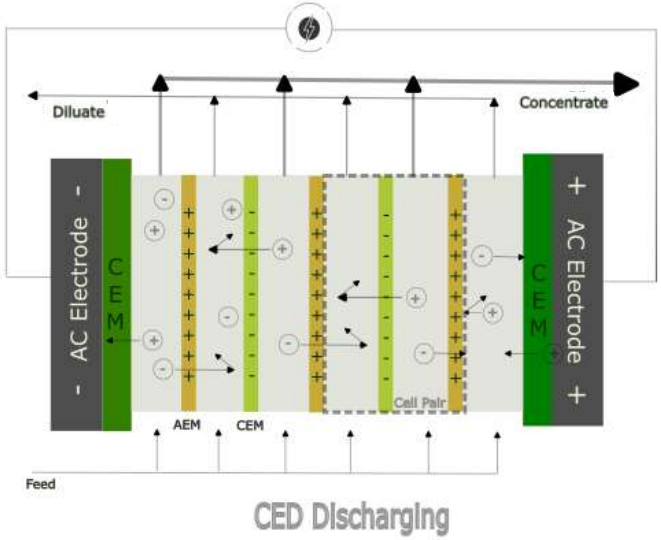
- Most potential based on comparative assessment
    - Tunable ion removal/concentration (lower brine)
    - Higher water recovery, energy efficiency and lower sensitivity to fouling
    - Adapts well to feed variations and fits the needs of greenhouse horticulture
- Technology at a mature stage

Capacitive Electrodialysis (CED)

- Uses carbon-based electrodes
- Functions through ion adsorption/desorption on porous capacitive electrodes
- Avoids harmful gas production and eliminates the need for electrode rinse solutions
- Energy efficient



CED Charging



CED Discharging

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

CED Pilot

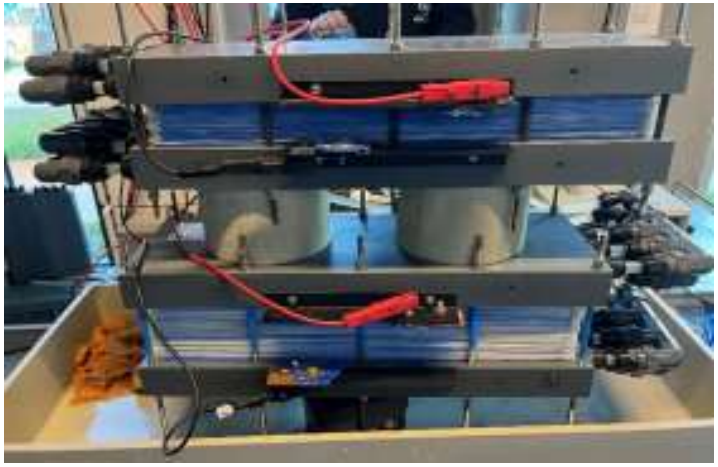
Configuration:

- 150 cell pairs (Industry standard)
- Membrane area 19.32 m^2 (capacity 1-4 m^3/day)
- Fujifilm Type 10 IEMs
- One-pass mode with alternating charging /discharging cycles

Key Parameters:

- 3 types of feed
- Applied voltage (6-16 V)
- Cross-flow velocity (5-7 cm/s)
- Staging (1 and 2-stack)
- Water recovery (60-90%)





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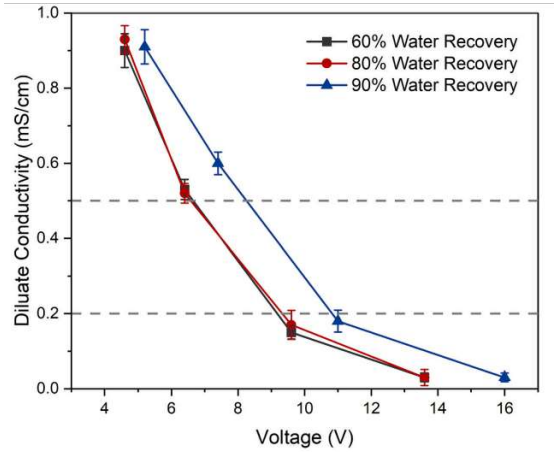
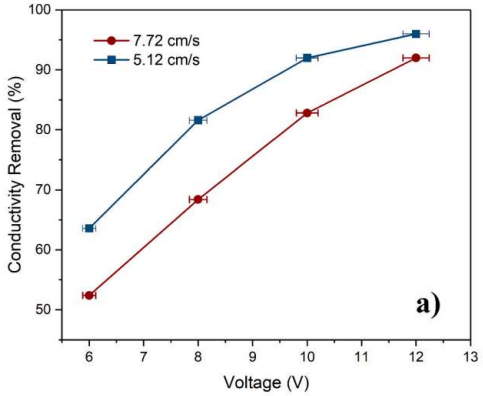
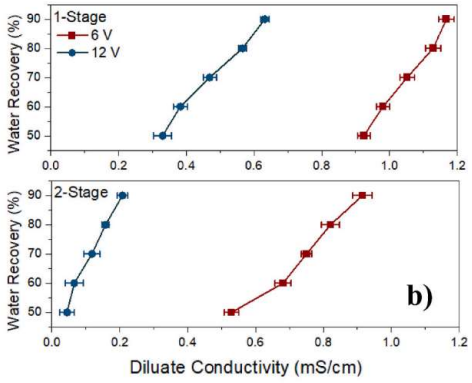
Results – CED Operating Parameters

- Optimal voltage at 12 V (membrane productivity of 4.5 $Lm^{-2}h^{-1}$)
- 80% WR showed diminishing returns in ion removal efficiency
- Higher WRs required more voltage to achieve equivalent ion removal
- Best performance at a crossflow velocity of 5.12 cm/s and with a 2-stack staging
- Higher feed concentrations showed improved ion removal







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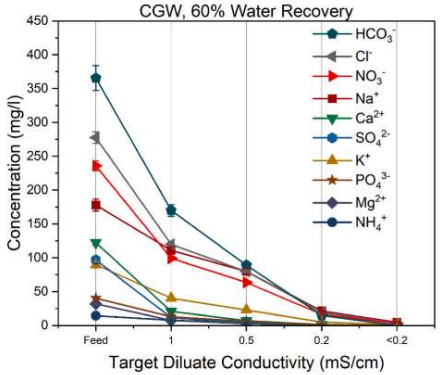
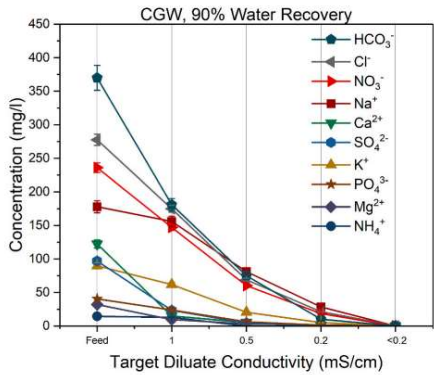
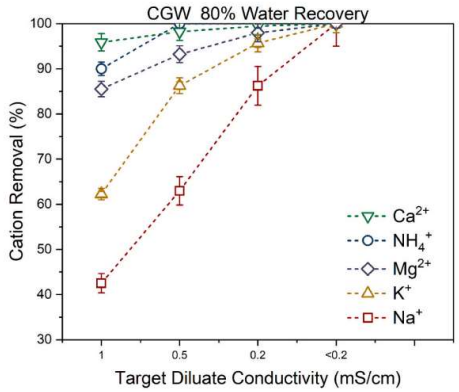
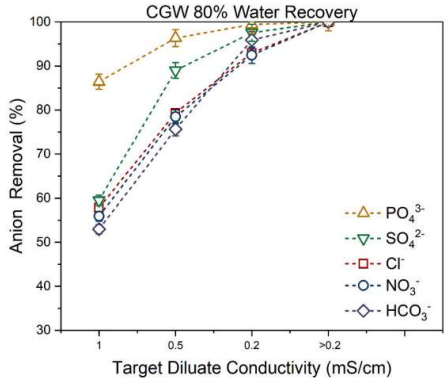
Results – Diluate Water Quality

- High-quality water achieved for reusing as irrigation water (EC<0.2 mS/cm, Na^+<0.1 mmol/L)
- Na^+ in diluate declined from 178 mg/L to 4.6 mg/L (60% WR) and <2.3 mg/L (80% WR)
- Ion removal trend Ca^{2+}>Mg^{2+}>K^+>Na^+ (cations) and PO_4^{3-}>SO_4^{2-}>NO_3^-~ Cl^->HCO_3^- (anions)
- Application of CED for specific requirements of the sector demonstrated









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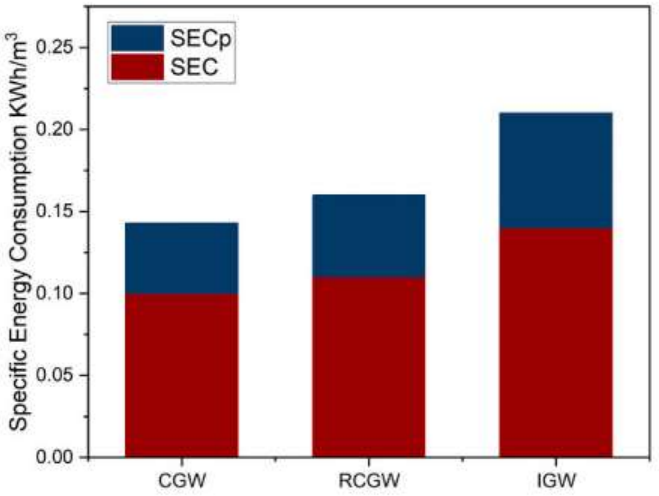
Results – Specific Energy Consumption (SEC)

- SEC (stack) ranged from 0.09–0.14 kWh/m3 and SEC (pump) from 0.043 and 0.120 KWh/m3
- Total energy consumption (stack and pump), was estimated as **0.14–0.24 kWh/m3**
- SEC decreased from 60% WR and then stabilized from 80% WR



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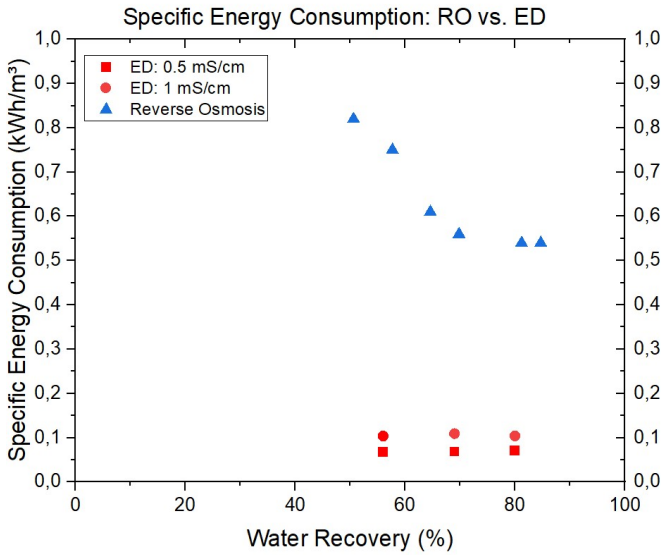
Results – Energy Comparison with RO (Model)

CED SEC: 0.14-0.24 kWh/m³
RO SEC (model): 0.56-0.8 kWh/m³

CED energy efficiency: 4-fold lower than RO!

- Design of CED; energy stored during charging used directly for desalination during discharging
- Losses at the electrodes lower due to absence of electrode reaction



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Initial Costs Assessment

- Technology would incur costs (CAPEX + OPEX) per year – **simulated calculations**
- **CAPEX** is roughly up **to <10% of overall cost**
- OPEX with cost of maintenance; specifically**, ion-exchange membranes about 10% of total cost** and **majority of the cost is the energy consumption (>80%)** – sensitive to energy prices
- **CED shows lower energy consumption than RO**, ease of coupling with renewable energy sources such as wind/solar
- Cost/m^3 of produced water **currently expensive but technology competitive**, stakeholders indicated energy prices can be lower than expected



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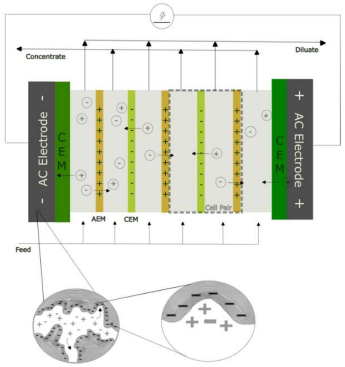
Conclusions

- Capacitive electrodialysis (CED) is a promising solution for **reclaiming fit-for-use irrigation water** from greenhouse wastewater.
- **High-quality irrigation water** (EC<0.2 mS/cm, Na^+<0.1 mmol/L) achieved (optimized parameters)
- Specific energy consumption (kWh/m^3) ~ **factor 4 lower than RO**
- **Competitive technology**, energy consumption and membranes can be majority of the cost
- Technology provides available for uptake





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Water reuse and resource recovery from greenhouse wastewater by capacitive electrodialysis at pilot scale

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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

Thank You!

tavishi.guleria@kwrwater.nl

KWR

ULTIMATE
WATER SMART INDUSTRIAL SYMBIOSIS

WATER SMART INDUSTRIAL SYMBIOSIS

ULTIMATE is a 4-year Horizon2020 project under the EU Water in the Context of the Circular Economy programme. The aim is to create economic value and increase sustainability by valorising resources within the water cycle.

FOLLOW US

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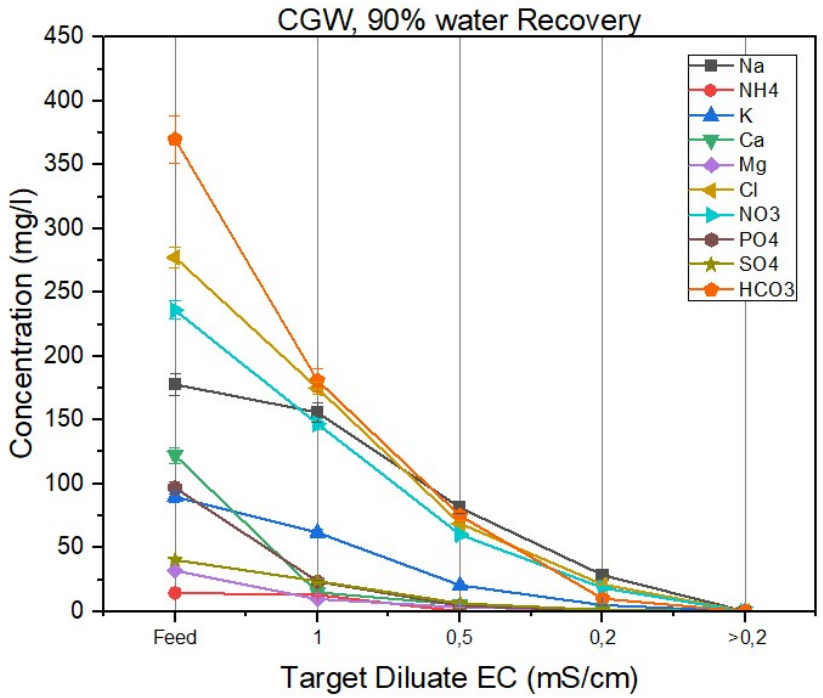
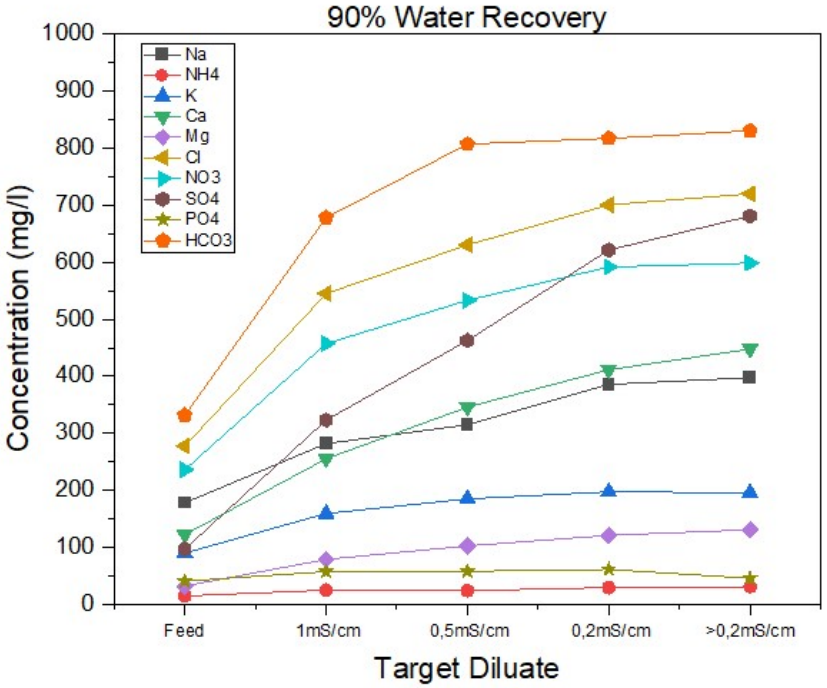
UNIVERSITEIT GENT

Results – CED Pilot





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ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

Case Study 3 – Rosignano, Italy

20 years of municipal water reuse in chemical industries: governance, technology and future perspectives

ENG. CAMILLO PALERMO
ENG. CHIARA GIANSANTI
ENG. CHIARA CUSENZA



ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS





CS3-Rosignano:
Partnership among a chemical industry (Solvay Chimica Italia spa) and a public water utility (A.S.A. Azienda Servizi Ambientali spa)

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

Case Study 3 - Rosignano (Italy)

Consorzio Aretusa

Azienda Servizi Ambientali SpA

Water Utility

Solvay

Chemical Industry

Termomeccanica Ecologia

Termomeccanica Group

Technology Provider

Since 2001



From **ARETUSA** WRP to **Solvay** Industry

3.8 M m3/y

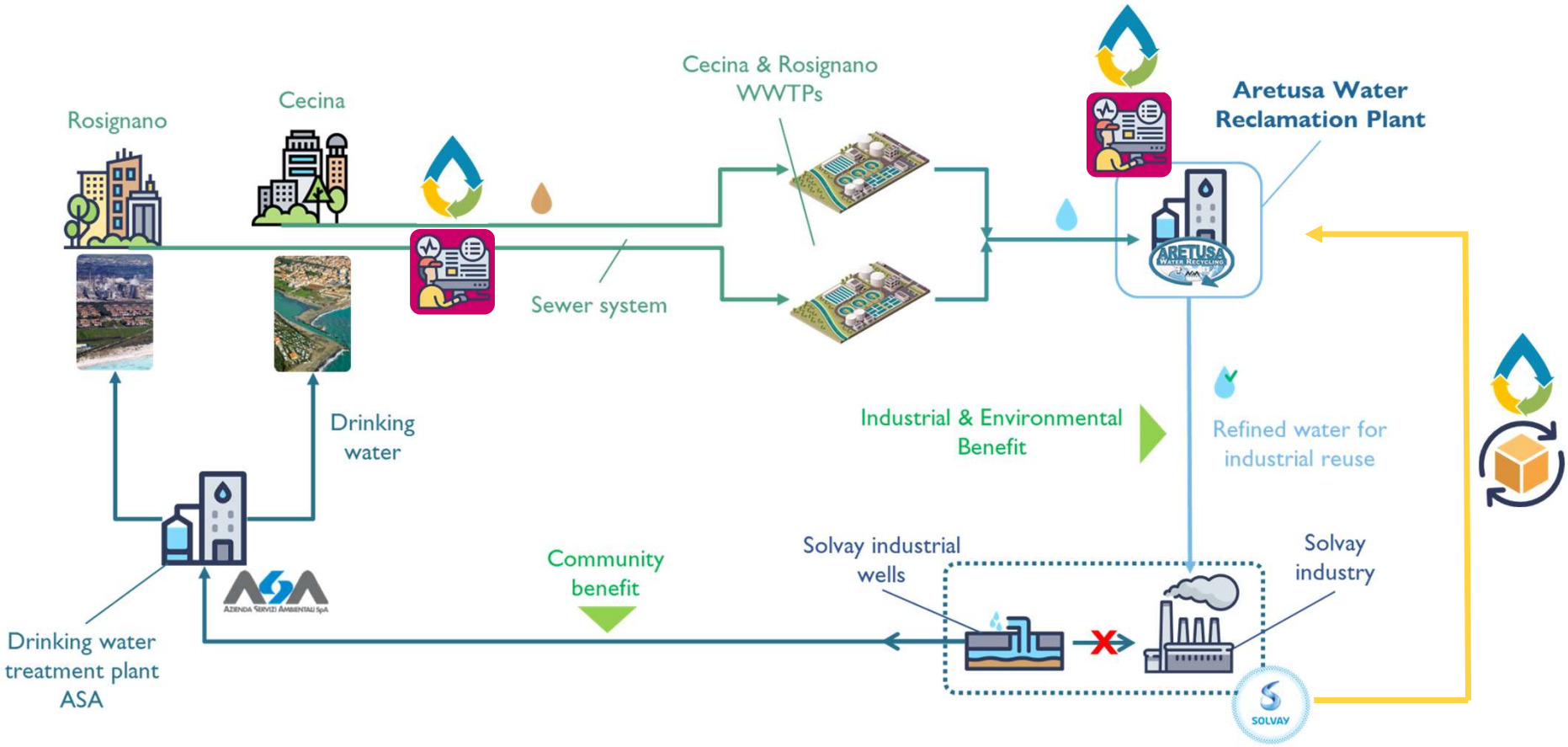


ARETUSA is a successful example of already established industrial symbiosis, optimized with ULTIMATE project

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

Case Study 3 - Rosignano (Italy)

Wastewater industrial reuse



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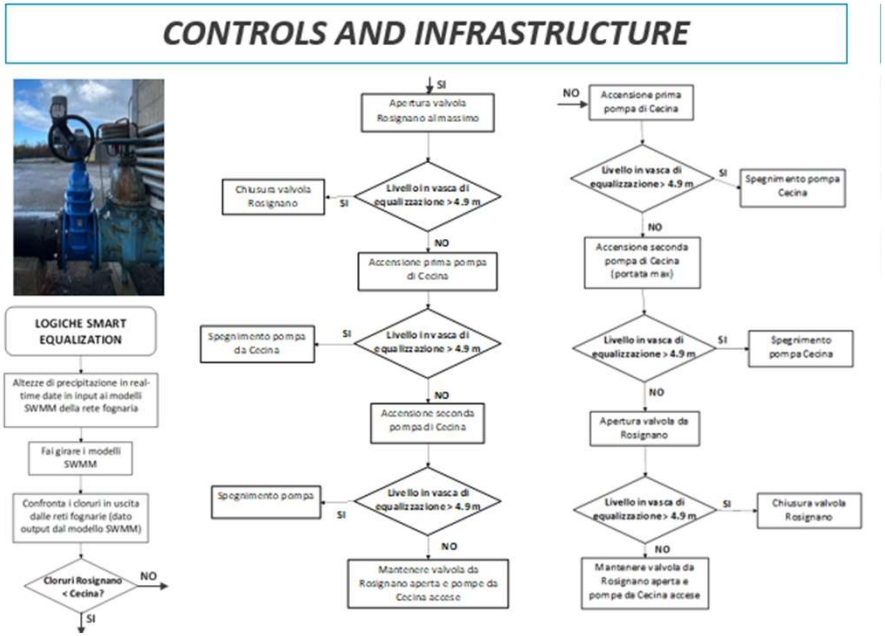
Case Study 3 - Rosignano (Italy)

Ultimate innovations: early warning system, smart equalization and matchmaking platform

Objectives:

1. Energy- and carbon - efficient prevention of chlorides peaks and other critical parameters in the WWRP influent;
2. Optimization of wastewater reuse;



Ultimate innovations:

- Real-time driven data process control for salinity management in order to get an **Early Warning System and a Smart equalization system.**







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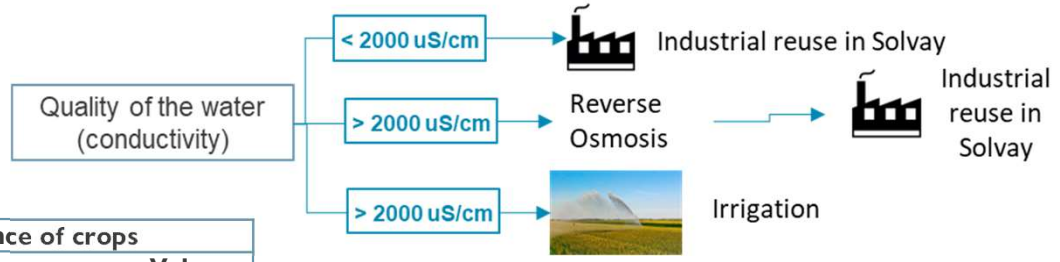
Case Study 3 - Rosignano (Italy)

Ultimate innovations: early warning system, smart equalization and matchmaking platform

Ultimate innovations:

Matchamaking platform: depending on the water quality, water will be used for industrial reuse rather than for irrigation



REGIONAL REUSE OPTIONS



Salinity tolerance of crops	
Crop	**Value (µS/cm)**
Bean; Carrot; Strawberry	1000
Onion	1200
Lettuce	1300
Vine; Almond; Plum; Pepper	1500
Apricot; Broad bean	1600
Peach; Orange; Lemon; Apple tree; Potato	1700
Grapefruit	1800
Watermelon; Spinach	2000
Melon	2200
Broccoli	2300
Tomato; Cucumber	2500
Olive tree	2700

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Case Study 3 - Rosignano (Italy)

Aretusa water quality

The Aretusa water reclamation plant is able to produce good quality water, which can be used both for **industrial** and **irrigation** purposes.

Parameter	Unit measure	Value
pH	-	7 - 8
COD	mgO2/l	<10
N-NH4	mgNH3/l	<15
Ptot	Mg/l	<1
Metals	Mg/l	<3
E.Coli	UFC/100ml	<10

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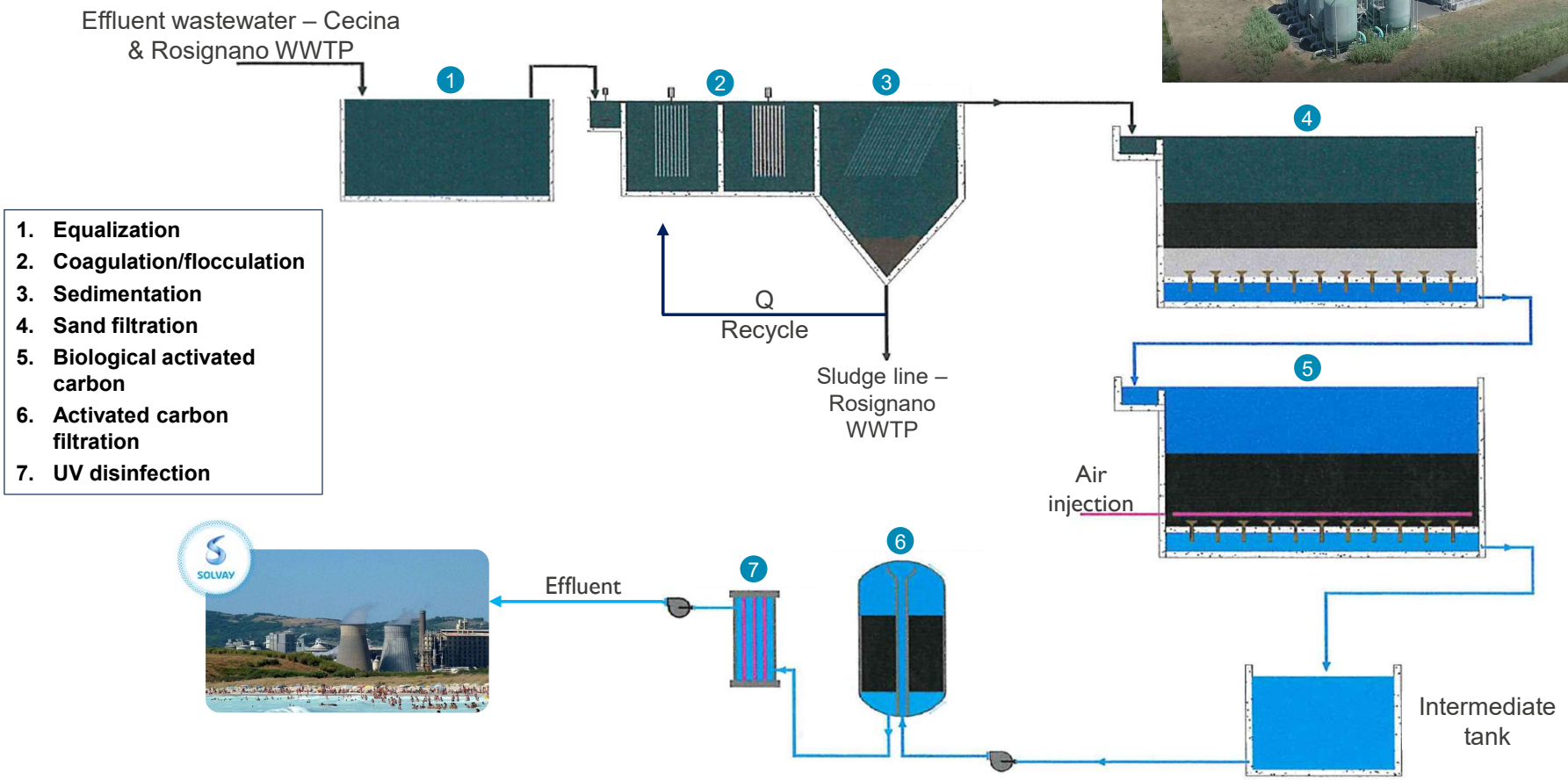
Case Study 3 - Rosignano (Italy)

Consorzio Aretusa Water Reclamation Plant



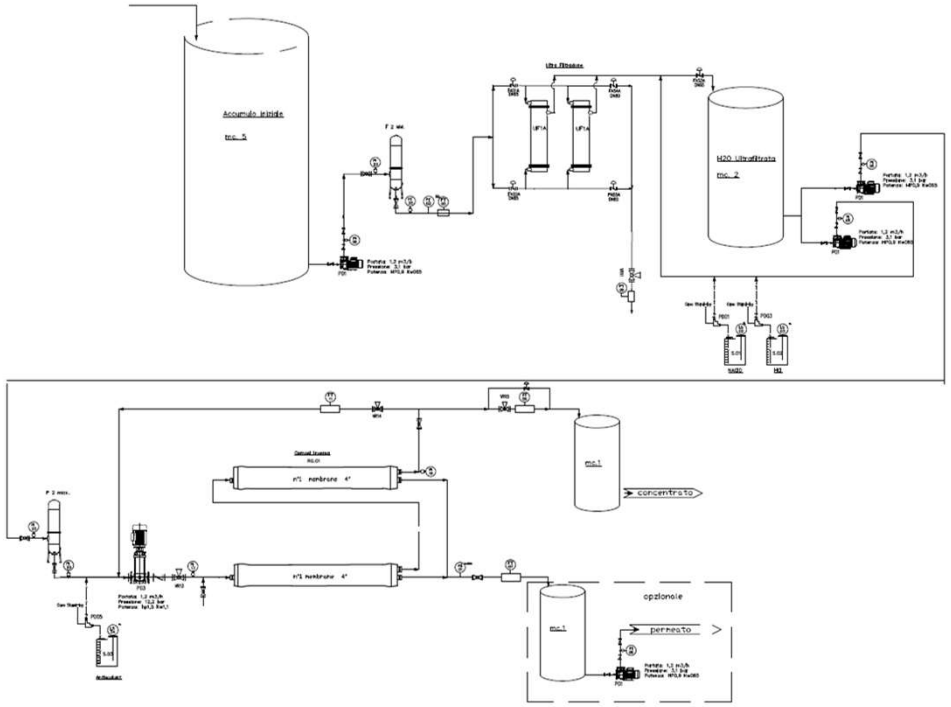


1. **Equalization**
2. **Coagulation/flocculation**
3. **Sedimentation**
4. **Sand filtration**
5. **Biological activated carbon**
6. **Activated carbon filtration**
7. **UV disinfection**

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

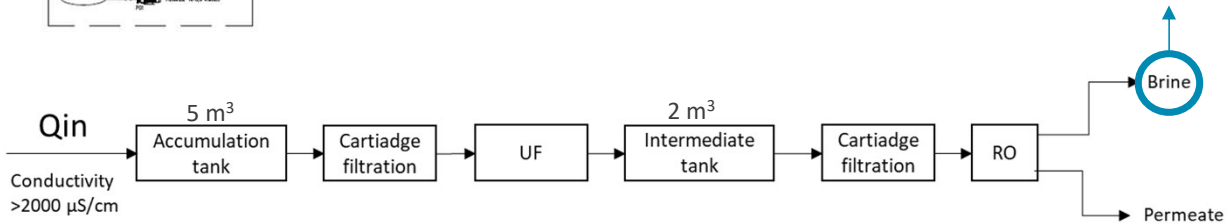
Case Study 3 - Rosignano (Italy)

Reverse osmosis pilot plant - Aretusa





LAB ANALYSIS TO CHARACTERIZE BRINE COMPOSITION



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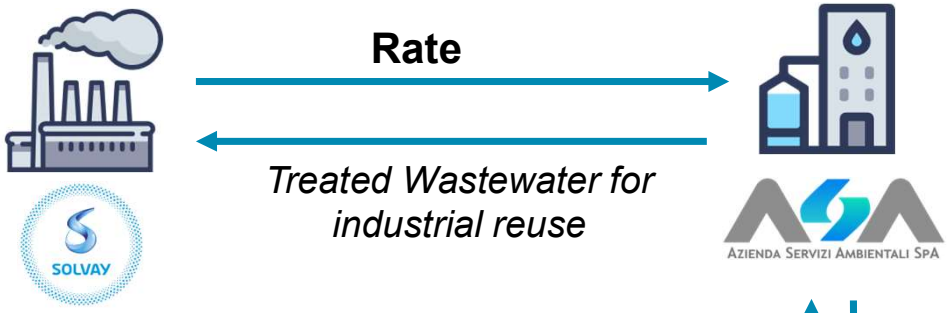
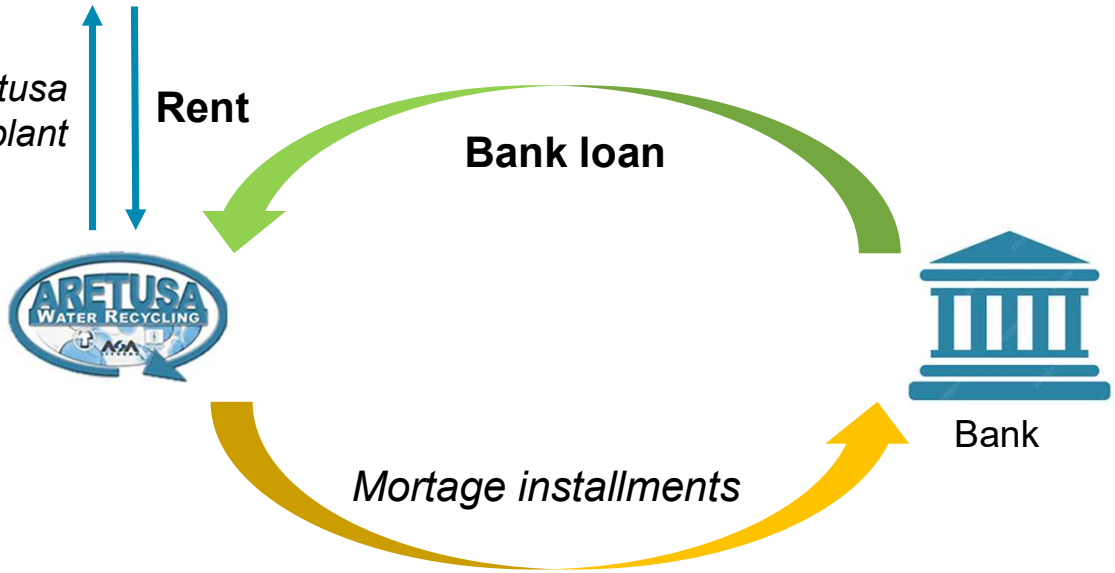
Consorzio Aretusa

Governance of a no-profit consortium



PPP Governance Model

Public Private Partnership



Main Contracts:

- **Bank loan**
- Supply of Treated Wastewater Contract (**Rate**)
- **Rent** contract ASA-Aretusa

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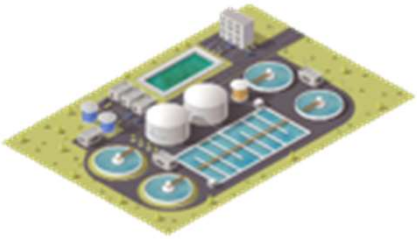
Consorzio Aretusa

Example of replicability

Mortgage to build the plant	
Share capital	€ xxxx
Grace period	xx years
Grace period interest costs	€ xxxx
Repayment	xx years
Annual installments	€ xxxxx
Interest rate	x%
Total interest cost	€ xxxxx

Bank



Treatment plant

Rental plant contract		
Years	xx	
Average annual rent linked to the mortgage	€	xxx
Annual rent linked to management costs	€	xxx

Water Utility

	Annual Plant Management Costs
Rental cost	€ xxxx
Electric Energy	€ xxxx
Reagents	€ xxxx
Ordinary maintenance	€ xxxx
Extraordinary maintenance	€ xxxx
Staff costs	€ xxxx
Work equipment	€ xxxx
Chemical analyses	€ xxxx
Sludge disposal	€ xxxx
Indirect costs	€ xxxx
TOTAL ANNUAL COSTS	€ xxxxxxxxxx

	Rate of treated waste water supplied
m3/y	xxxxxx
Total annual costs	€ xxxxxxxx
Rate	€ /m³ xxxxxxx

Industry

ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

THANK YOU FOR THE ATTENTION

ENG. CAMILLO PALERMO
ENG. CHIARA GIANSANTI
ENG. CHIARA CUSENZA

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

Membrane technology for reuse of treated wastewater as fit-for-purpose water –

Results from the first test period in Kalundborg (CS9)

J. Jährig, A. Kleyböcker, U. Miehe, L. Vredenbregt, F. Brendecke,
L. Rodenkam Melchiorsen, P. Thisgaard

06.03.2023



Case Study 9 – Kalundborg



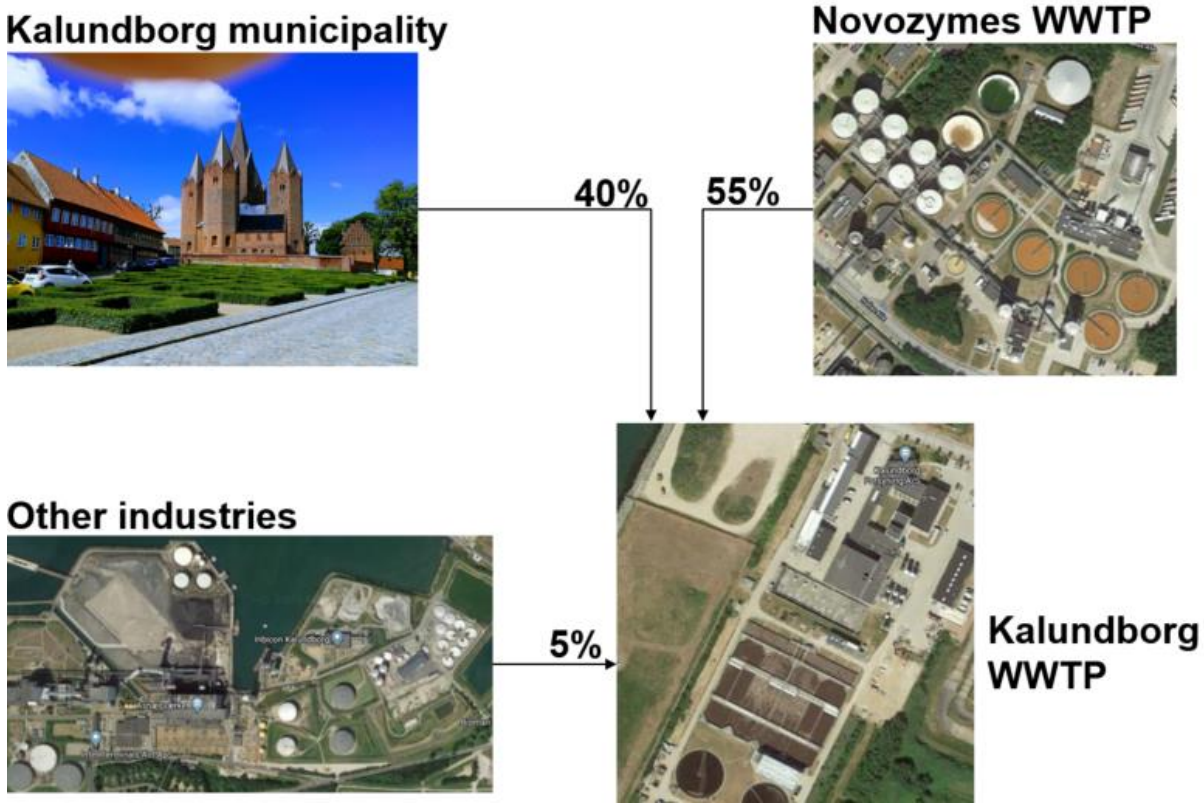
The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

What are the goals at CS 9 – Kalundborg?

- Biotech & pharmaceutical industry, etc.
- No water reclamation from WWTP effluent
- Each WWTP has its separate control system

Goals of the project:

- Joint control system for two WWTPs
- Fit-for-purpose water for industrial reuse



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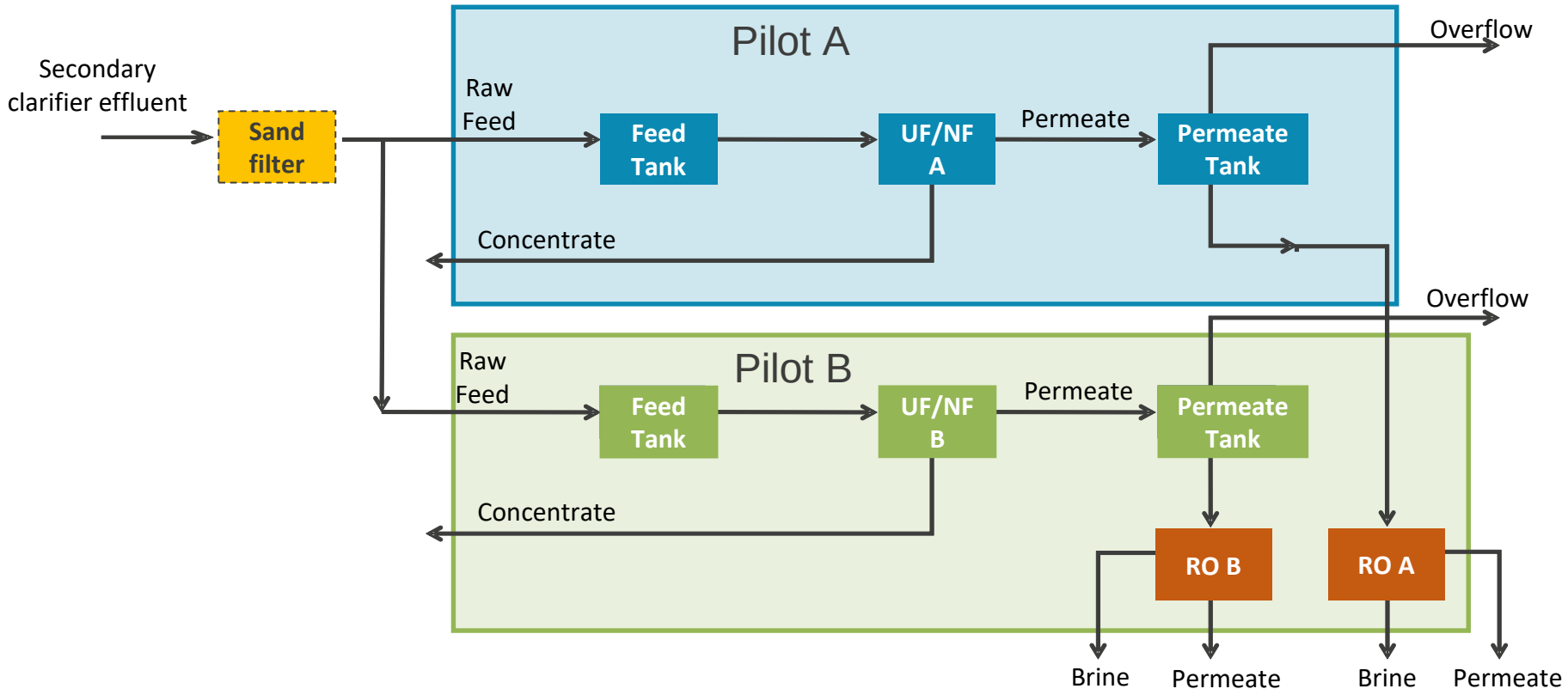
Fit for purpose water production via membranes



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Membrane pilot plants

Pilot container A



Pilot container B



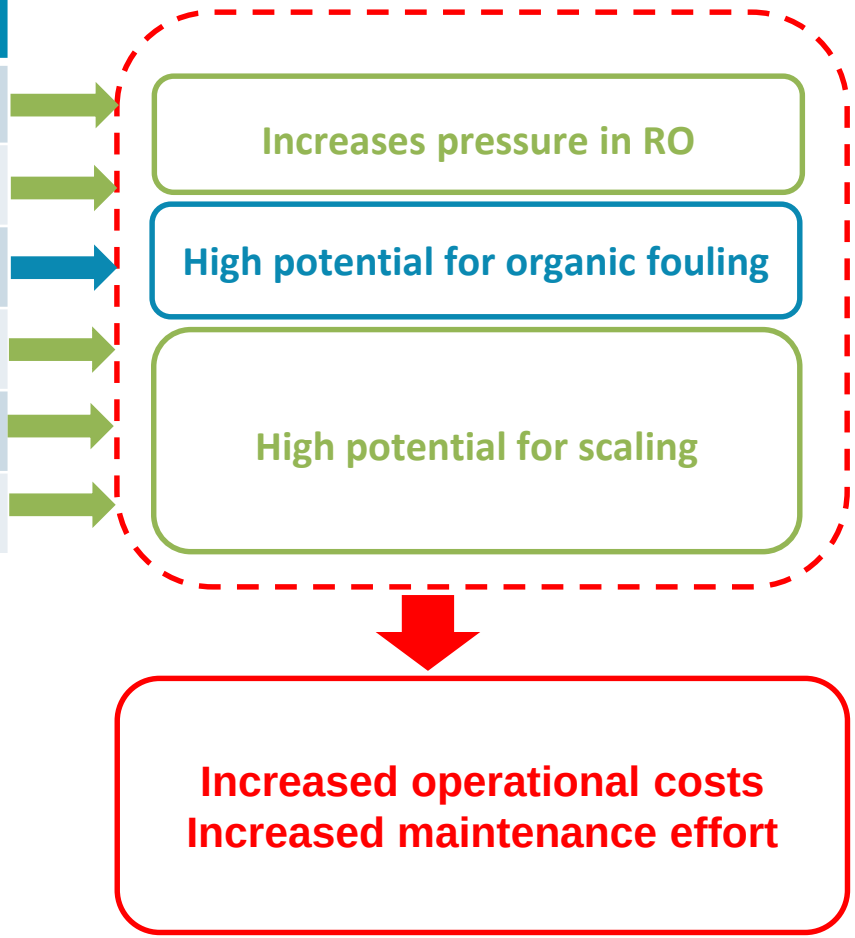
Reverse osmosis



Specific challenges at KCR WWTP

Parameter	Unit	Content
Electrical conductivity	µS/cm	2800-8200
Total dissolved solids	mg/L	3500-4200
TOC / COD	mg/L	20-60 / 50-190*
Calcium	mg/L	98-130
Hydrogen carbonate	mg/L	1000-1100
Sulfate	mg/L	440-510

* before ozonation for COD removal



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Why do we need research?

Fouling prevention:

- Does the novel ultra-tight UF membrane prevent better the RO from fouling than a conventional UF or open NF?

➢ performance comparison in parallel pilot containers

Production of fit-for-purpose water:

- Can we produce fit-for-purpose water for cooling towers and/or boilers?
- Which water quality is reached after UF/NF and for which reuse purpose can the water be used (truck or street cleaning)?

➢ Investigation of water quality after each treatment step

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

Practical challenges: pretreatment



pre-filter of UF/NF



blocked screen of pre-filter → requires a lot of manual cleaning



pre-filter of RO



cartridge of pre-filter → requires exchange very often

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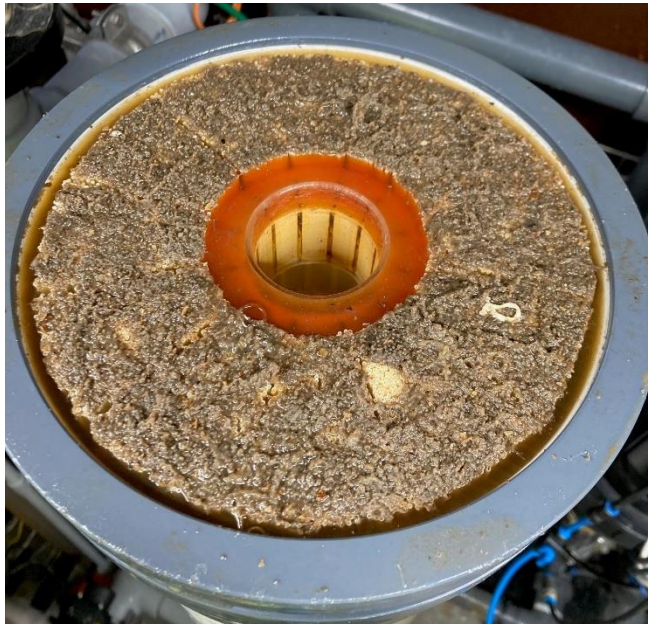
Practical challenges: membranes



UF/NF membrane module



clean UF/NF membrane



blocked UF/NF membrane

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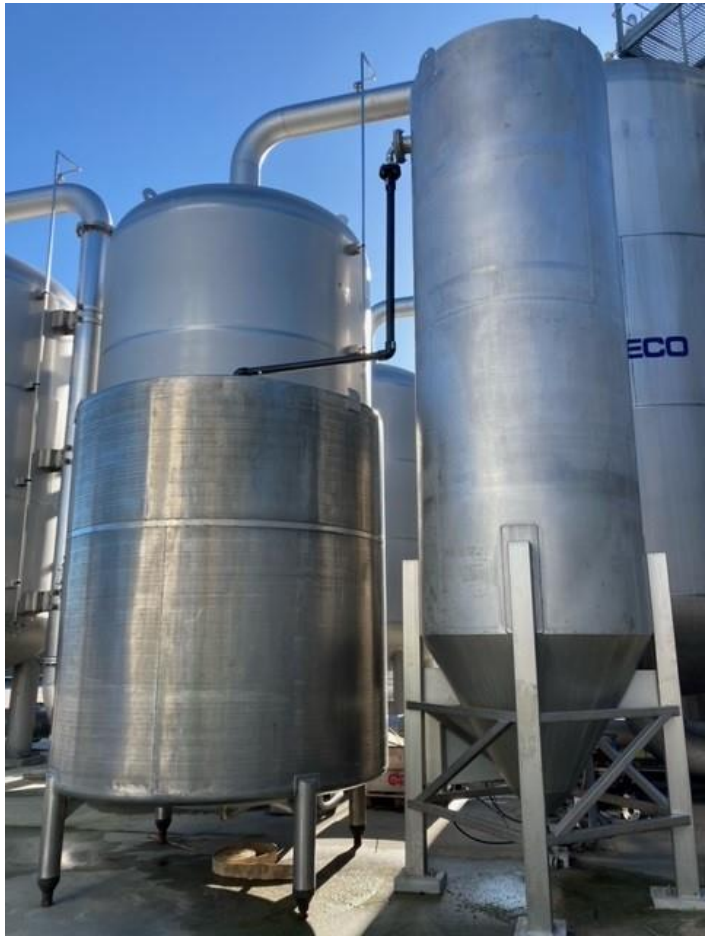
Intermediate solution: Install a DynaSand filter





continuously operated sand filter

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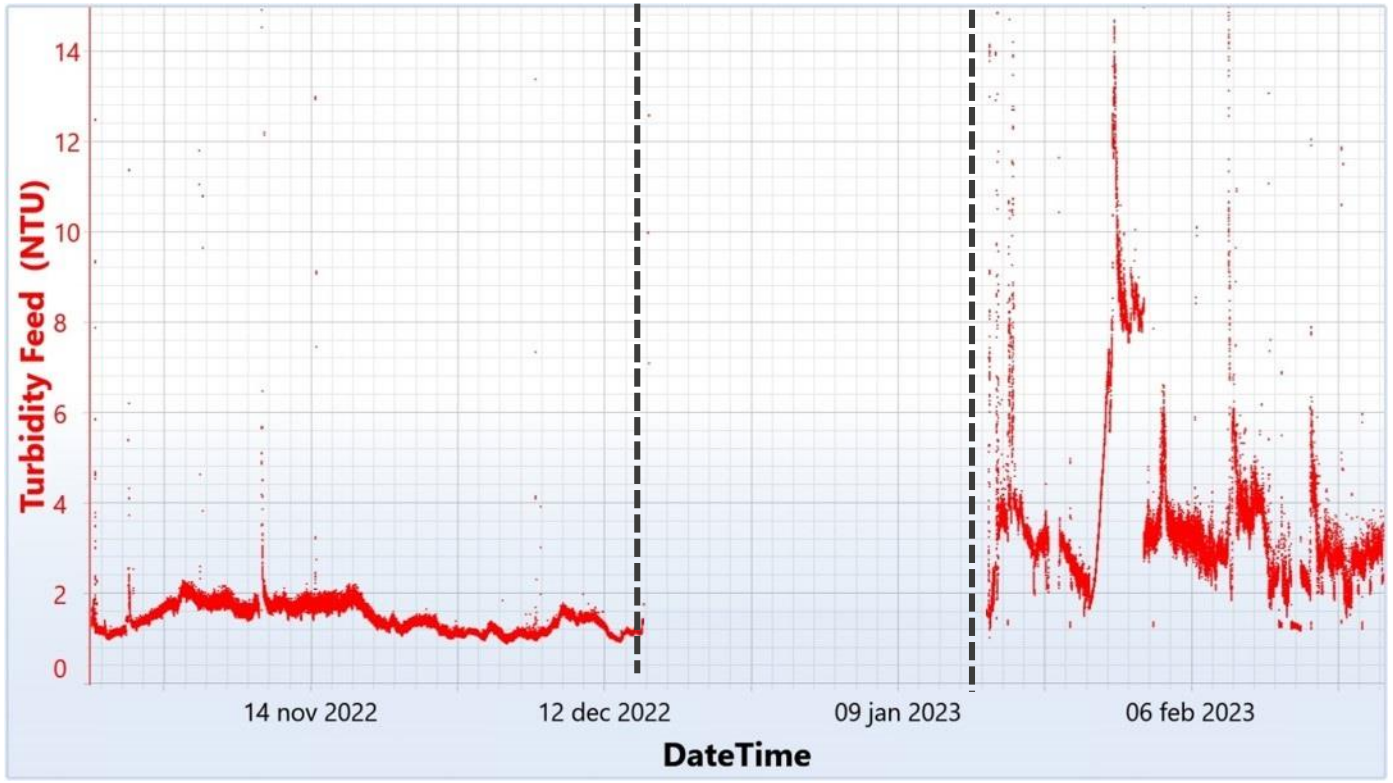
Impact of DynaSand filter

SF in operation

pilots out of operation

no SF operation



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Which treatment stage has which purpose?

Parameter	Sand filter	Prefilter	Ultrafiltration/ Nanofiltration	Reverse osmosis
Suspended solids	+	(+)	++	-
Microorganisms (bacteria, virus, protozoa)	(+)	-	++	+
Dissolved salts / hardness				++
Heavy metals				++
Dissolved organic matter and chemicals	-	-	-	++
	pretreatment		**main treatment**	

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Results: cooling water quality

Parameter	Unit	Goal: cooling tower	UF 150 kDa [1]	n	Ultra tight UF 4 kDa [1]	n	open NF 1 kDa [1]	n	RO [2]	n
Aluminium	µg/L	<500	< 30 ✓	4	38 ✓	6	< 30 ✓	3	✓	
Calcium	mg/L	> 20 / <500	127 ✓	6	135 ✓	12	140 ✓	7	< 0,5	6
Carbon. hardness	°dH	< 4 / < 20	26	2	29	4	33	3	0,13 ✓	6
Chloride	mg/L	< 50 / <250			1100	1	1000	1	19 ✓	7
Copper	µg/L	< 500			1,1 ✓	1	0,6 ✓	1	2,6 ✓	7
Conductivity	µS/cm	50 - <3000	5030	6	5200	8	5040	7	69 ✓	10
Iron	mg/L	< 0,1 / < 0,5			< 0,05 ✓	1	< 0,05 ✓	1	< 0,05 ✓	7
Magnesium	mg/L	<100	28,17 ✓	6	24 ✓	12	21 ✓	7	0,17 ✓	5
pH		7 - 9	8,2 ✓	2	8,2 ✓	5	8,1 ✓	4	6,4	10
Sulphate	mg/L	< 50 / < 600	498 ✓	4	437 ✓	10	337 ✓	6	2,0 ✓	6
TDS	g/L	<1,8	3,0	2	3,2	3	2,9	3	0,05 ✓	4
Total hardness	°dH	0,1 - <8	26	2	23	4	24	3	< 0,1 ✓	6
TSS	mg/L	<5	1,2 ✓	2	0,6 ✓	3	3,9 ✓	3	1,6 ✓	4
Turbidity	FNU	< 1	1,4	6	0,39 ✓	10	< 0,1 ✓	6	✓	
Escherichia coli	MPN/100 mL	Absence			< 2 ✓	1	< 2 ✓	1	✓	
Legionella	CFU/L	< 100			< 10 ✓	1	< 10 ✓	1	✓	

1) Independent from operational parameter
2) Independent from pre-treatment, results of both ROs together
3) Only one grab sample, currently reuse water quality
4) Only one grab sample, drinking water quality

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

Results: steam production quality

Parameter	Unit	Goal: steam production	UF 150 kDa [1]	n	Ultra tight UF 4 kDa [1]	n	open NF 1 kDa [1]	n	RO [2]	n
Alkalinity	mmol/L	0.5-15	18	2	15	4	16	3	0,2 ✓	7
Clarity		clear, free from particles	6/7		13/13 ✓		8/8 ✓		10/10 ✓	
COD	mg/L	3-5	61	7	55	16	42	11	< 5 (✓)	12
Copper	µg/L	< 3 - < 100			1,1 ✓	1	0,6 ✓	1	2,6 ✓	7
Conductivity	µS/cm	≤ 30/ > 30 *	5030	6	5200	8	5040	7	69	10
Oil and fat	mg/L	< 1 / < 0.5			< 0,1 ✓	1	< 0,1 ✓	1	✓	
Iron	mg/L	< 0.01 - < 0,3			< 0,05 ✓	1	< 0,05 ✓	1	< 0,05 ✓	7
Sodium	mg/L	< 0.01 (Na+K)			890	1	870	1	15	7
pH		> 7.0 / > 9.2 / 7-10	8,2 ✓	2	8,2 ✓	5	8,1 ✓	4	6,4	10
Potassium	mg/L	< 0.01 (Na+K)			210	1	200	1	3,8	7
Silicate	mg/L	< 0,02	7,9	4	8,6	8	9,1	5	0,09 **	7
TOC	mg/L	< 0.2 - < 0.5	25	6	23	11	17	8	0,46 ✓	7
Total hardness	°dH	< 0,028 - < 0,28	26	2	23	4	24	3	< 0,1 ✓	6

* very wide range, depending on the type of vessel

1) Independent from operational parameter
2) Independent from pre-treatment, results of both ROs together
3) Only one grab sample, currently reuse water quality
4) Only one grab sample, drinking water quality

** 4/7 samples < LOQ (< 0,02)

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What have we learned from the pilot operation?

- Chemical parameters for cooling water can be easily met with UF-RO treatment
- ➢ Current used Lake water/Tisso II water could be substituted with RO permeate (pH adjustment/ stabilization required)

- Main challenge is the operation (no standard secondary effluent)
- ➢ More efforts on proper prefiltration (With DynaSand: reliable operation for 5 months)
- ➢ Significant fouling potential on membranes (high organic matter, high alkalinity)

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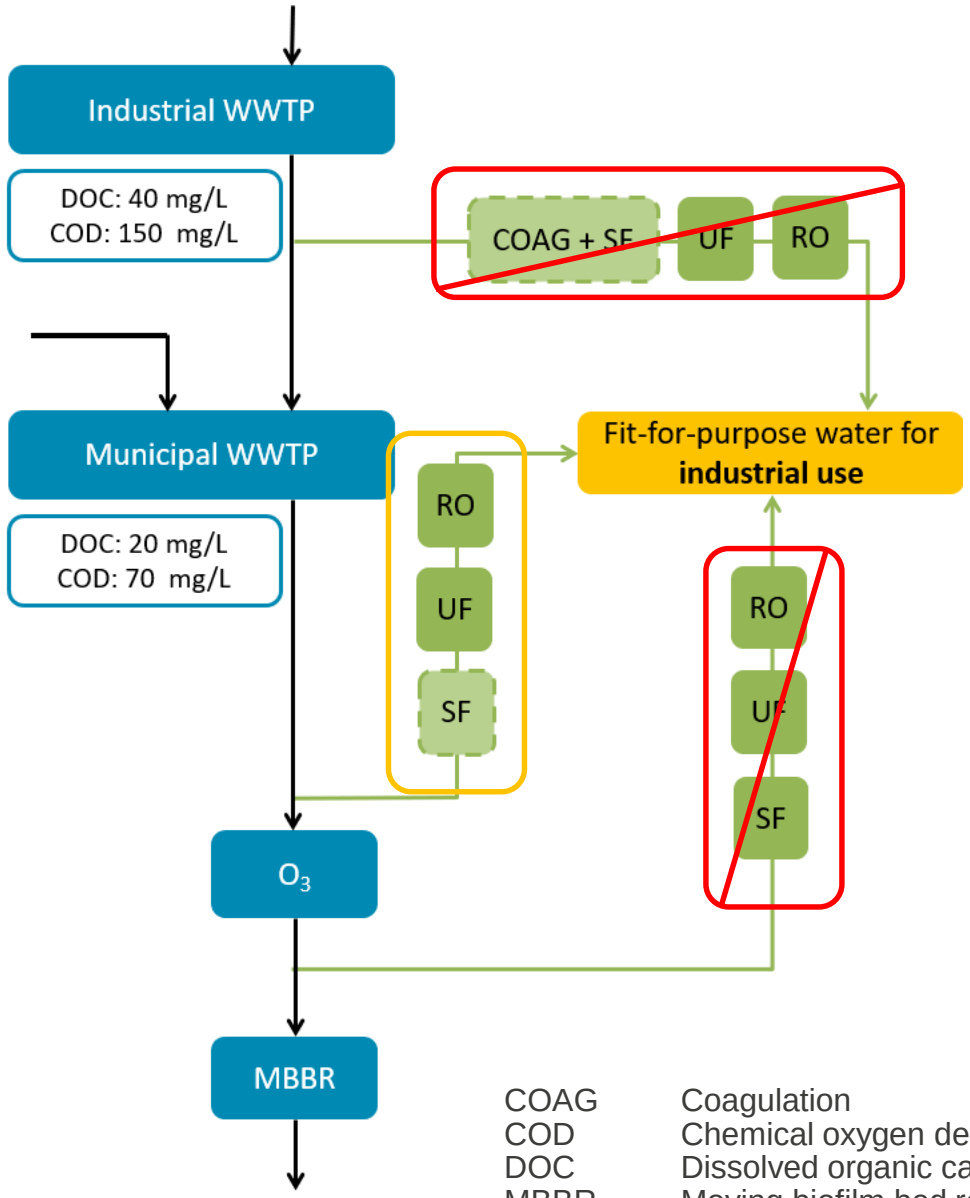
What are the next steps?

- Installation of dual media filter before membrane unit
- Optimization of operational parameter for continuous and reliable operation
- More measurements on microbial parameter needed for validation of cooling water quality
- Microbial risk assessment concept



COAG	Coagulation
COD	Chemical oxygen demand
DOC	Dissolved organic carbon
MBBR	Moving biofilm bed reactor
RO	Reverse Osmosis
SF	Sandfiltration
UF	Ultrafiltration
WWTP	Wastewater treatment plant

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ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

Than you for your attention!



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ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

LCA CS9 Kalundborg

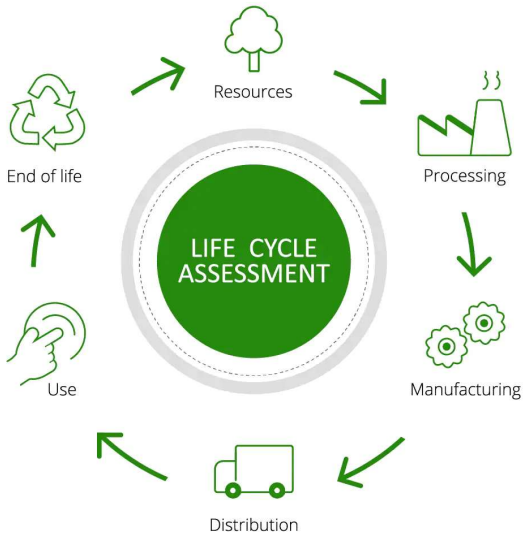
Final Results 27.05.2024



Motivation

Goal: investigate the potential environmental impacts of different membrane schemes for Kalundborg utility for industrial water reuse as cooling water

- Standardized method defined in ISO 14040/44
- For products / processes / services
- Includes all parts of the life-cycle:
  - Direct emissions (= on-site)
  - Indirect emissions + resource use (electricity, chemicals, waste, …)
  - Credits for products (reclaimed water, nutrients in water for irrigation, heat)



Source: Consulting Deloitte

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Scenarios per m^3 of water for cooling purposes

- Freshwater from **Lake Tisso**
- Freshwater from **Seawater desalination**
- Water reclamation from wastewater treatment plant effluent:
  - **cUF:** Ultrafiltration & Reverse Osmosis
  - **cUF-UV:** Ultrafiltration & UV-treatment & Reverse Osmosis
  - **utUF:** ultra tight Ultrafiltration & Reverse Osmosis
  - **oNF:** open Nanofiltration & Reverse Osmosis
  - **cUF-brine tr.:** Ultrafiltration & Reverse Osmosis & brine treatment without heat recovery
  - **cUF-brine tr.-heat-rec.:** Ultrafiltration & Reverse Osmosis & brine treatment with heat recovery

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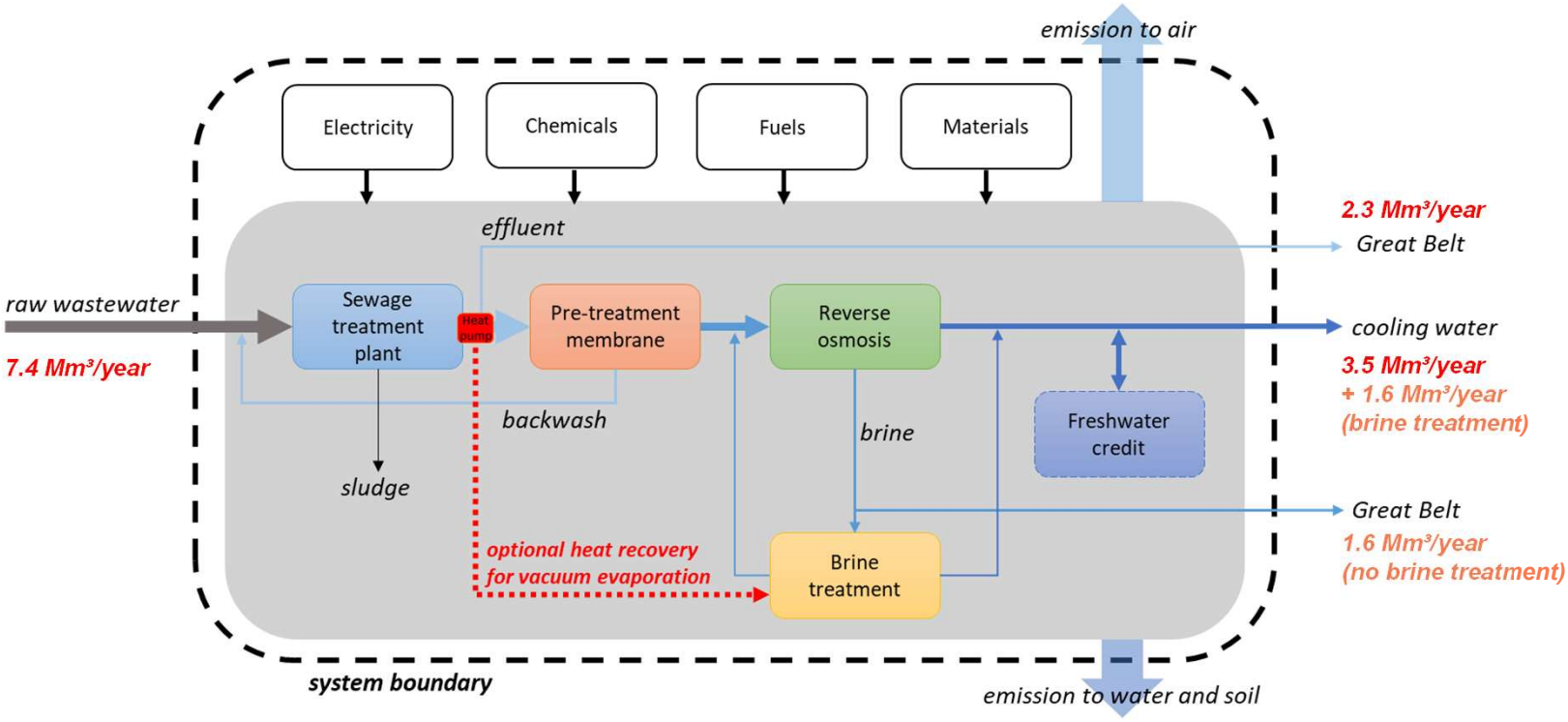
System boundary



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Data input and quality

- Freshwater sources estimated from pilot study and literature
- Water quality and chemical consumption from pilot plant
- Electricity consumption calculated via pressure of pumps and WAVE software
- Potential brine treatment estimated based on literature

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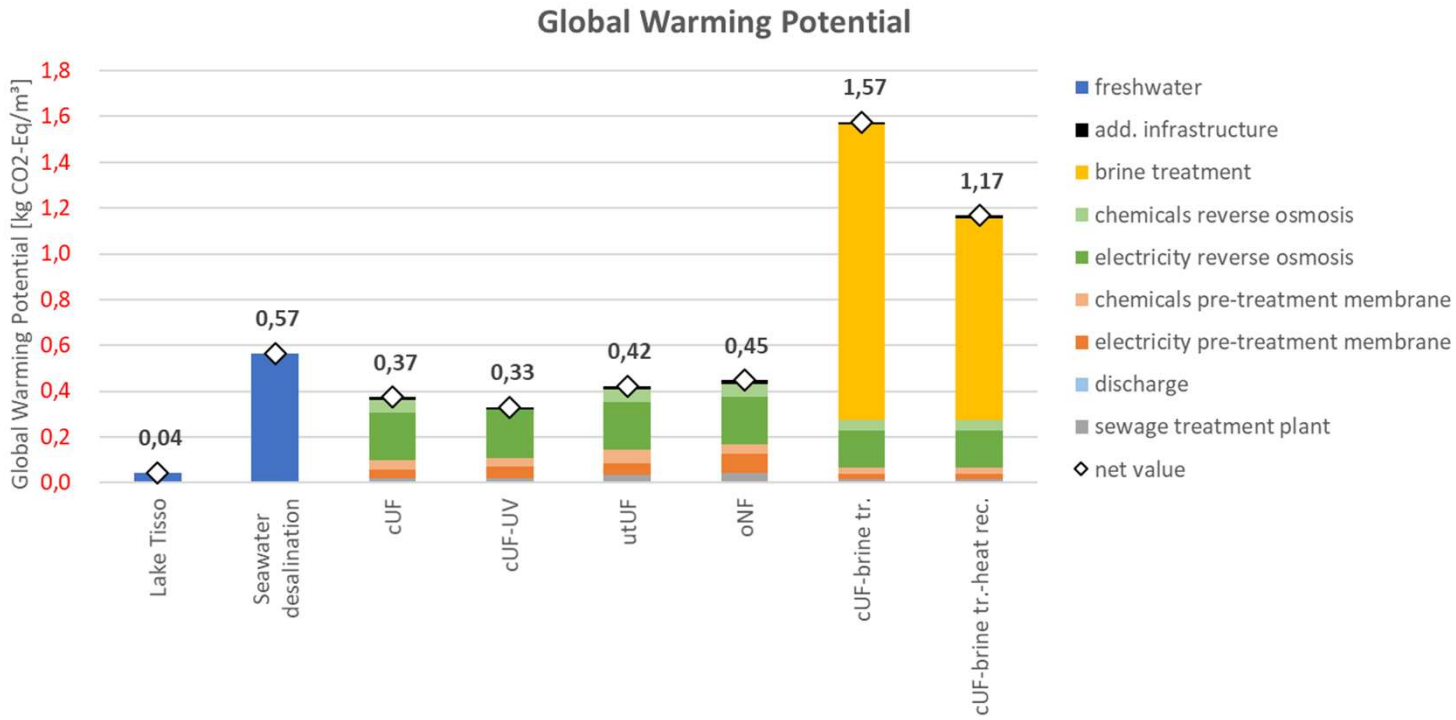
Global warming potential – changes per m³
CO_2, CH_4, N_2O



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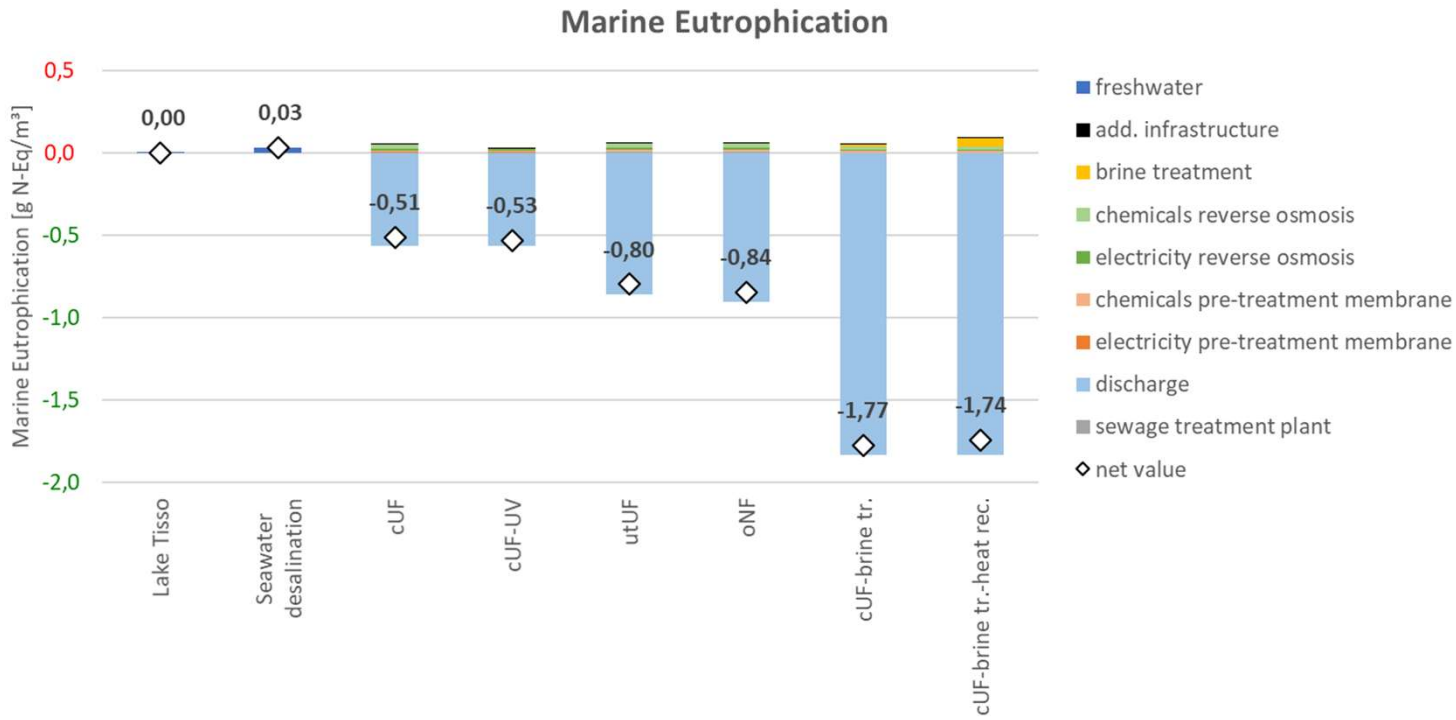
Marine eutrophication potential – changes per m³
N in aquatic environment



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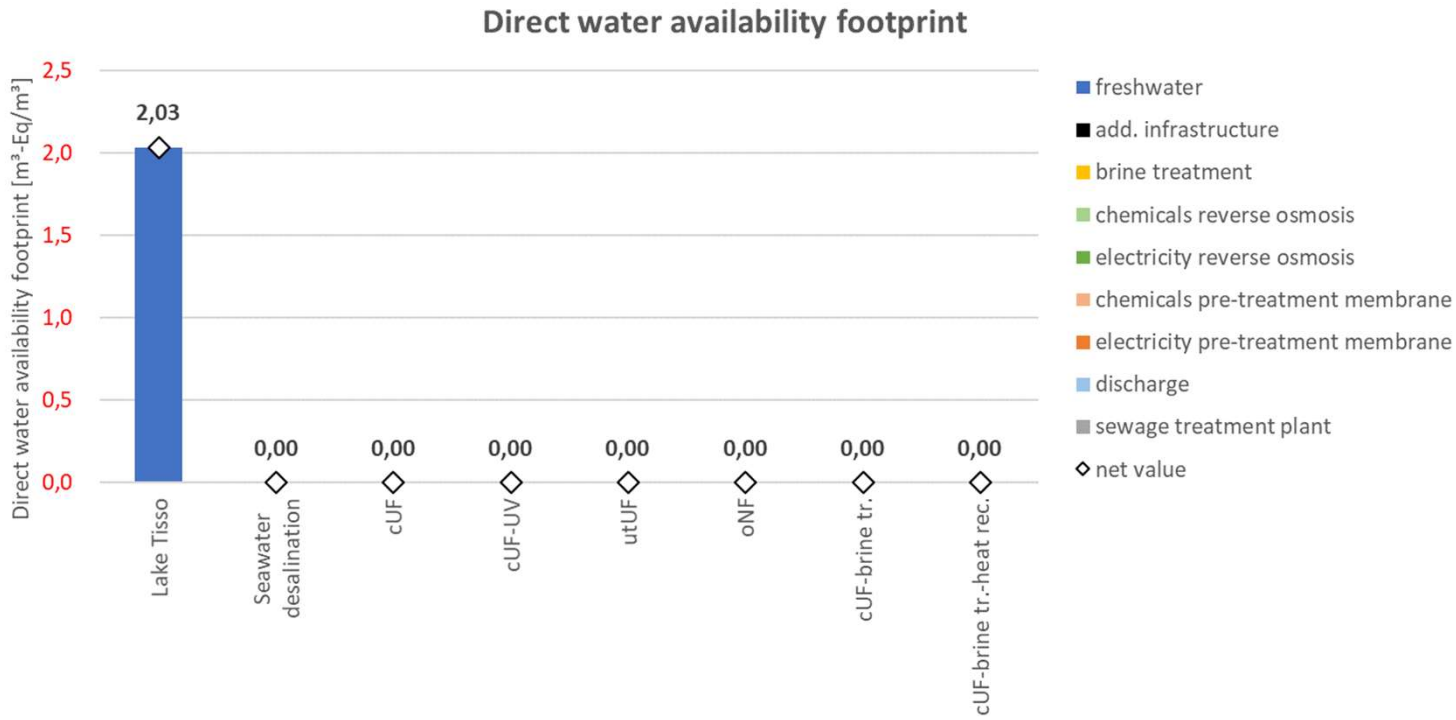
Direct water availability footprint – changes per m³
Avoided freshwater use



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Overall conclusions LCA

- Water reuse increases greenhouse gas emissions compared to lake water, while reducing the water footprint and nutrient release to the Great Belt
- Compared to seawater desalination, water reuse decreases the greenhouse gas emissions
- If brine treatment towards Zero Liquid Discharge is necessary the greenhouse gas emissions of water reuse increases significantly

- **Preferred treatment train:** conventional UF and Reverse Osmosis, preferably with UV disinfection of RO feed water instead of biocide dosing → lowest footprints!

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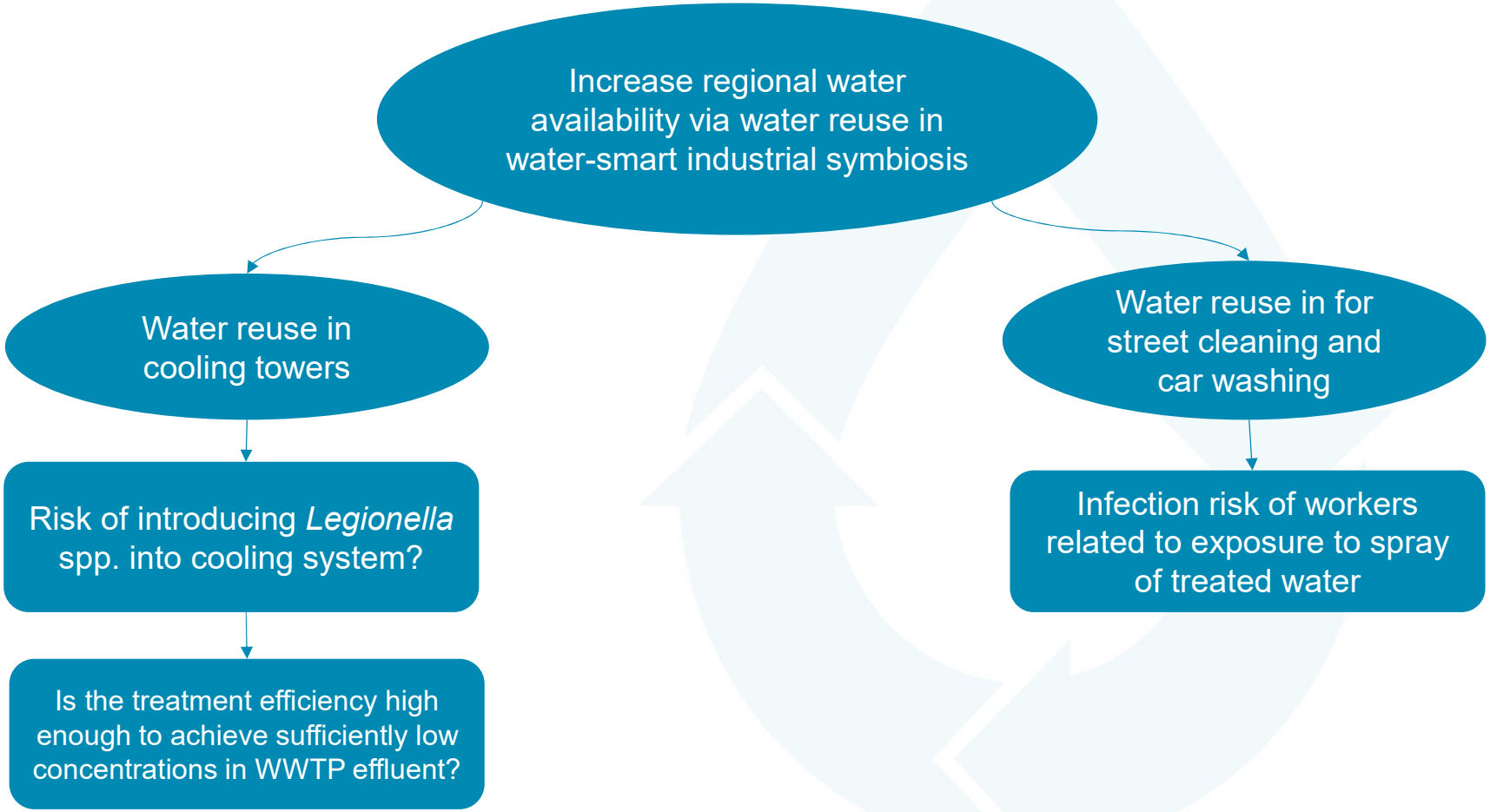
ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

Quantitative microbial risk assessment (QMRA)



Background CS9: Kalunbourg



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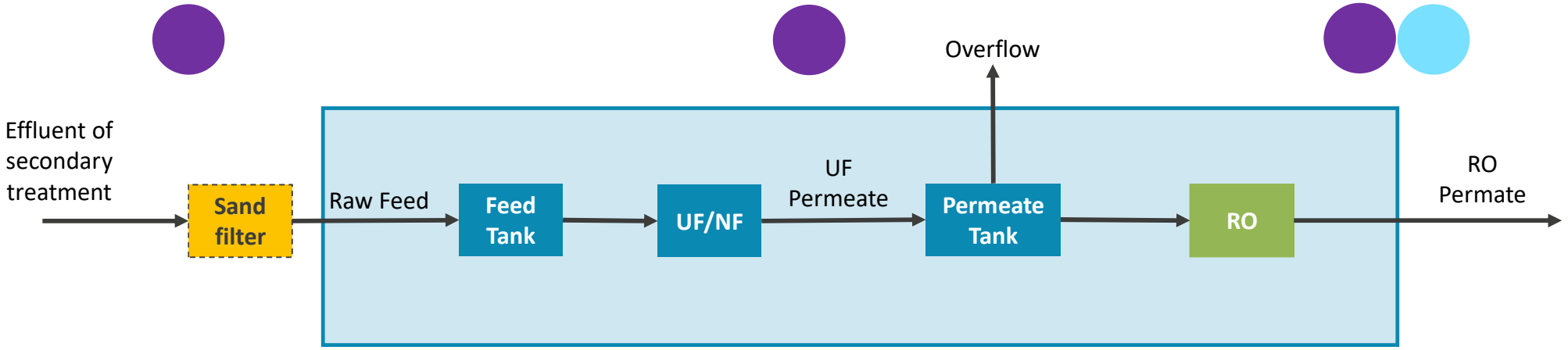
Pilot Plant - Flow scheme and points of assessment



Assessment point for water reuse for street cleaning and car washing

Assessment point for *Legionella* spp. contamination of cooling 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

QMRA to assess infection risk from street cleaning / car washing

Two major exposure pathways:

1. Ingestion:
    - risk of gastroenteritis caused by ingestion of water aerosols containing relevant concentrations of reference pathogens for viruses, bacteria, and protozoa (based on literature information)
2. Inhalation:
    - risk of *Legionella* infection caused by inhalation of water aerosols (based on local measuements



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System description and assumptions for exposure modelling

Source water	Model input	Information
Secondary effluent	Distribution of pathogen source water concentrations	*Legionella* (local measurements) Reference pathogens (literature)
Treatment alternatives	Distribution of average log removal values (LRV) for: • UF • NF • UF / RO • NF / RO	Local measurements complemented with literature information
Exposure ingestion (Gastroenteritis)	Point estimates: • 200 µl per event • 25 events per year	Sinclair et al. 2016
Exposure inhalation (*Legionella*)	Point estimates: • 0.2 µl per event • 25 events per year	Ahmed et al. 2010

Sinclair, M., F. Roddick, T. Nguyen, J. O'Toole and K. Leder (2016). "Measuring water ingestion from spray exposures." Water Research **99: 1-6.**
Ahmed, W., A. Vieritz, A. Goonetilleke and T. Gardner (2010). "Health risk from the use of roof-harvested rainwater in Southeast Queensland, Australia, as potable or nonpotable water, determined using quantitative microbial risk assessment." Appl Environ Microbiol **76(22): 7382-7391.**

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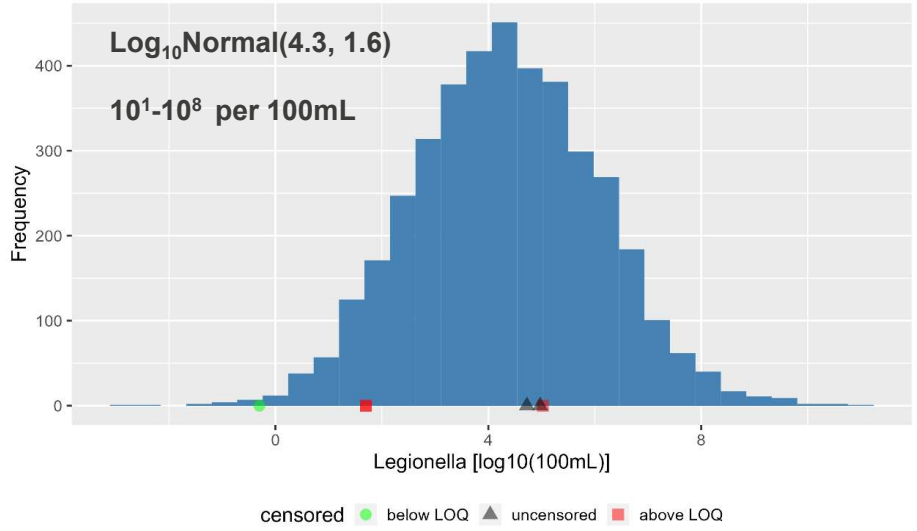
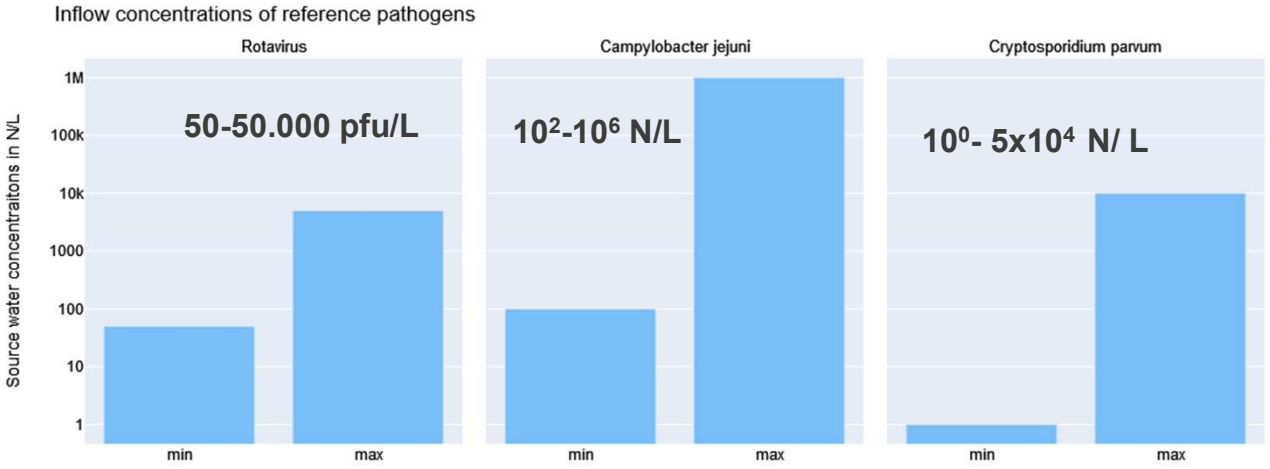
Source water concentrations



***Distribution of Legionella* spp. in secondary effluent based on local measurements**

For comparison:

- Wastewater Netherlands 10^8 CFU/L (Loenenbach et al. 2018, Medema et al. 2004)
- Norway > 10^{10} CFU/L (Olsen et al. 2010)



WHO (2006). Guidelines for the safe Use of Wastewater, Excreta and Greywater. Wastewater use in agriculture. **2: 222.**

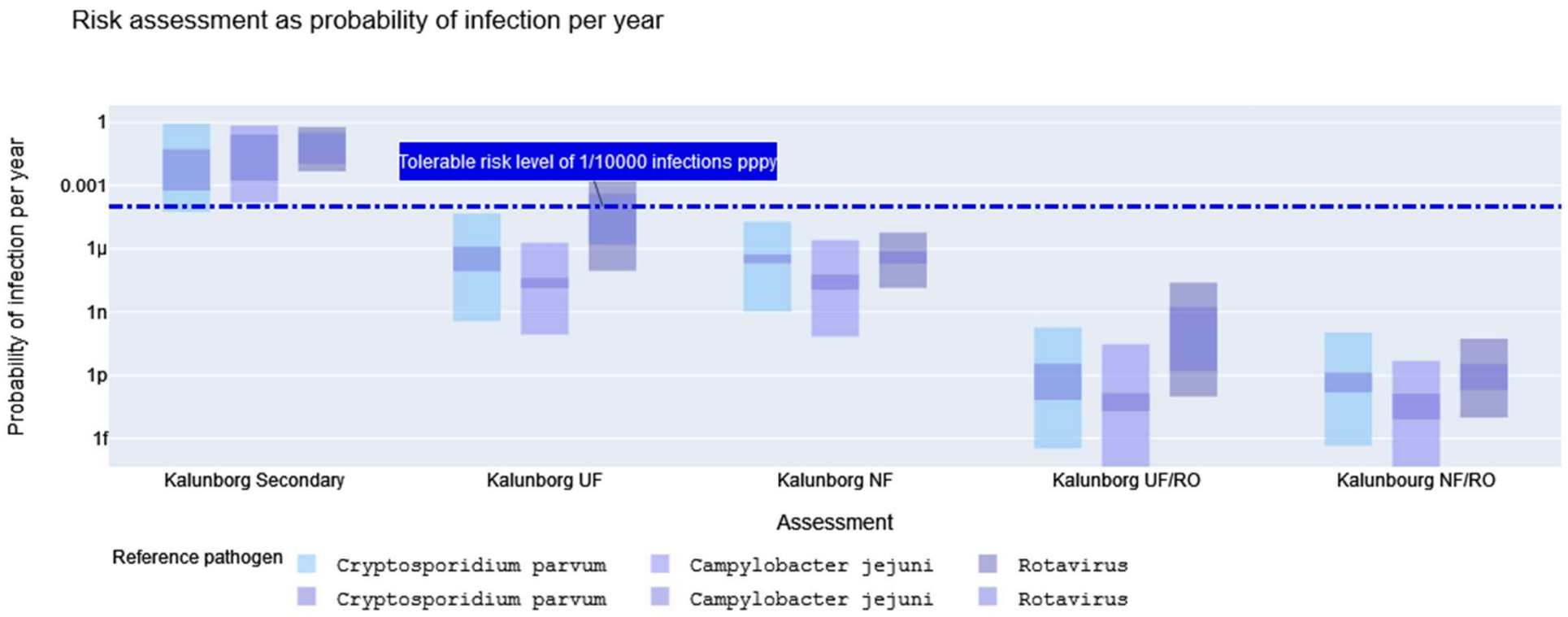
Expected Log_{10}-Removal

Treatment step	Pathogen	Applied range (uniform distribution)	Source*
Ultrafiltration	Virus	2.7 - 5.1	NSF/ANSI 419 validation
	Bacteria	5.5 - 6	
	Protozoa	5.5 - 6	
Nanofiltration	Virus	5.4 – 6	NSF/ANSI 419 validation
	Bacteria	5.8 - 6.3	
	Protozoa	5.4 – 6	
Reverse Osmosis	Virus	5.4 - 6	NSF/ANSI 419 validation
	Bacteria	5.4 - 6	
	Protozoa	5.8 - 6.3	
Total UF/RO	Virus	**8.1 - 11.1**	
	Bacteria	**10.8 -12**	
	Protozoa	**10.9 - 12.3**	
Total NF/RO	Virus	**10.9 - 12**	
	Bacteria	**11.5 – 12**	
	Protozoa	**10.9 – 12-6**	

*https://kwb-r.github.io/qmra.db/articles/database_content.html

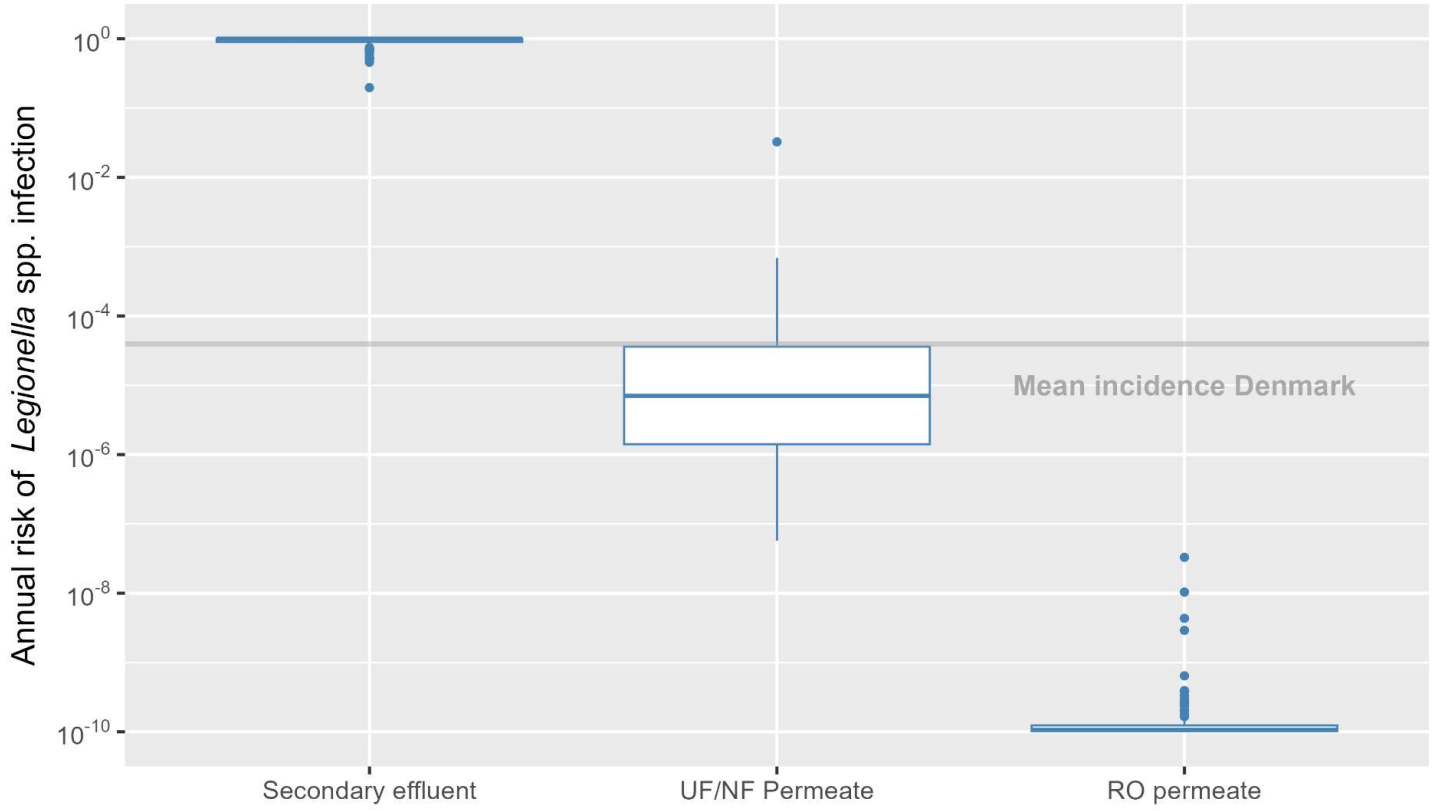
The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

Results: Street cleaning / Car washing



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

Results: Street cleaning / Car washing *Legionella* spp.



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

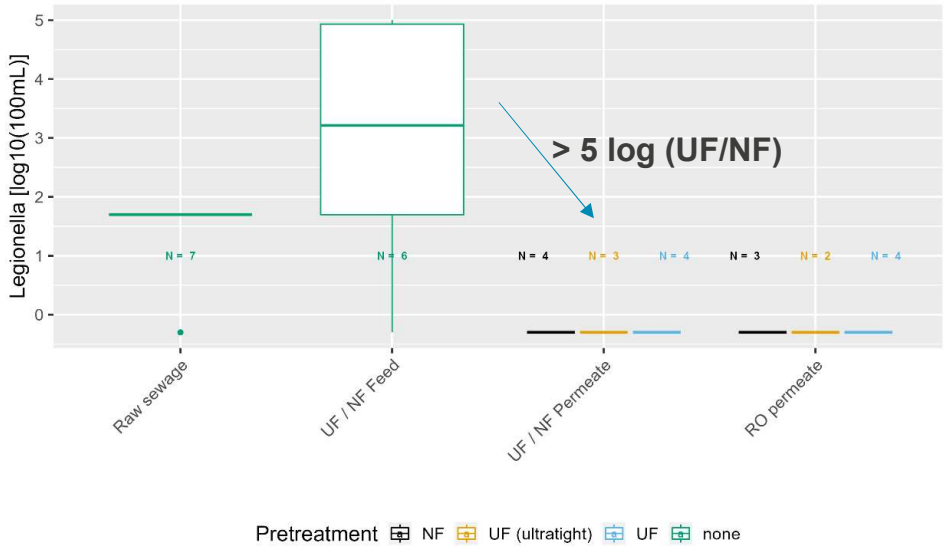
Results: cooling water

Information provided by scientific literature

UF	NF	RO	Total UF/RO	Total NF/RO
5.5 – 6	5.8 – 6.3	5.8 - 6.3	11.3 – 12.3	11.6 – 12.6

Assessment of treatment efficiency based on local measurement

Measurement of *Legionella* spp. in the effluent the RO



Good agreement between literature and pilot study

Very low risk of Legionella transport into cooling towers after UF/RO or NF/RO 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

Summary

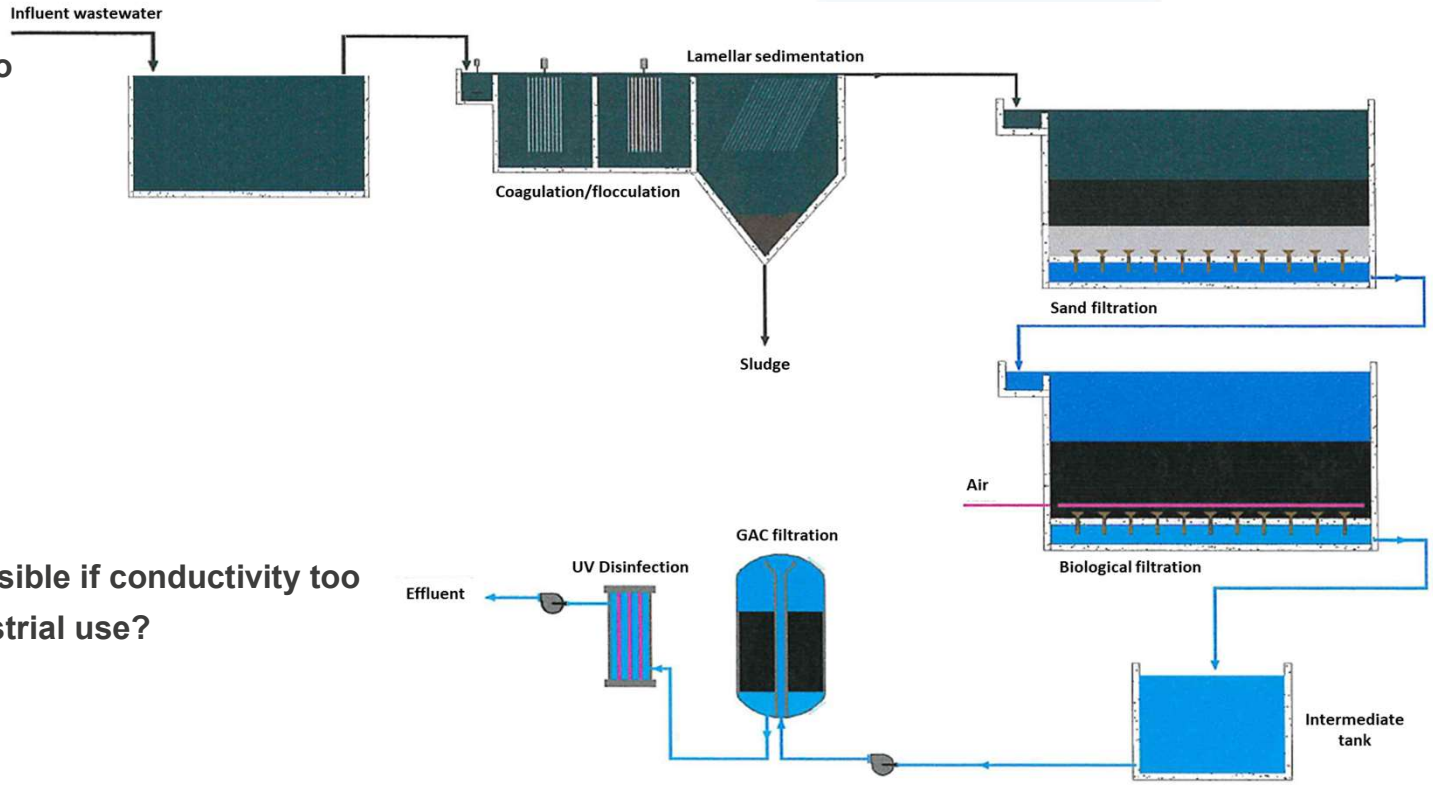
- Results indicate ***low risk of Legionella contamination of cooling waters*** after UF/RO or NF/RO treatement.
- For car washing and street cleaning purposes, **risk stays below drinking water standards for NF, UF/RO, and NF/RO** treatment.
- For the case of **UF as single pre-treatment** prior to car washing, additional verification monitoring should be conducted to reduce remaining uncertainties regarding virus removal.
- After secondary treatment, local measurements and literature information **indicate elevanted risk from car washing activities** → not recommended without further 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

CS3 Aretusa: concept study

Cecina

Rosignano



Irrigation possible if conductivity too high for industrial use?

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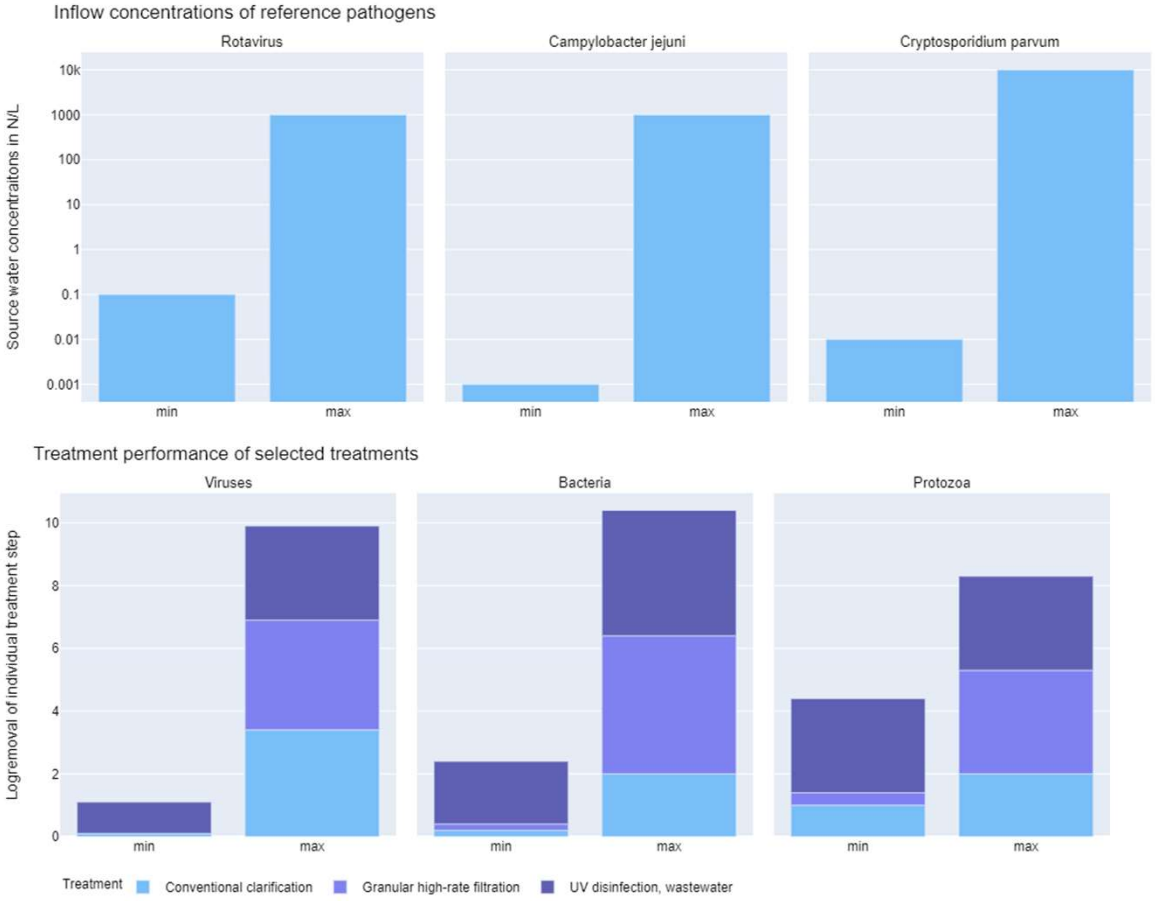
Assumptions for source water concentrations and treatment performances

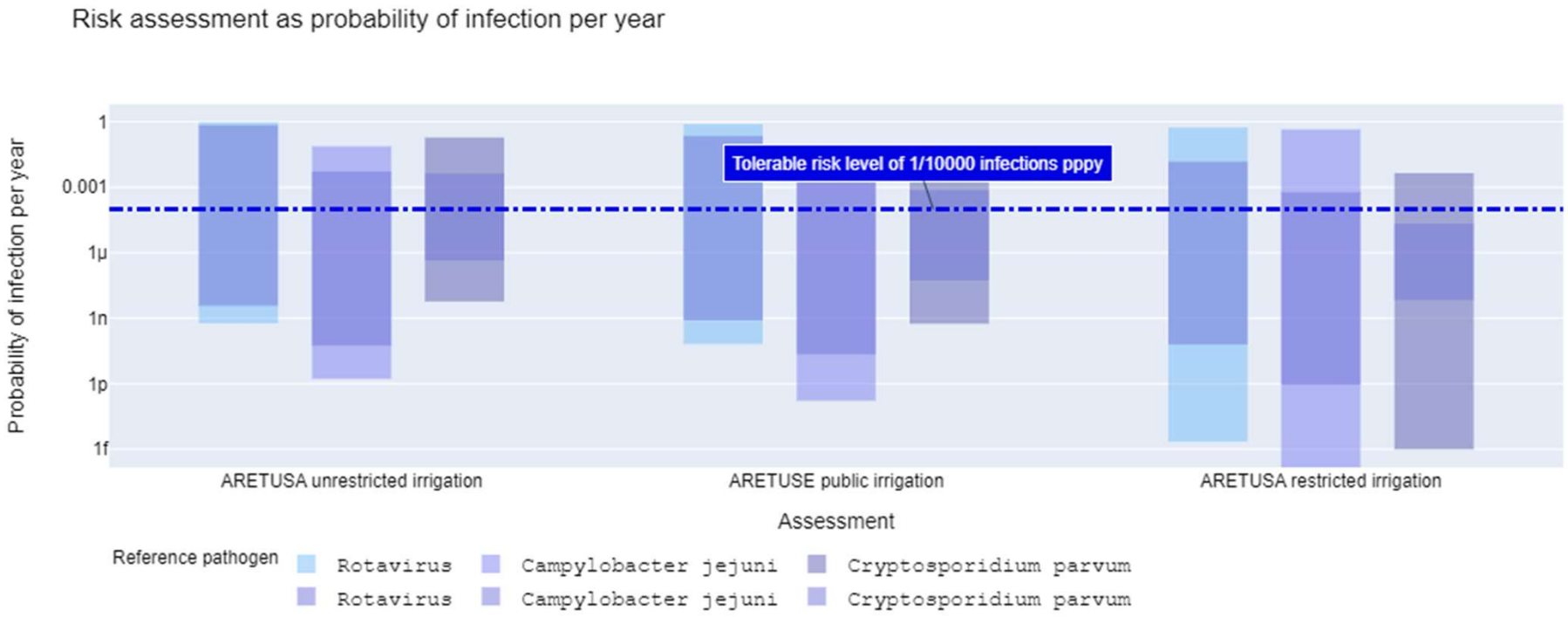


WHO (2006). Guidelines for the safe Use of Wastewater, Excreta and Greywater. Wastewater use in agriculture. **2: 222.**

https://kwb-r.github.io/qmra.db/articles/database_content.html#treatment-1

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

Results: Status quo assessment for different irrigation options



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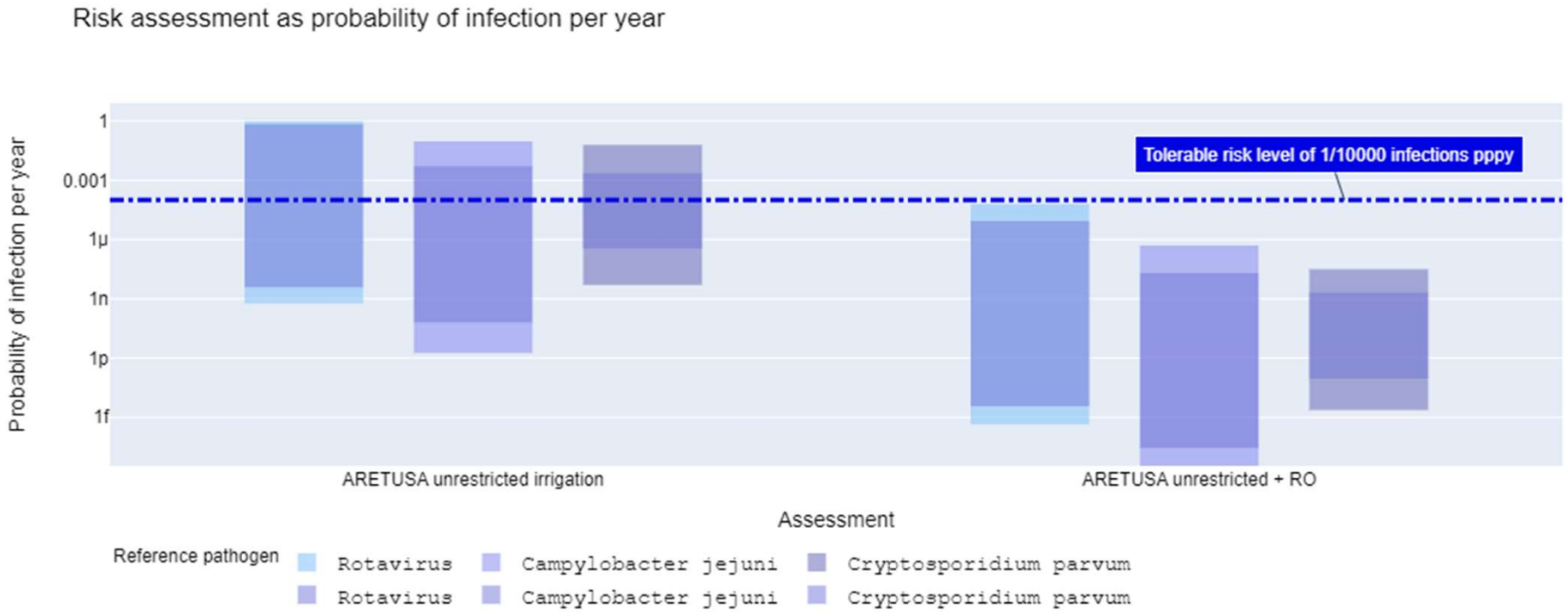
Scenario: RO enhanced reuse scheme



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

Summary

- Status quo treatment scheme indicates high potential of achieving health-based targets for irrigation in agriculture
- Risk is identified due to the lack of local validation data of the implemented treatment train

  → Futher monitoring recommended
- Additional RO units expected to reduce risk well below health based targets

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

B-WaterSmart policy recommendations leveraging water reuse in the EU

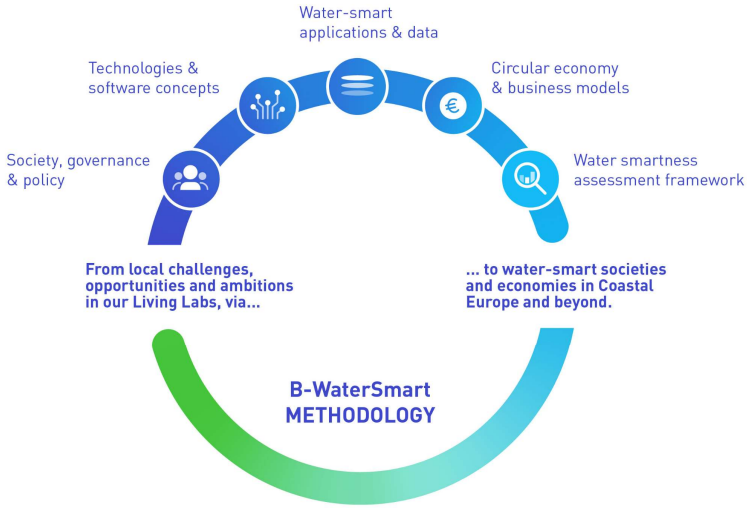
Ultimate Workshop 11 June 2024

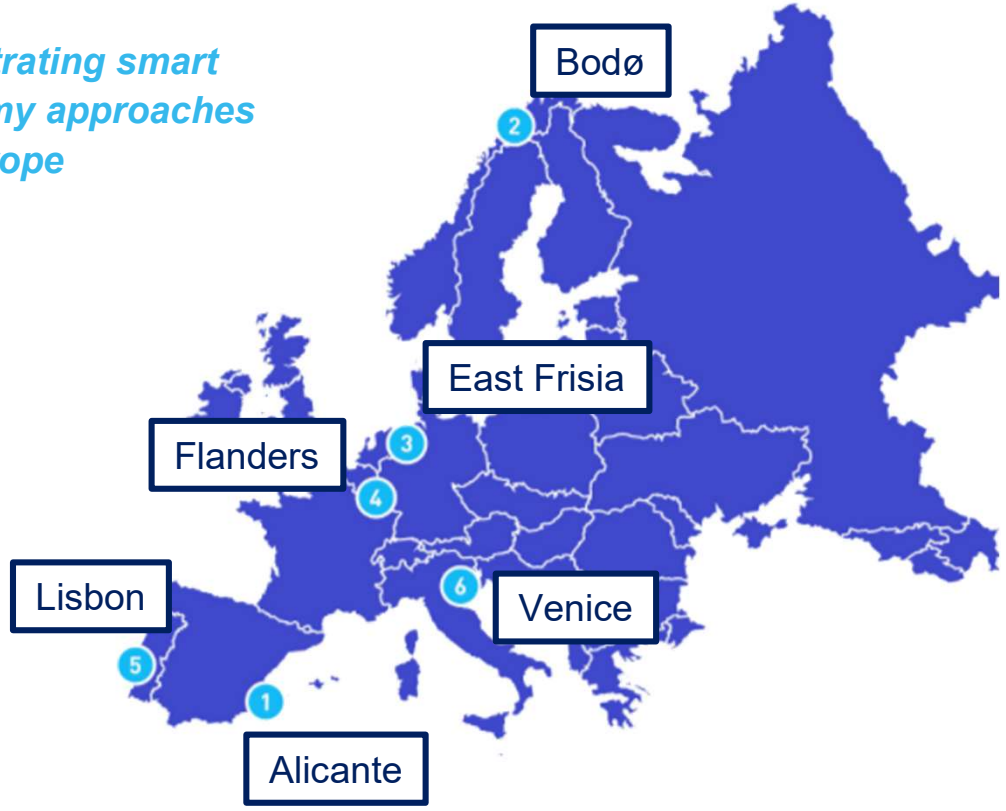
Kristina Wencki (IWW), Maria Adriana Cardoso (LNEC), Rita Ribeiro (LNEC), Maria João Rosa (LNEC)

b-watersmart.eu

B-WaterSmart (EU Horizon project) boosts innovation for building a water-smart society and economy

… by developing and demonstrating smart technologies and circular economy approaches at 6 Living Labs in Europe





P&R major common issues across B-WaterSmart LLs regarding water reuse

- Increased **treated wastewater quality requirements for discharge** to be introduced by the UWWTD recast can facilitate water reuse (lower or no additional/advanced treatment needed for reclamation)
- **Monitoring** is very relevant but often represents a big share of the direct costs of water reuse
- Need of **EU policies** for public engagement, awareness, and communication to overcome the perception of worse water quality and high risk, among other ("yuck") factors, to increase the water reuse acceptance

P&R major common issues across B-WaterSmart LLs regarding water reuse

- **Business models, funding and pricing** are critical factors
- **Multiple users** improve technical (e.g., decrease peak demands) and economic feasibility of water reuse
- Need to clarify if reclaimed water supply must be defined as an **autonomous water service** with a clear definition of responsibilities
  → Water reuse often requires a dedicated treatment for reclamation and direct water reuse always requires a distribution network, the production and the distribution are not necessarily conducted by the same utility
- Need of **guidelines** for the water reuse licensing process by the water authorities

Policy and regulation recommendations from B-WaterSmart leveraging water reuse at EU level

- Develop an **EU strategic agenda on water reuse** covering all uses (non-potable and potable), indirect (including managed aquifer recharge) and direct
  → monitor and increase the safety of the current indirect reuse and facilitate the development of the circular paradigm / water-energy-waste-food nexus
- Encourage the member-states to define **priorities for reclaimed water uses**, according to the local environmental, technical, economic & social circumstances
  → reclaimed water should be clearly integrated in local/regional water balance (no investment in reuse if this is not needed to secure supply continuity)
- Agree on a uniform position across the EU countries on **if and how to account for indirect water reuse** – clarifying the boundaries between treated wastewater discharge and (indirect) water reuse / permits and treatment required
  → the cost coverage of the additional treatment (if needed) should reflect the best site-specific water resource management
  → the environmental uses should be accounted for as direct or indirect water reuse, as well as managed aquifer recharge

Policy and regulation recommendations from B-WaterSmart leveraging water reuse at EU level

- **Managed aquifer recharge** - clear instructions should be delivered for environmental impact assessment and for risk assessment and management
- A future **revision of the Regulation (EU) 2020/741** should:
  (i) consider the establishment of minimum requirements for other uses than agricultural irrigation (industrial and urban uses), maintaining the fit-for-purpose principle
  (ii) provide clearer instructions on the risk assessment process, e.g., on how extensive the risk assessment should be
  (iii) reflect in the monitoring the knowledge about the system and its reliability, i.e., a higher effort during the validation period and then a decrease upon data records of water quality reliability
- Promote research and provide guidance on how to upgrade the current urban WWTPs to cope with the new requirements of the **UWWTD recast** and enable water reuse (e.g., to address both quaternary treatment and disinfection)

Policy and regulation recommendations from B-WaterSmart leveraging water reuse at EU level

- Account for the beneficial **use or recovery of P** through the irrigation with reclaimed water
- Promote EU policies for **public engagement, awareness, and communication** to overcome the often-biased perception of worse water quality and high risk, among other ("yuck") factors, to increase the water reuse acceptance
- Develop guidelines for a Europewide coherent **water reuse licensing** (e.g., how far should the risk assessment go) and **water reuse service provision** (dedicated treatment, storage, and conveyance) **and pricing**
- Promote research & innovation and subsequently develop policy and regulation on **water reuse business models, funding mechanisms and pricing**
- Promote research and pilot demonstration projects of **direct potable reuse** to develop sound guidelines of water quality and treatment process operation and redundancy
  → anticipate a solution (water scarcity, localised needs & emergency situations)
  → build the trust of the society in water reuse safety



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 869171. The publication reflects only the authors' views and the European Union is not liable for any use that may be made of the information contained therein.

ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

Industry water utility symbiosis for a smarter water society: energy recovery

A. Kleyböcker, F. Fatone, J. Gonzalez Camejo and A. Naves Arnaldos

May 14th 2024



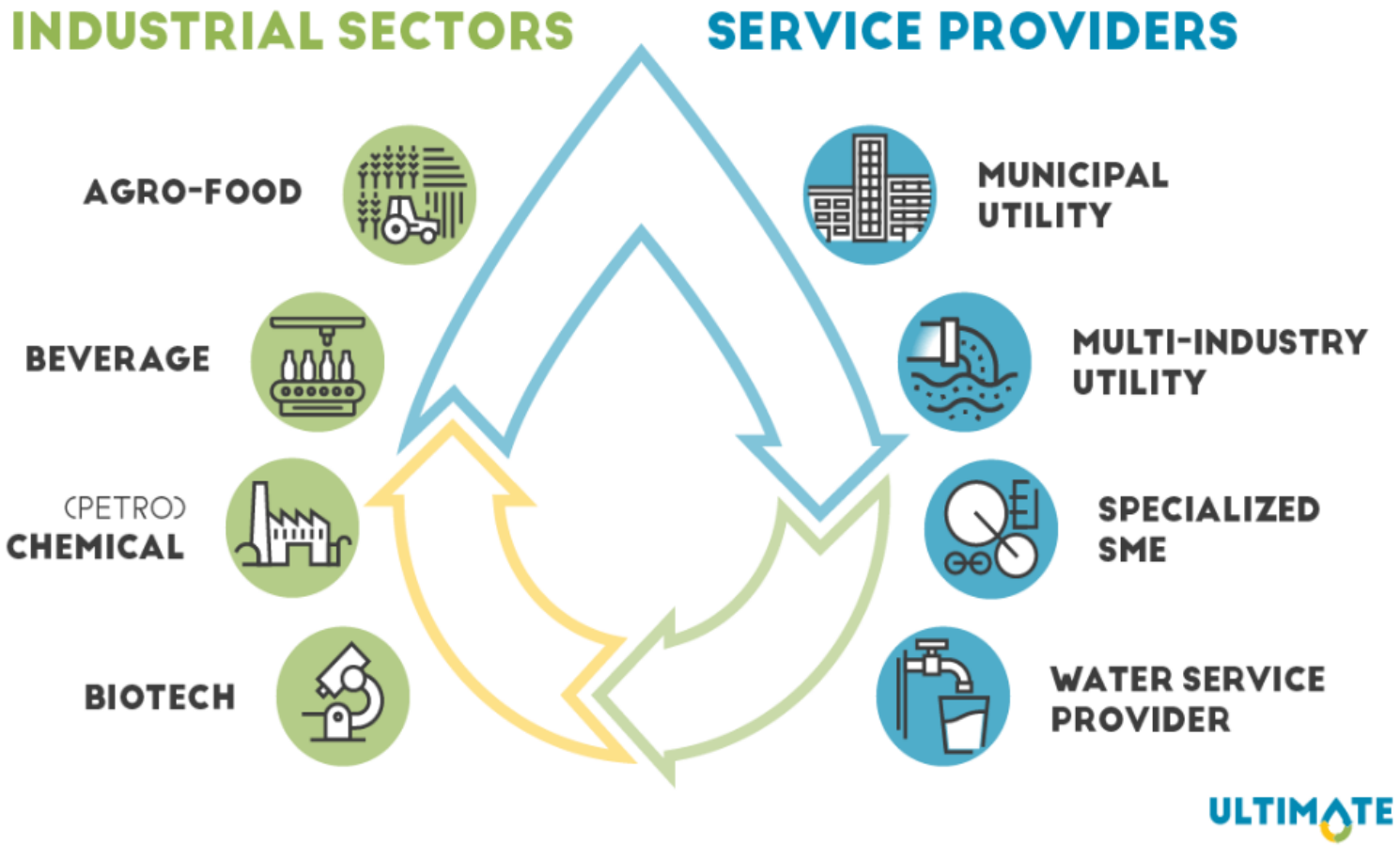
Coordinator: KWR

9 Case Studies



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 SMART INDUSTRIAL SYMBIOSES BETWEEN:



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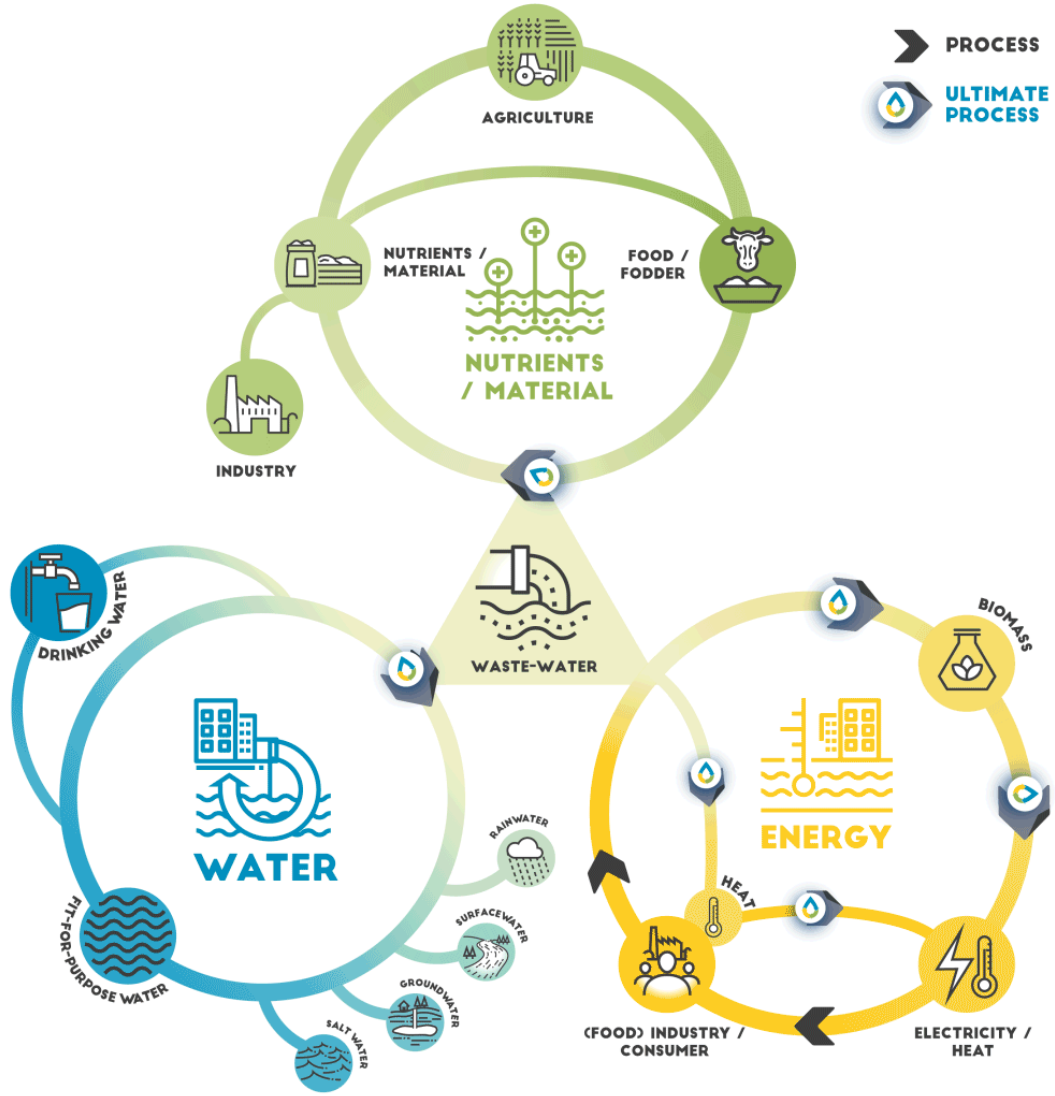
ULTIMATE solutions involve circular economy technologies



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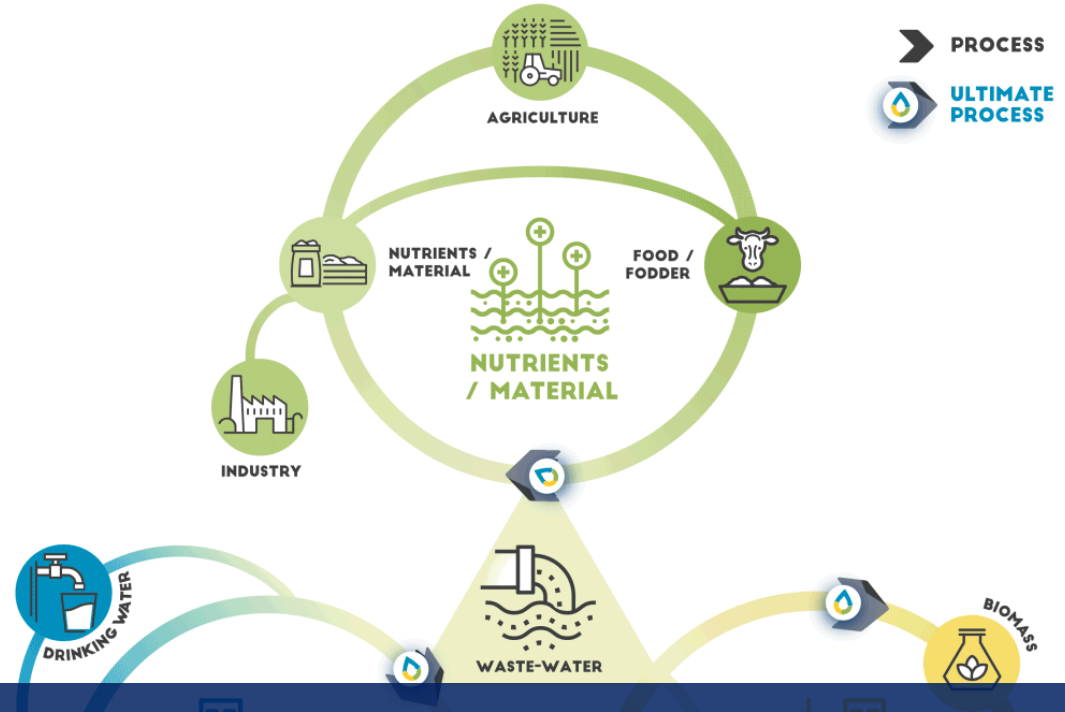
ULTIMATE solutions involve circular economy technologies



- Membrane technologies
- Adsorption technologies
- Electrostimulated systems

- 24 pilot plants
- 3 control and/or early warning systems
- 6 concept studies

- Biogas technologies
- Heat recovery
- Digitalization

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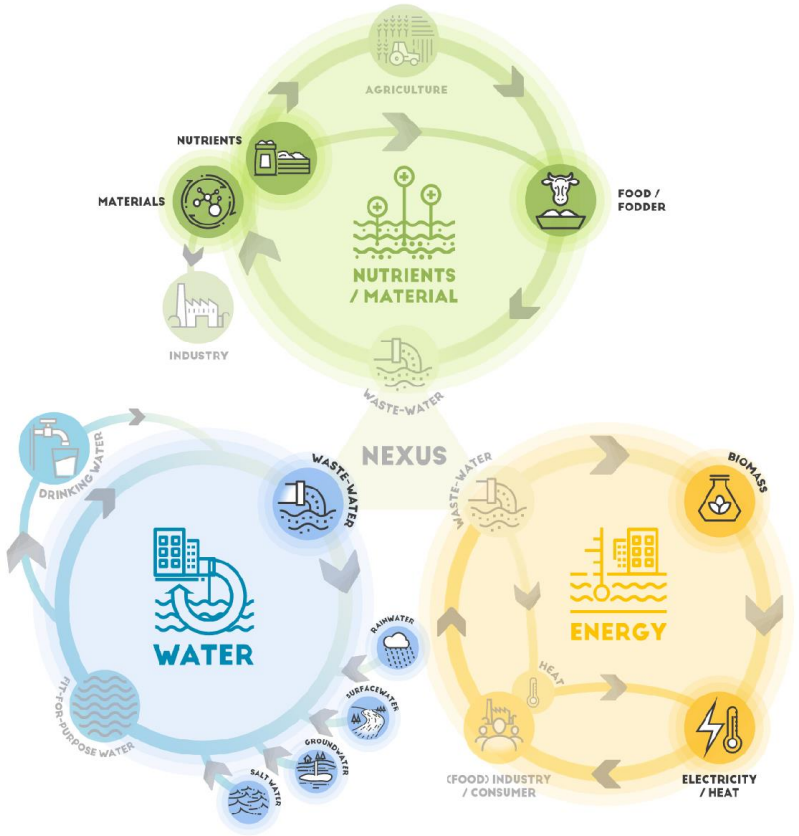
Technology Evidence Base: https://mp.watereurope.eu/teb/

Water Europe
Marketplace

- About the Marketplace
- Technologies +
- Products
- Case studies +

- Marketplace
- Events
- Networking



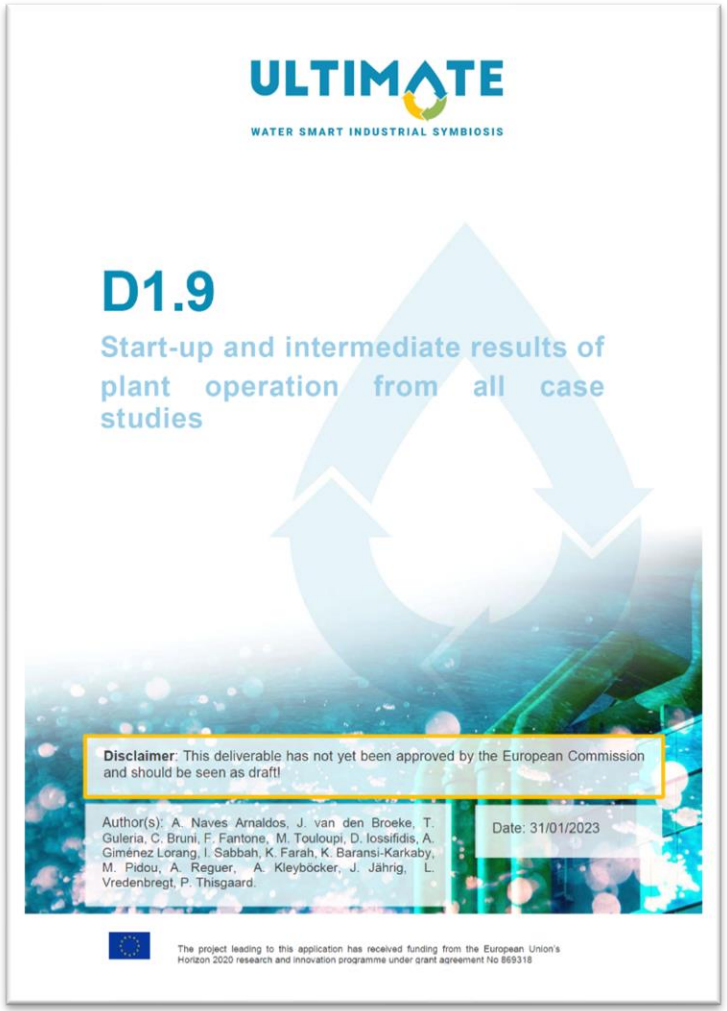
Endorsed by

nextGen Circular Water Solutions

B-WaterSmart

ULTIMATE

Report about pilot plants (Jan. 2023)



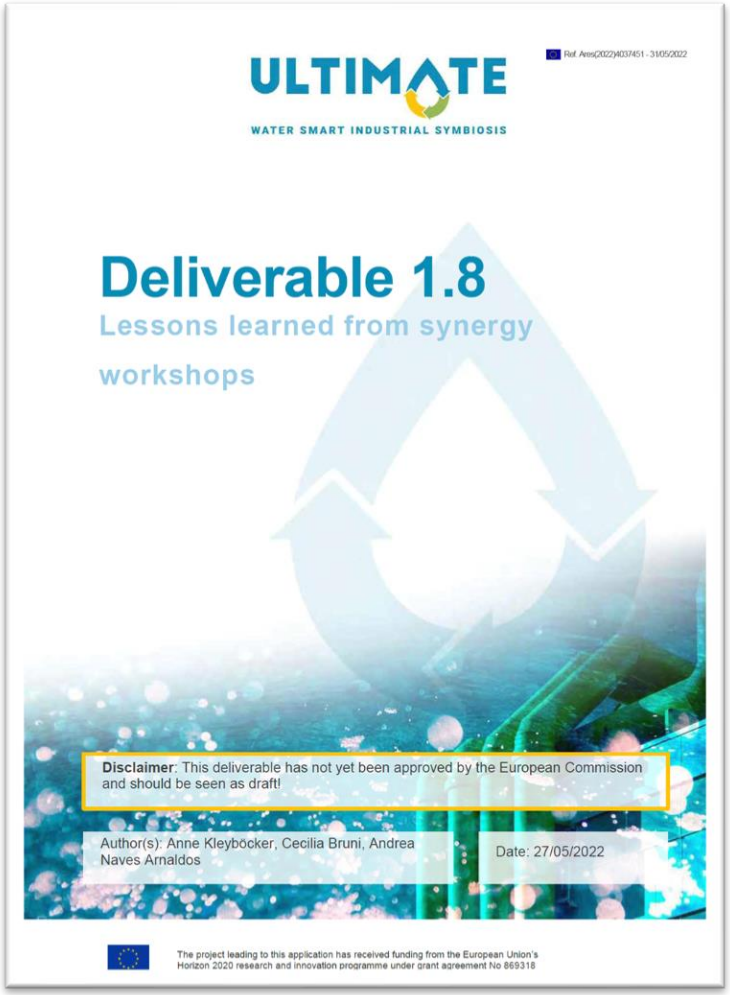
- **Start-up of pilot plants**
- **Intermediate results**

→ Accessible at:

https://ultimatewater.eu/results/

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

Report about synergy workshops (May 2022)



- Membrane & adsorption technologies
- Biogas& heat recovery systems
- Material & nutrient recovery systems
- Digitalisation
- Secret of sucessful symbioses

→ Accessible at:

https://ultimatewater.eu/results/

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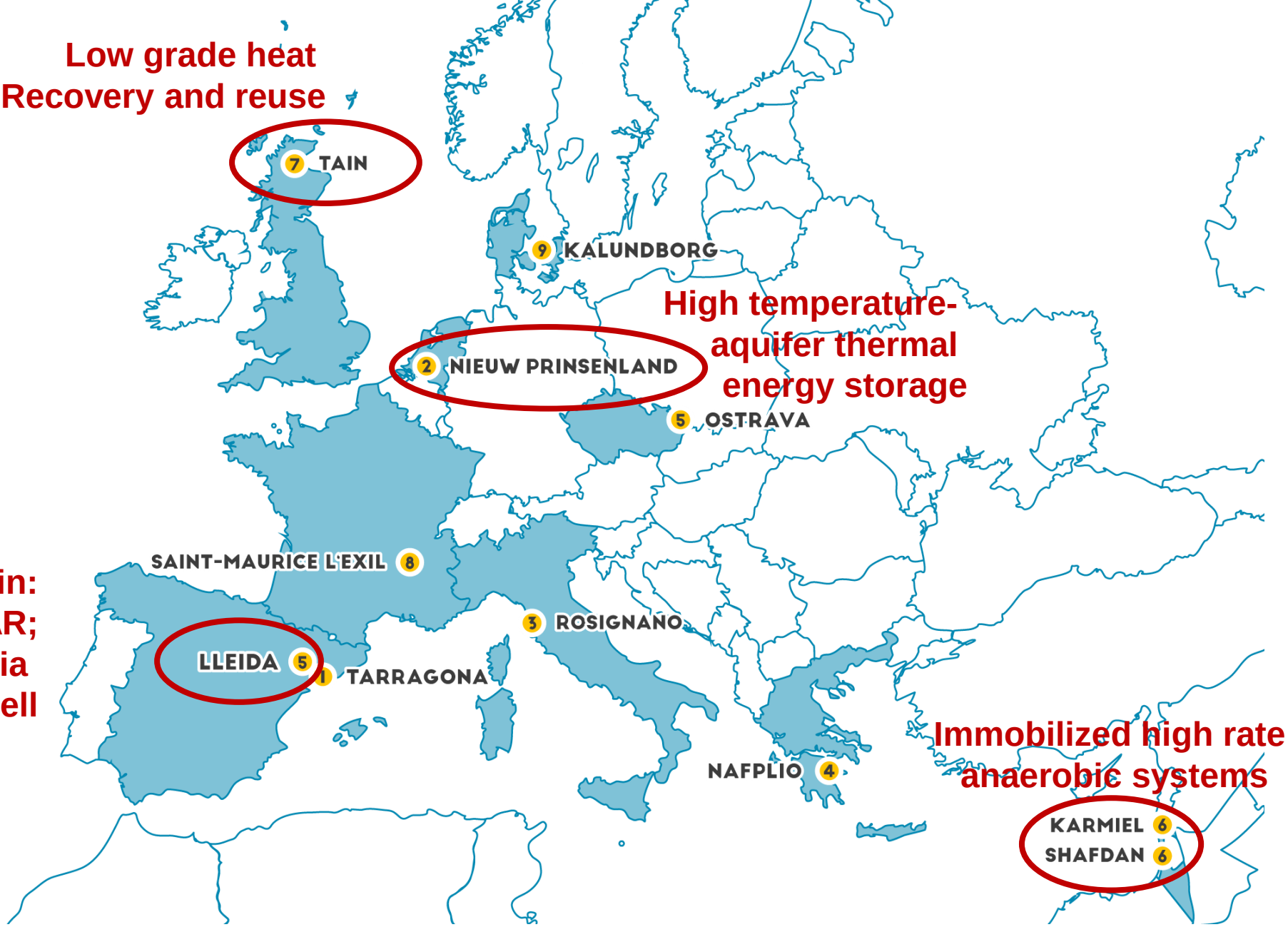
Today

Low grade heat
Recovery and reuse

High temperature-
aquifer thermal
energy storage

Biogas production in:
AnMBR & ELSAR;
Biogas utilization via
solid oxide fuel cell

Immobilized high rate
anaerobic systems



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Agenda

10:00	**Welcoming** *Anne Kleyböcker (KWB)*
10:05	**CS7 Tain**: Heat recovery from anaerobic membrane bioreactor effluent *Marc Pidou (Cranfield University)*
10:15	**CS2**: **Large scale seasonal subsurface heat storage** *Stijn Beernink (KWR)*
10:25	**CS2 Life cycle assessment** for HT-ATES *Christian Remy (KWB)*
10:35	**Discussion: heat recovery** • What is the main challenge/barrier to replicate your technology (technological, economical, legal, environmental, social) and why? • What might help to tackle this challenge? • From your perspective, how can EU policy support you to make your business case a success?
10:55	**Break**
11:00	**CS6 Biogas production in CS6 Shafdan & Karmiel**: Immobilized high rate anaerobic system (AAT) & biogas process stabilizing measures (PAC) *Katie Karkaby (The Galilee Society)*
11:10	**CS5 Lleida**: Biogas production and valorization in Lleida: Anaerobic membrane bioreactor (AnMBR) versus electrostimulated anaerobic reactor (ELSAR) & solid oxide fuel cell (SOFC) using biogas to produce electricity and heat *Antonio Giménez Lorang (FFC Aqualia)*
11:25	**CS5: Environmental impact of anaerobic treatment of brewery wastewater** *Lea Conzelmann (KWB)*
11:35	**Discussion: biogas production** • What is the main challenge/barrier to replicate your technology (technological, economical, legal, environmental, social) and why? • What might help to tackle this challenge? • From your perspective, how can EU policy support you to make your business case a success?
12:00	**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. Based in the recording, we will prepare detailed minutes of the meeting including all the questions of the participants and our answers.

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)

Residual heat utilisation

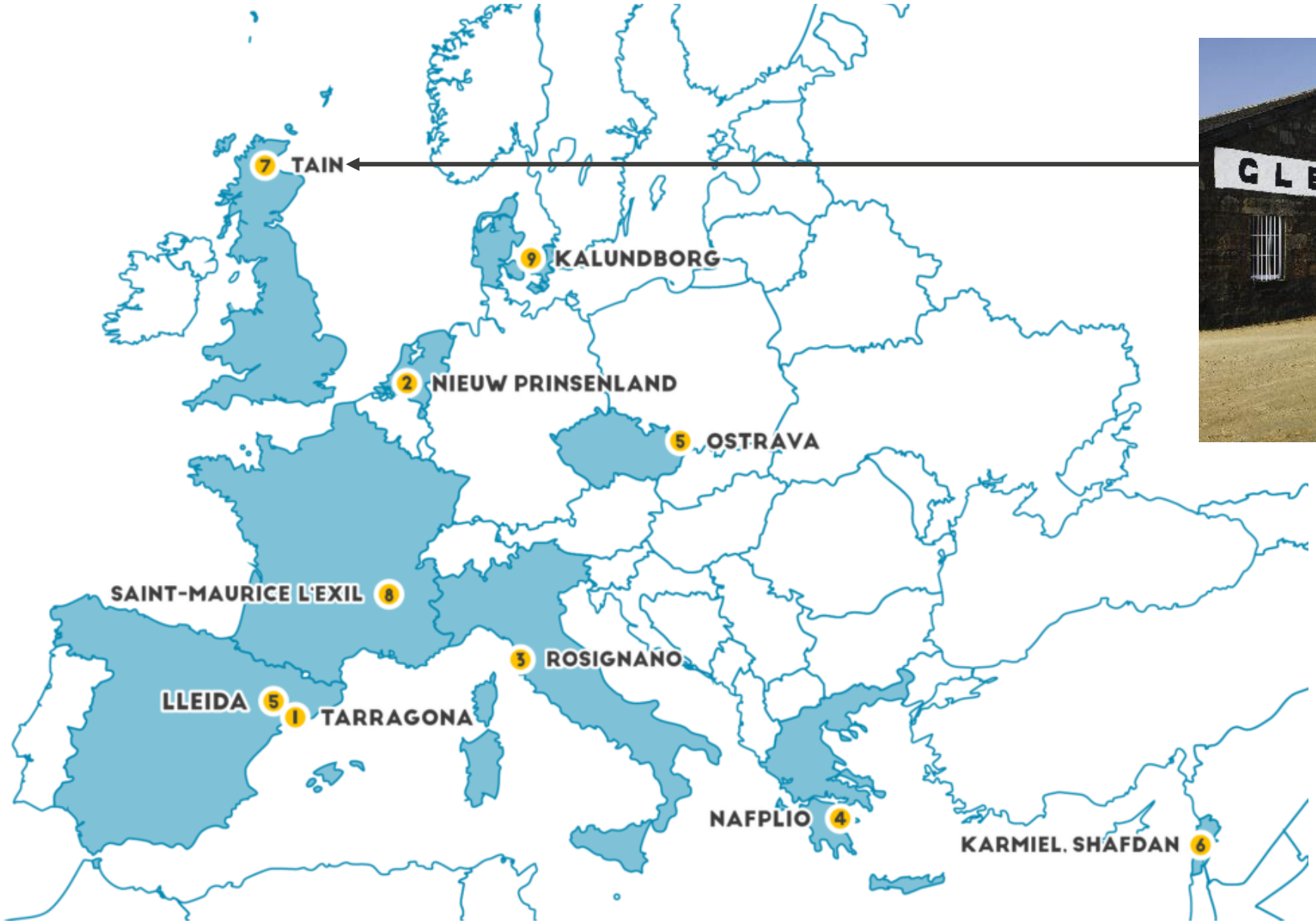
Cranfield University

Aquabio

Meeting: 14th May 2024



CS7 - Glenmorangie distillery







CS7 - Glenmorangie distillery

Partners:

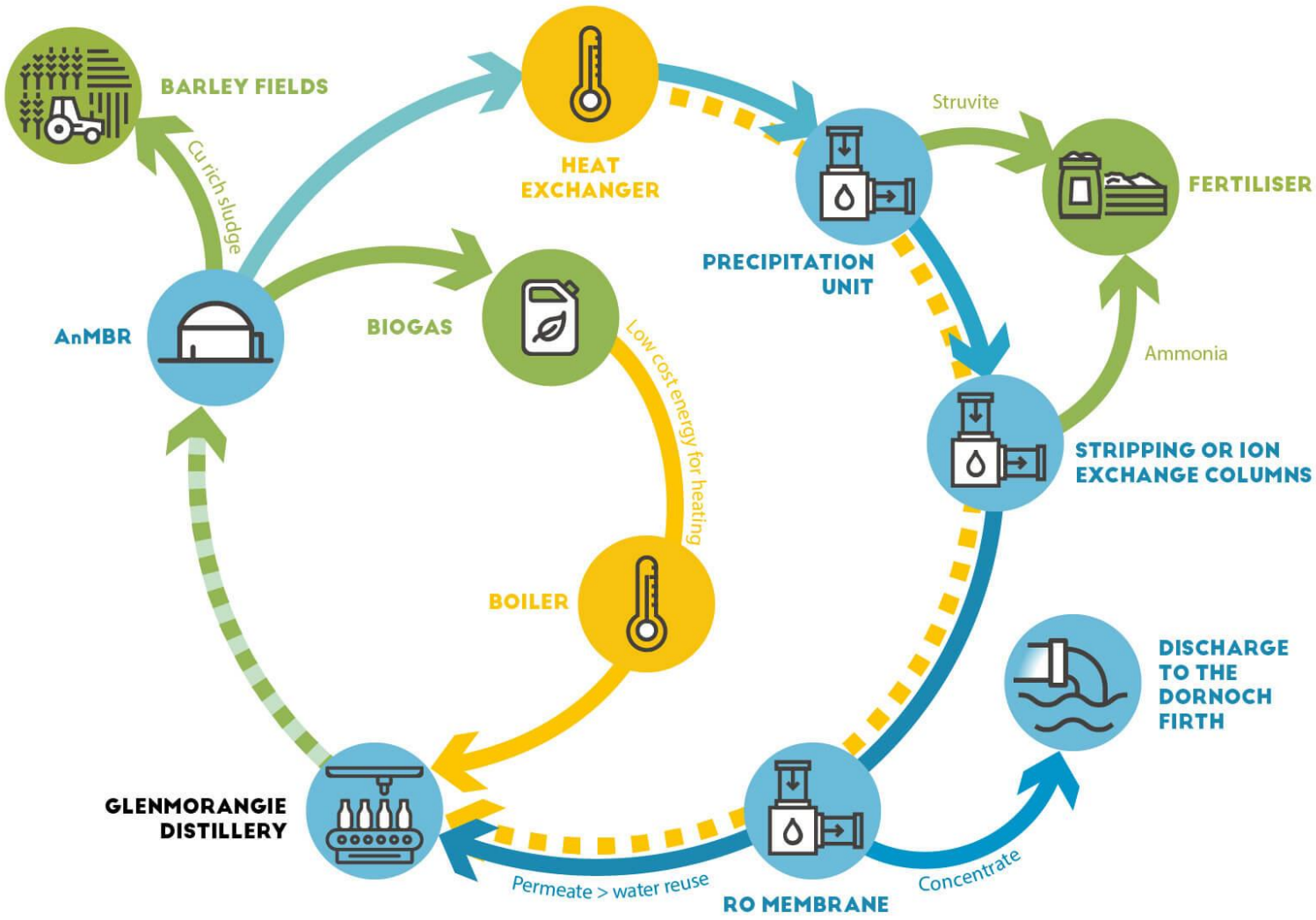
Aquabio

Cranfield University

With the support of:

The GLENMORANGIE COMPANY

Alpheus
part of the Anglian Water Group



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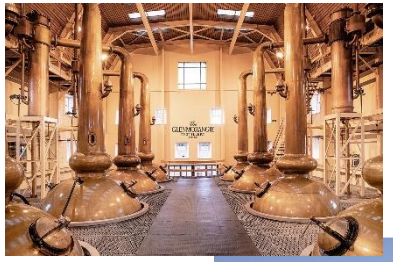
Current system

Reduces the dependence in fossil fuel

of the distillery by 15%











Parameter	Unit	Raw waste	AnMBR effluent
Chemical oxygen demand (COD)	mg/l	33247	673
Total suspended solid (TSS)	mg/l	8380	3
pH		4.44	7.03
Ammonia (N-NH4)	mg/l	39	789
Nitrates (N-NO3)	mg/l	41	5.6
Phosphate (P-PO4)	mg/l	289	236
Magnesium (Mg)	mg/l	107	43

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Ultimate interventions



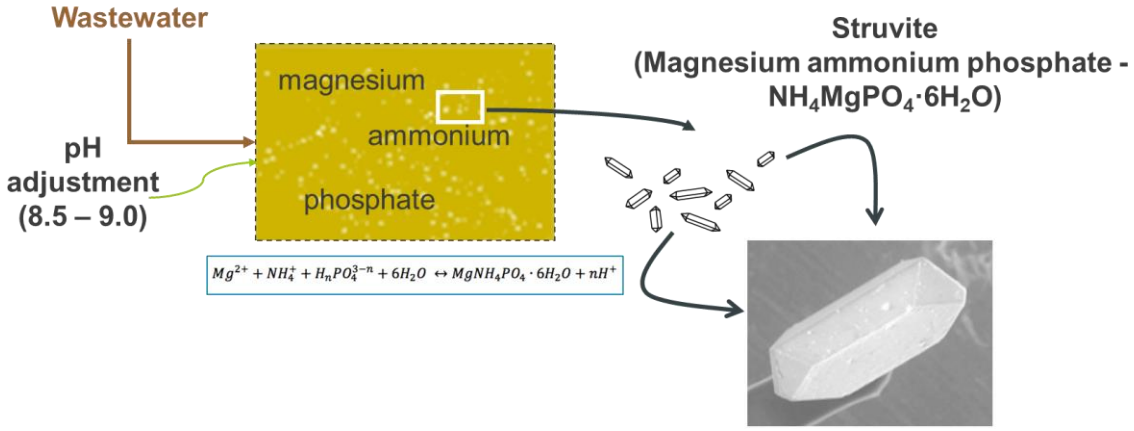


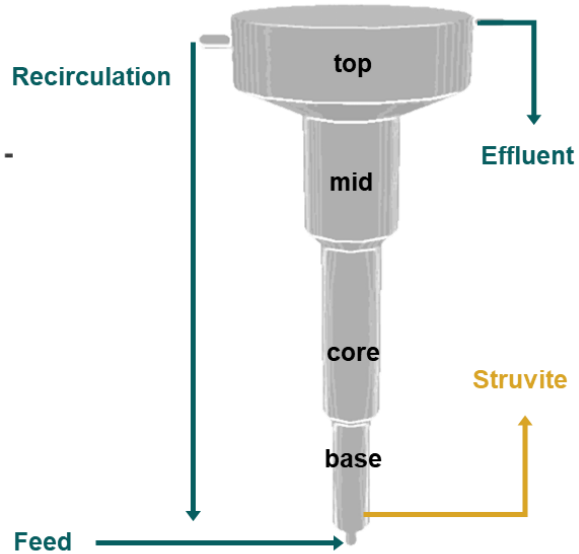




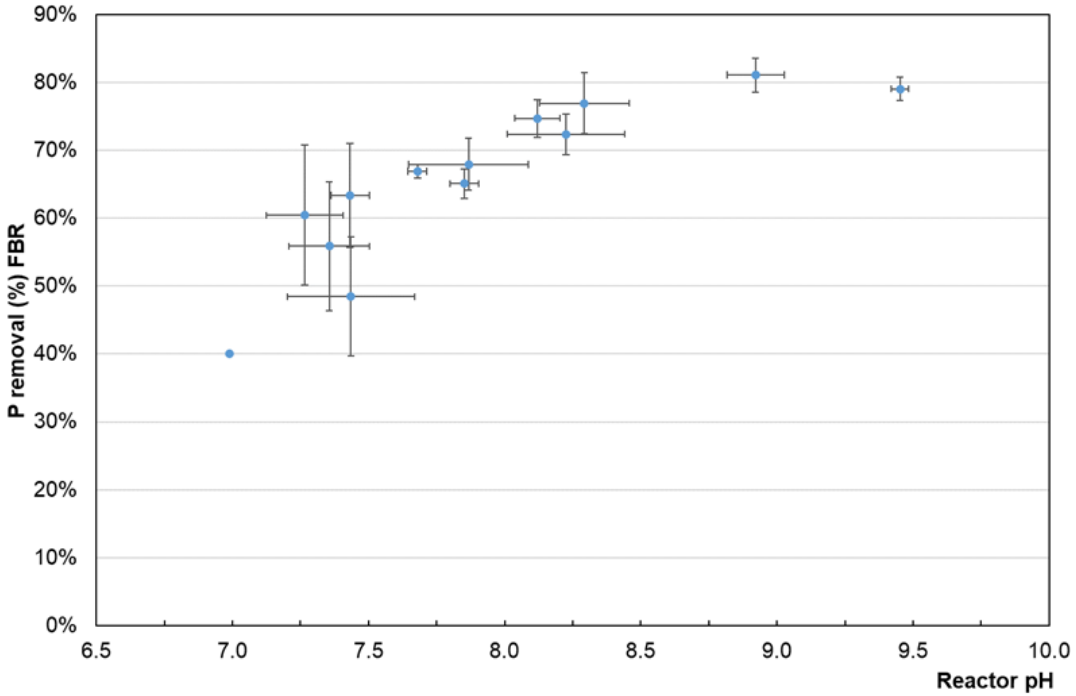
Low-cost energy for heating
Boiler
Biogas
Ww
Effluent
Pre-precipitation
Fertiliser
Ammonia
Concentrate
Discharge to the Dornoch Firth
Heat utilisation
RO membranes
Permeate
Heat utilisation
Stripping column and scrubber
AnMBR
Struvite
Barley fields
Cu rich sludge
Water reuse

Struvite precipitation





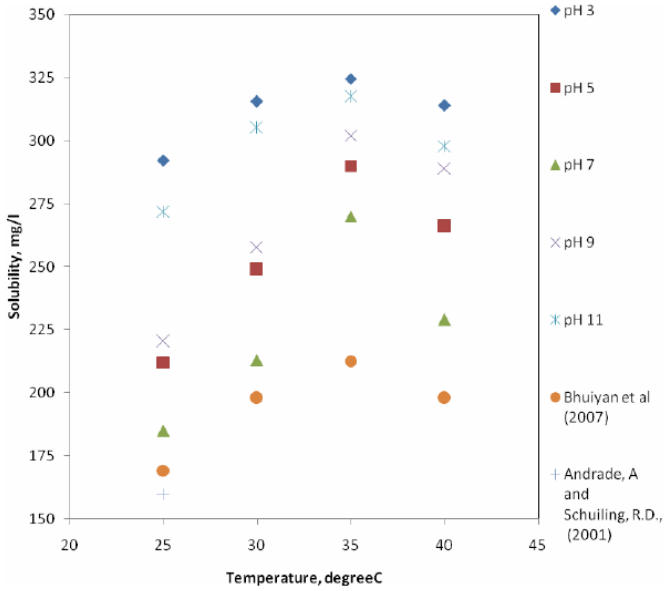




- P removal increased with ↑ reactor pH
- Highest P removal (79%-81%) at pH ≥ **8.9** (SSR = ca. 16)

Struvite precipitation

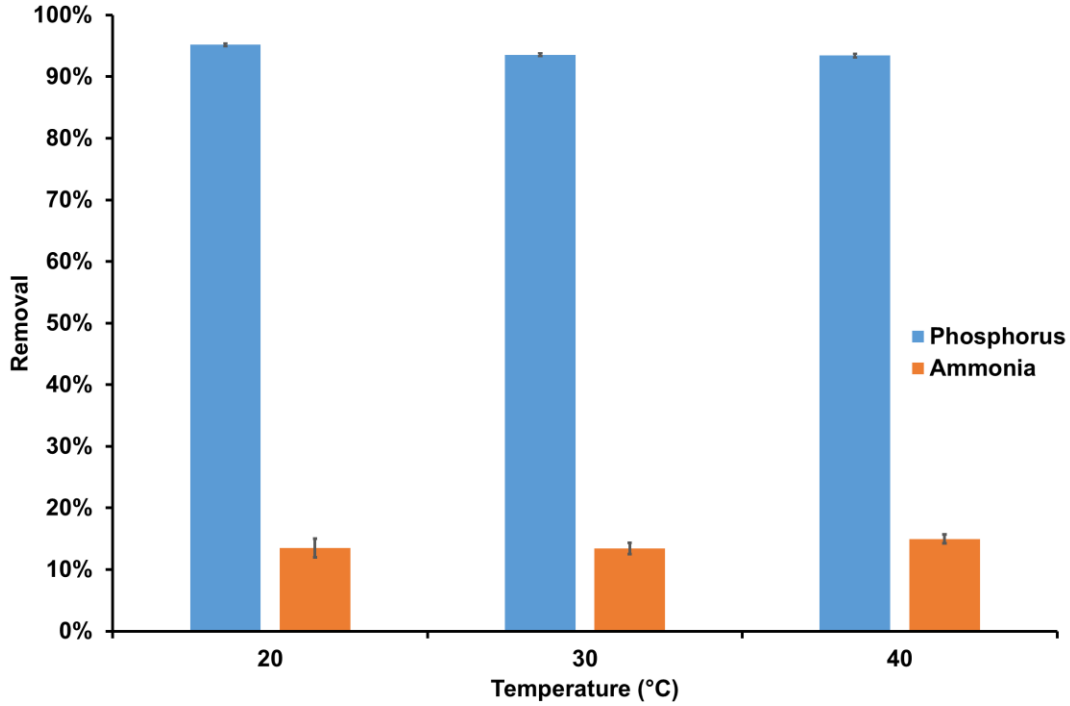
Why does heat matter?



The solubility of struvite is affected by temperature

https://www.researchgate.net/figure/Solubility-of-Struvite-in-various-pH-of-solution-at-different-temperature-This-work-and_fig2_267784704#:~:text=The%20solubility%20of%20struvite%20in,to%20disrupt%20the%20crystal%20...

What we observed…

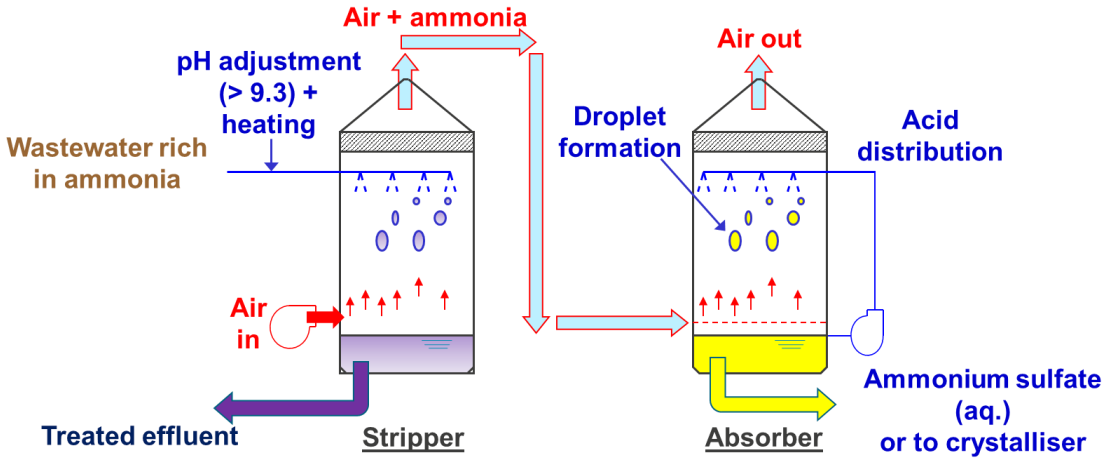


No clear impact of temperature on struvite formation and P and N removal in the distillery wastewater

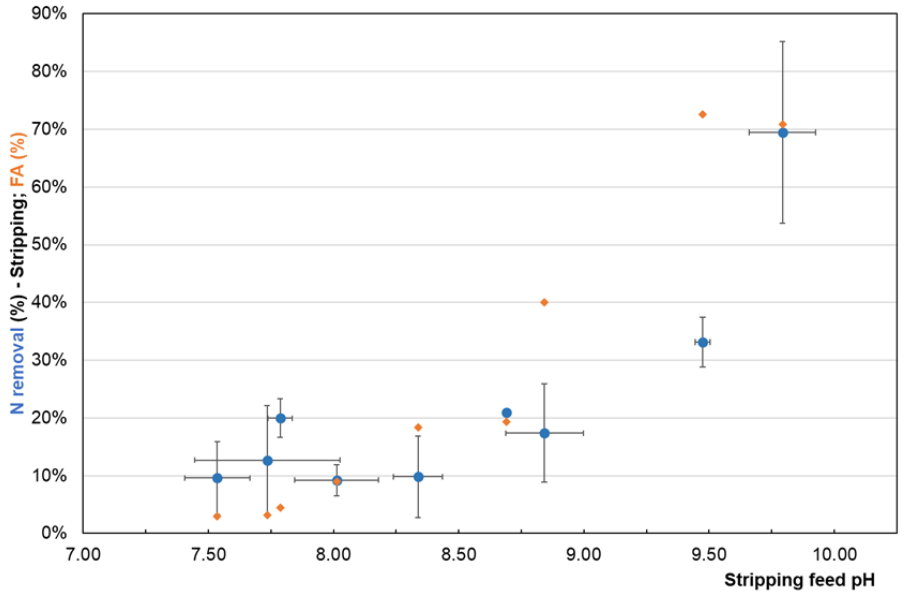
The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

Ammonia stripping

Stripping



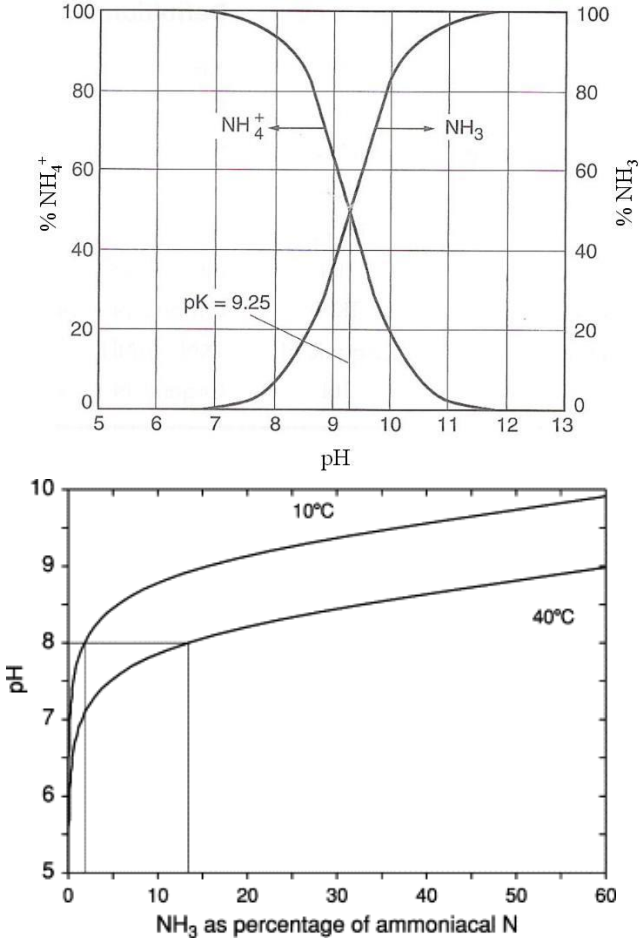




- N removal increases with ↑ pH
- Highest N removal at pH 9.8 ± 0.1 = 69 ± 16%

Ammonia stripping

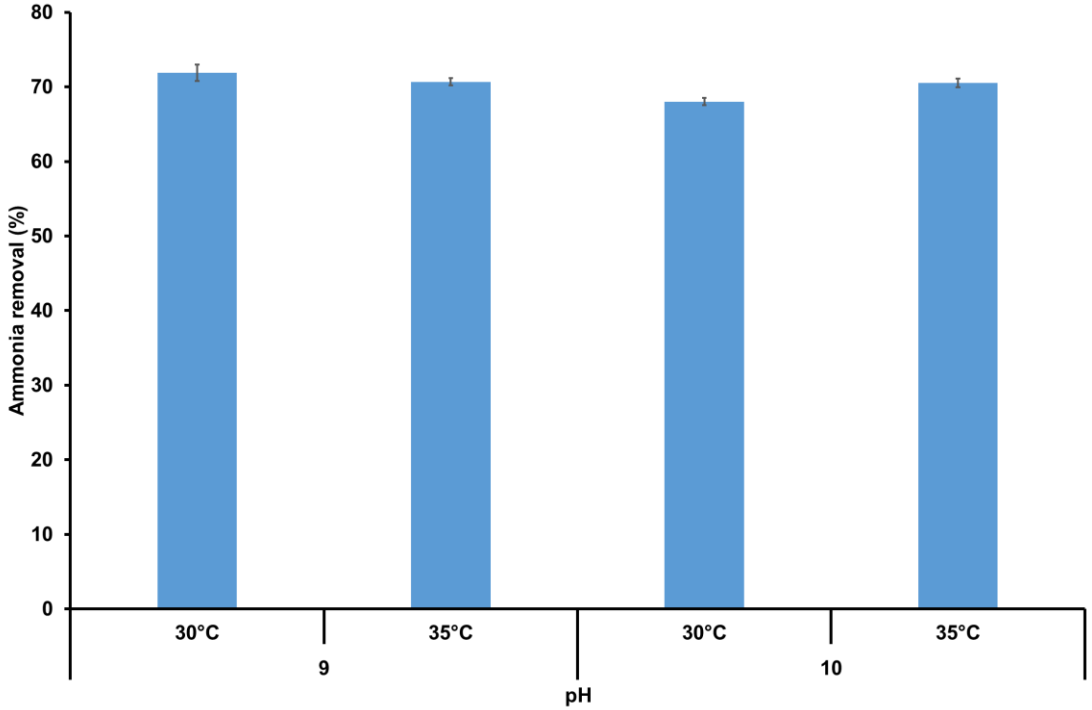
Why does heat matter?



Stripping is controlled by pH and temperature through the conversion of NH_4^+ into NH_3

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

What we observed…



No clear impact of temperature on and pH on ammonia in the distillery wastewater after struvite precipitation

?

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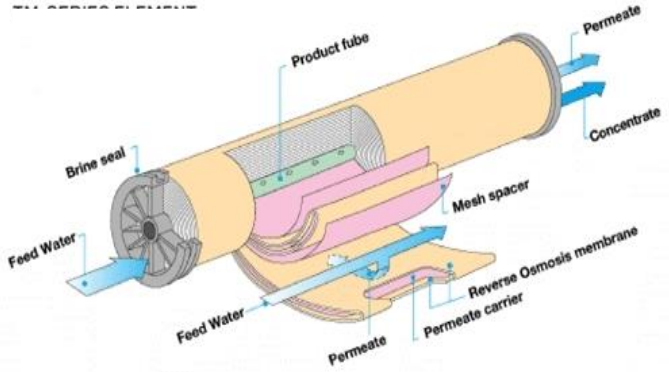
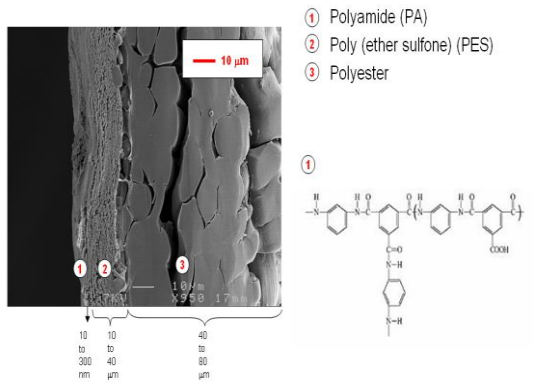
Reverse osmosis membranes for water reuse







Parameters	Permeate 1st pass	Permeate 2nd pass				Concentrate 2nd pass			
		50%	75%	80%	85%	50%	75%	80%	85%
pH	6.61	9.11	9.66	9.92	9.92	8.39	8.54	8.57	8.56
EC (µS/cm)	178.3	12.14	19.84	23.3	27.2	314	558	67	818
COD (mg/L)	5[1]	5[1]	5[1]	5[1]	5[1]	5[1]	6	11	14.1
TN (mg/L)	14	10[1]	10[1]	10[1]	10[1]	32	58	67	82
TAN (mg/L)	16.8	0.2[1]	0.32	0.57	1.14	52.8	54	61.4	76.7
PO4-P (mg/L)	0.26	0.05	0.05	0.05	0.05	1.2	2.35	2.91	3.6
Cl^- (mg/L)	5.68	0.53	0.30	0.42	0.49	9.09	18.22	23.64	30.24
$SO4^{2-}$ (mg/L)	7.69	0.45	3.66	0.04	1.77	5.74	17.07	18.91	11.46
Ca^{2+} (mg/L)	3.03	3.13	0.93	0.85	1.22	1.45	1.45	1.41	1.38
Mg^{2+} (mg/L)	1.40	0.13	0.25	0.04	0.10	3.03	3.42	3.67	3.85
K^+ (mg/L)	11.33	0.72	1.14	1.51	1.78	3.82	7.09	8.52	10.69
Na^+ (mg/L)	4.88	0.25	0.40	0.57	0.57	1.85	3.30	3.97	4.97

If treating the wastewater directly after the AnMBR (no nutrients recovery) a two pass RO an achieve the quality for reuse

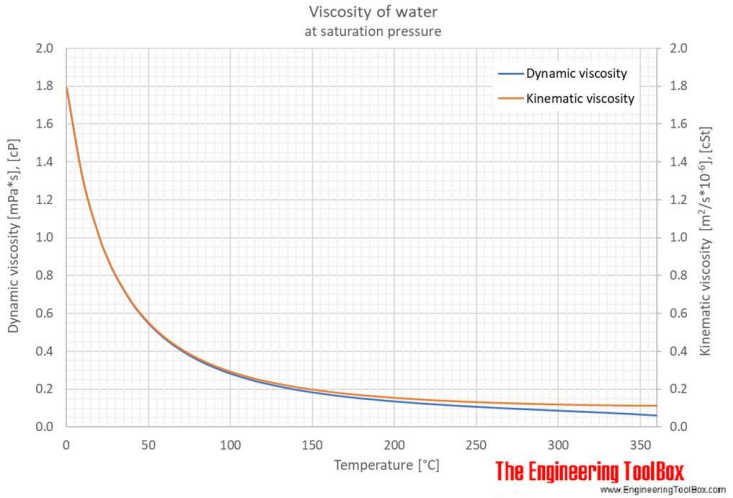
The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

Reverse osmosis membranes

Why does heat matter?

Flux $J = \frac{Q_p}{A} = \frac{P - \pi}{\eta \cdot R}$ **Pressure** **Resistance** **Viscosity**

Higher temperatures have the potential to improve filtration but reduce permeate quality



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.engineeringtoolbox.com/water-dynamic-kinematic-viscosity-d_596.html

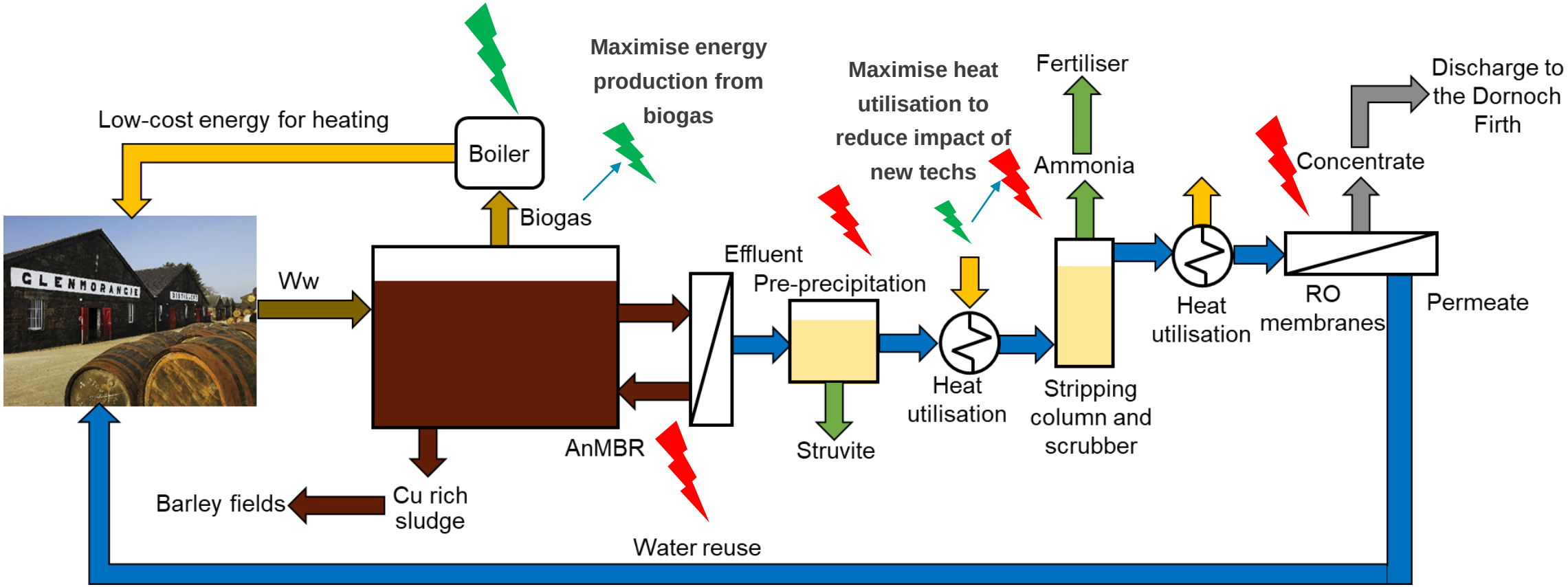
https://www.researchgate.net/publication/264420571_Performance_of_Reverse_Osmosis_Units_at_High_Temperatures

What we observed…

	COD mg/L	TAN mg/L	PO4-P mg/L	TN mg/L	pH -	EC mS/cm
AnMBR effluent	523	920	193	900	7.87	2.1
Concentrate						
T = 20°C	1044 ± 174	1433 ± 86	343 ± 29	1460 ±139	8.29 ± 0.16	11.3 ± 2.7
T = 30°C	1157 ± 210	1493 ± 110	379 ± 26	1540 ±180	8.53 ± 0.02	13.7 ± 1.4
T = 40°C	985 ± 165	1393 ± 27	342 ± 8	1450 ± 50	8.52 ± 0.11	12.6
Permeate						
T = 20°C	20 ± 6	101 ± 5	4 ± 0.2	119 ± 25	8.56 ± 0.55	0.72 ± 0.4
T = 30°C	46 ± 40	147 ± 17	6 ± 1.3	151 ± 22	9.08 ± 0.1	1.1 ± 0.1
T = 40°C	31 ± 15	137 ± 29	5 ± 1.8	96 ± 54	9.10 ± 0.22	1.0

	Flux L/(m².h)
T = 20°C	7.3 ± 0.3
T = 30°C	8.0 ± 0.6
T = 40°C	8.2 ± 0.6

Energy balance



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

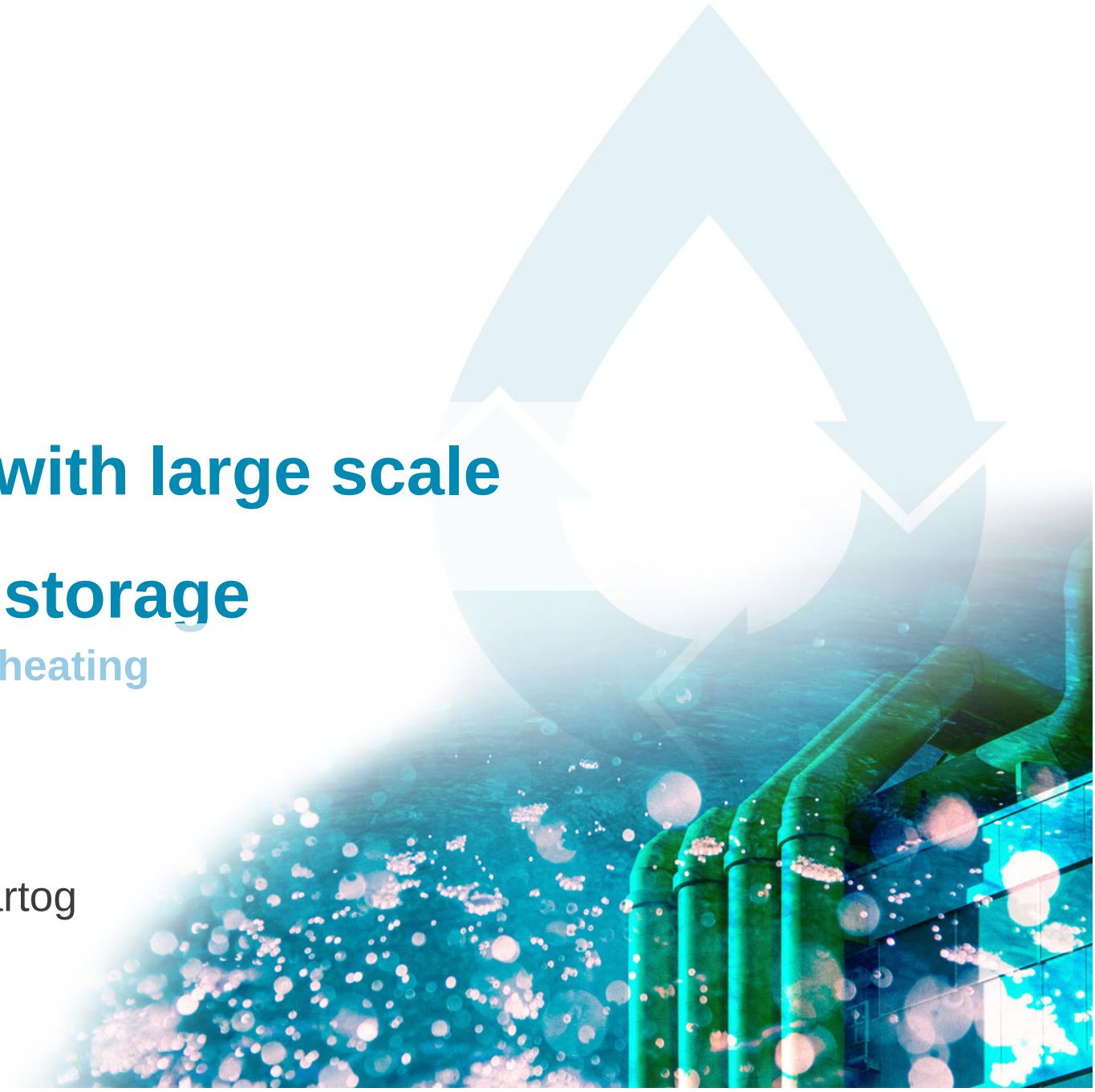
Thank you!

ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

Reducing CO2 emissions with large scale seasonal subsurface heat storage

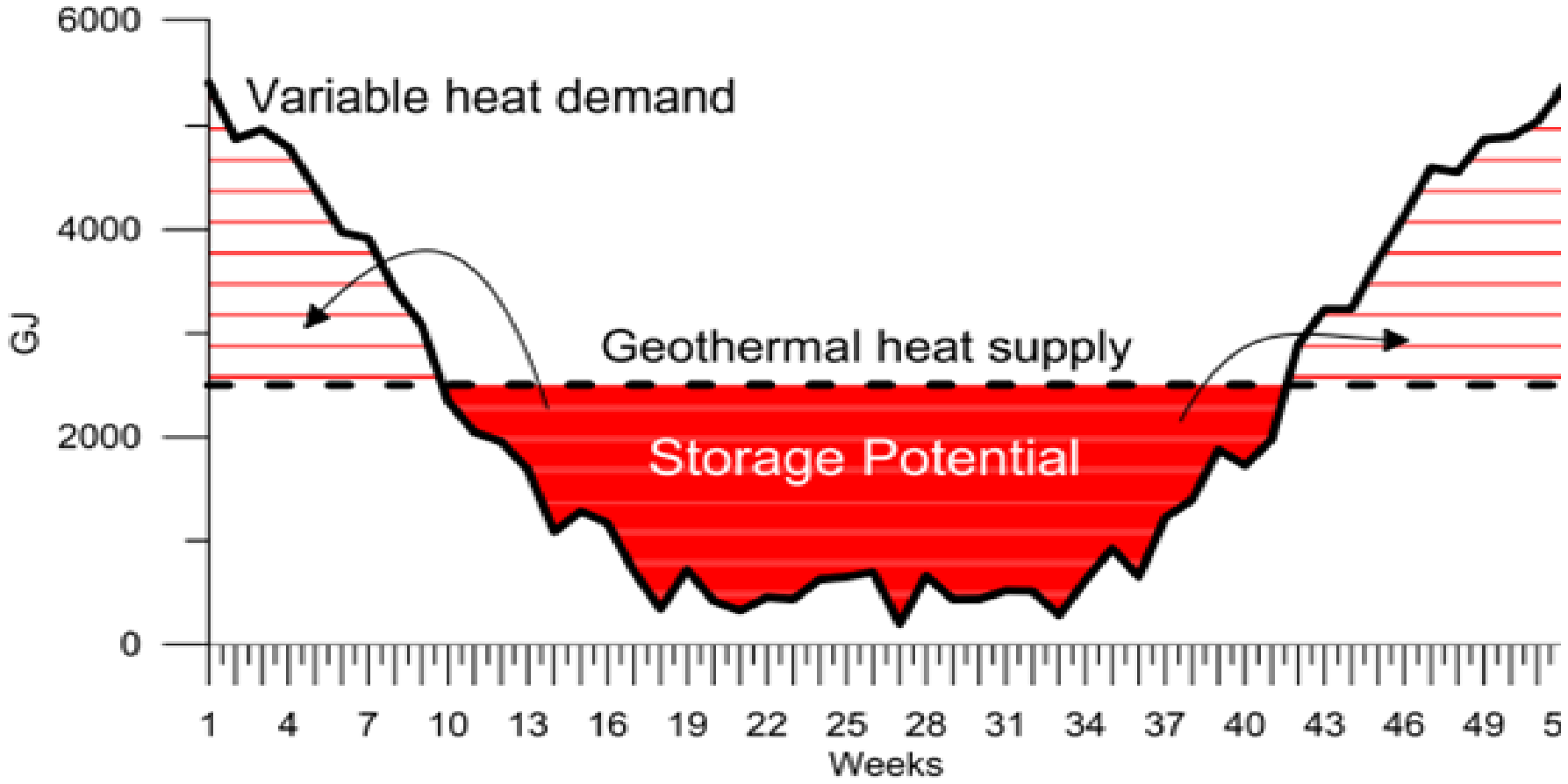
Feasibilty study for a greenhouse district heating network in NL



Stijn Beernink, Martin Bloemendal, Niels Hartog

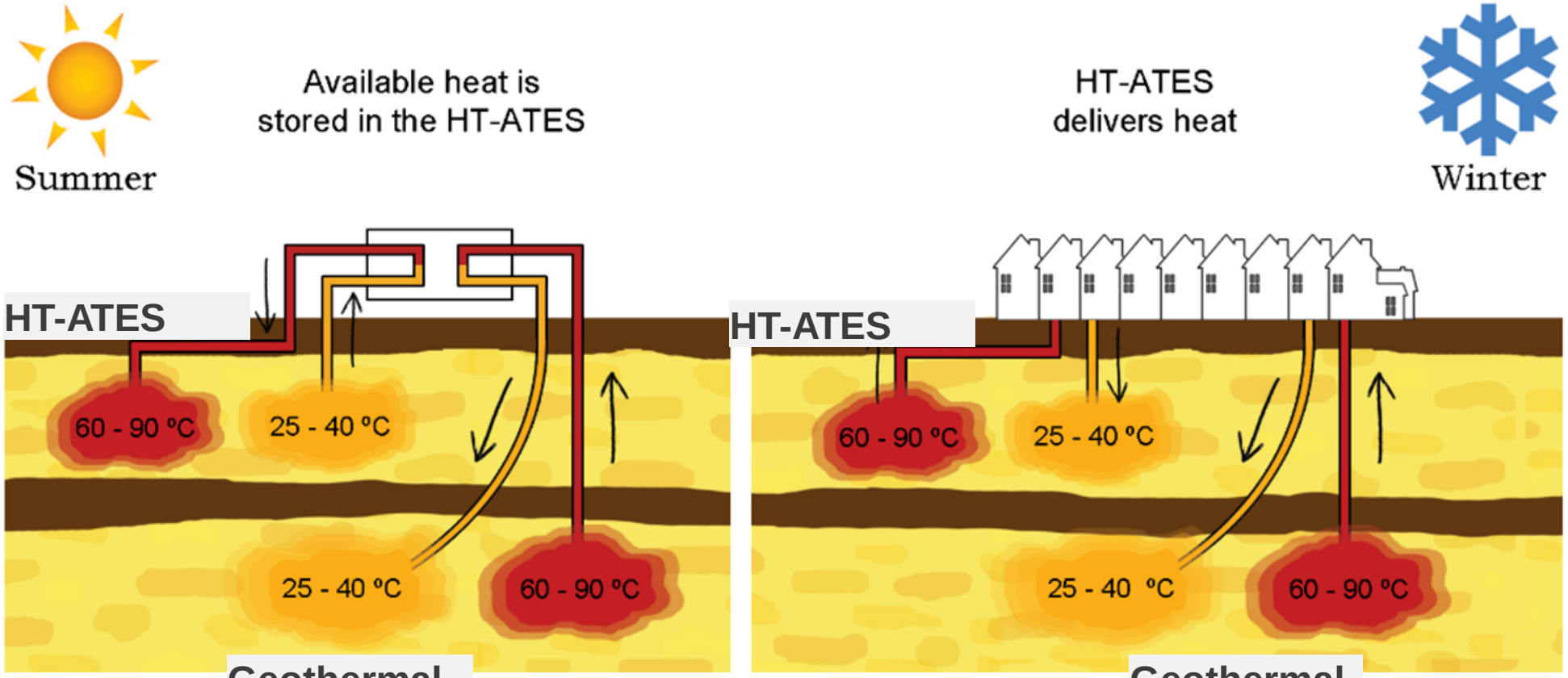
KWR

Heat storage important in the heat transition



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

High Temperature Aquifer Thermal Energy Storage (HT-ATES)

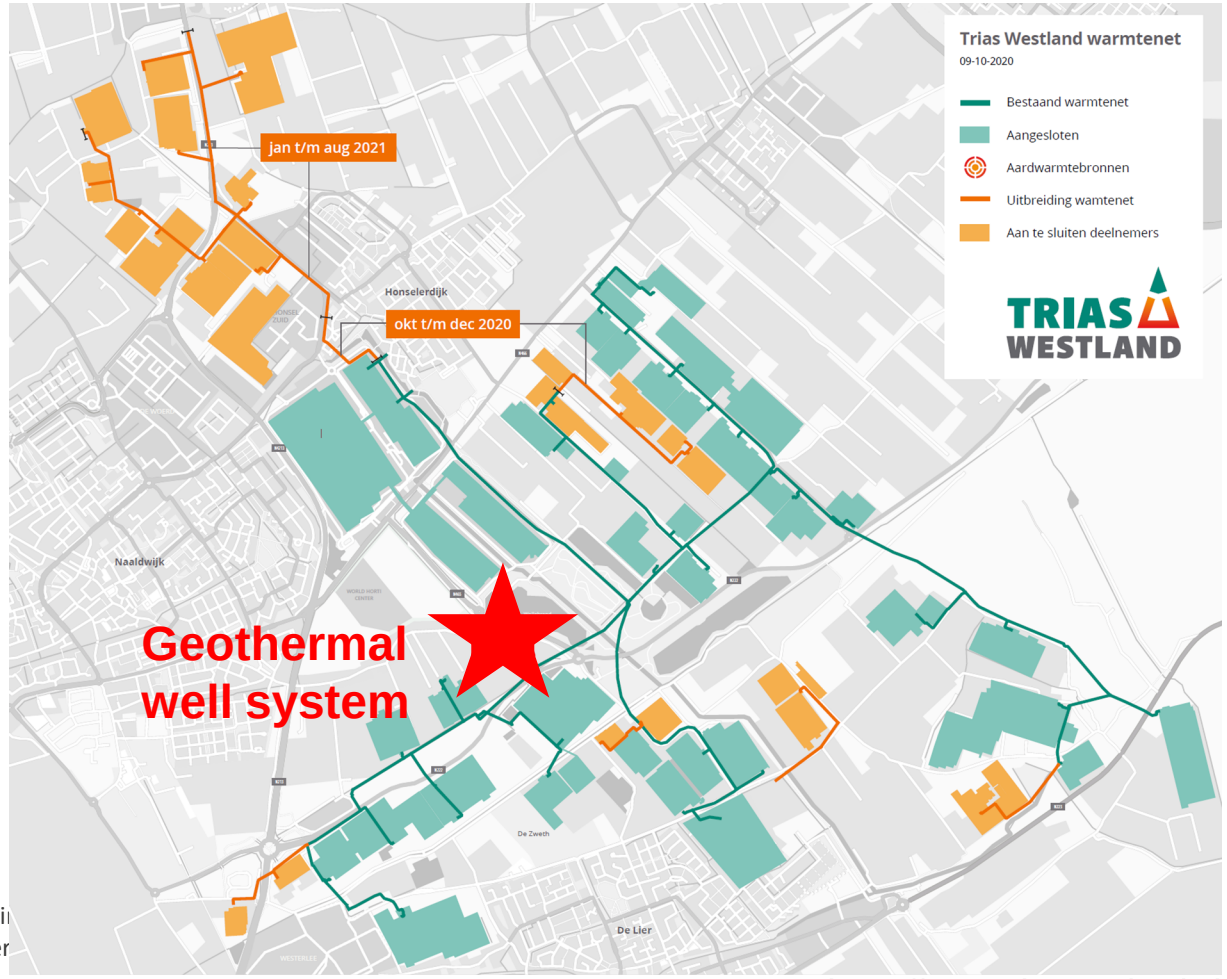


The project leading to t
Horizon 2020 research
funding from the European Union's
under grant agreement No 869318

ULTIMATE: feasibility of HT-ATES for TRIAS greenhouse district heating network

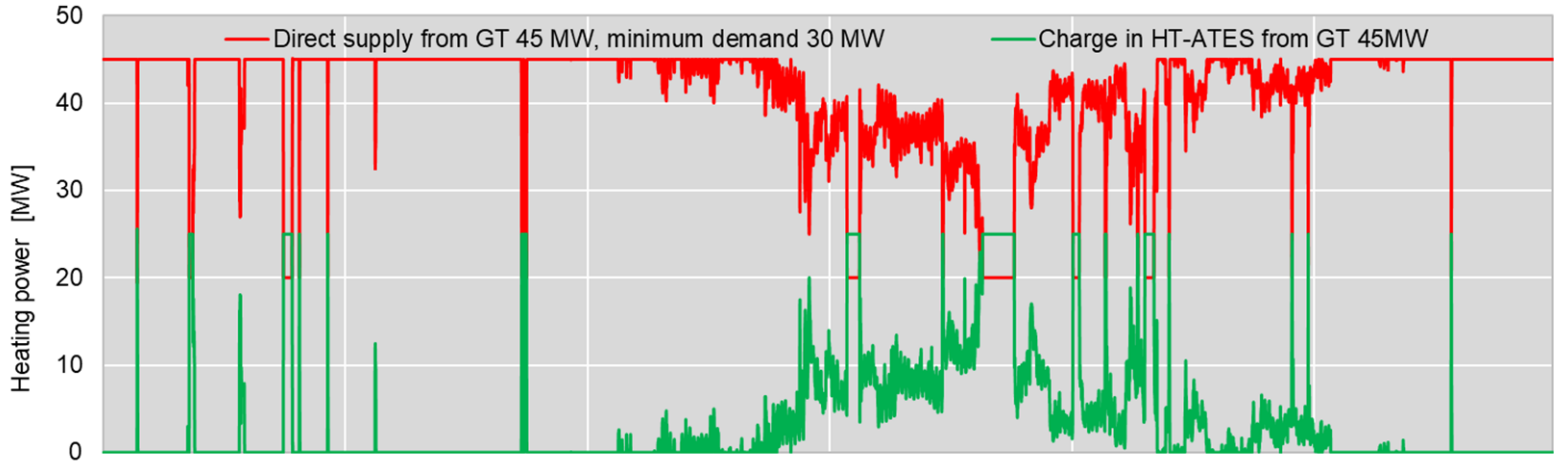






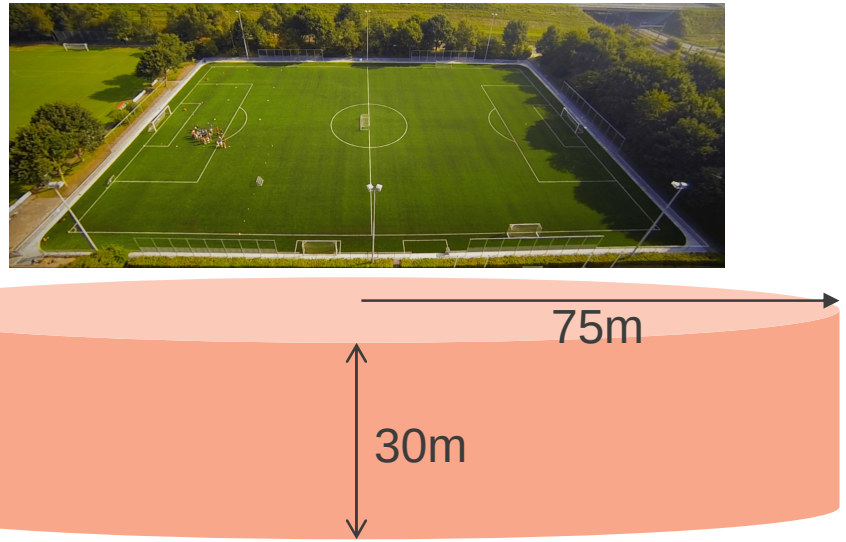
https://www.triaswestland.nl

1. Is there a mismatch in heat availability & demand?



Potential for HT-ATES

- Storage potential 57 – 107 TJ/year
- Yearly storage volume 0.31 – 0.52 Mm^3/year



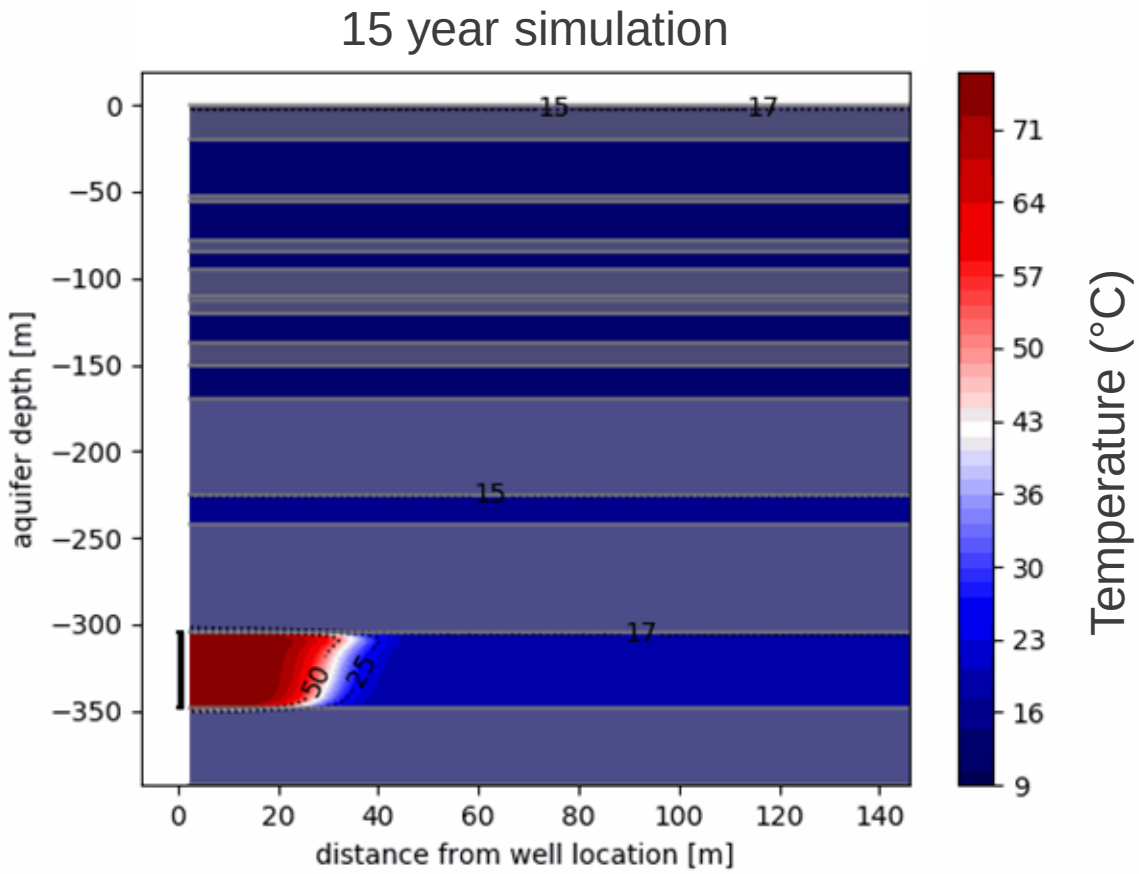
The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

2. Are local subsurface conditions suitable?

$$RE = \frac{E_{out}}{E_{in}}$$

Thermal recovery efficiency (RE) for TRIAS:

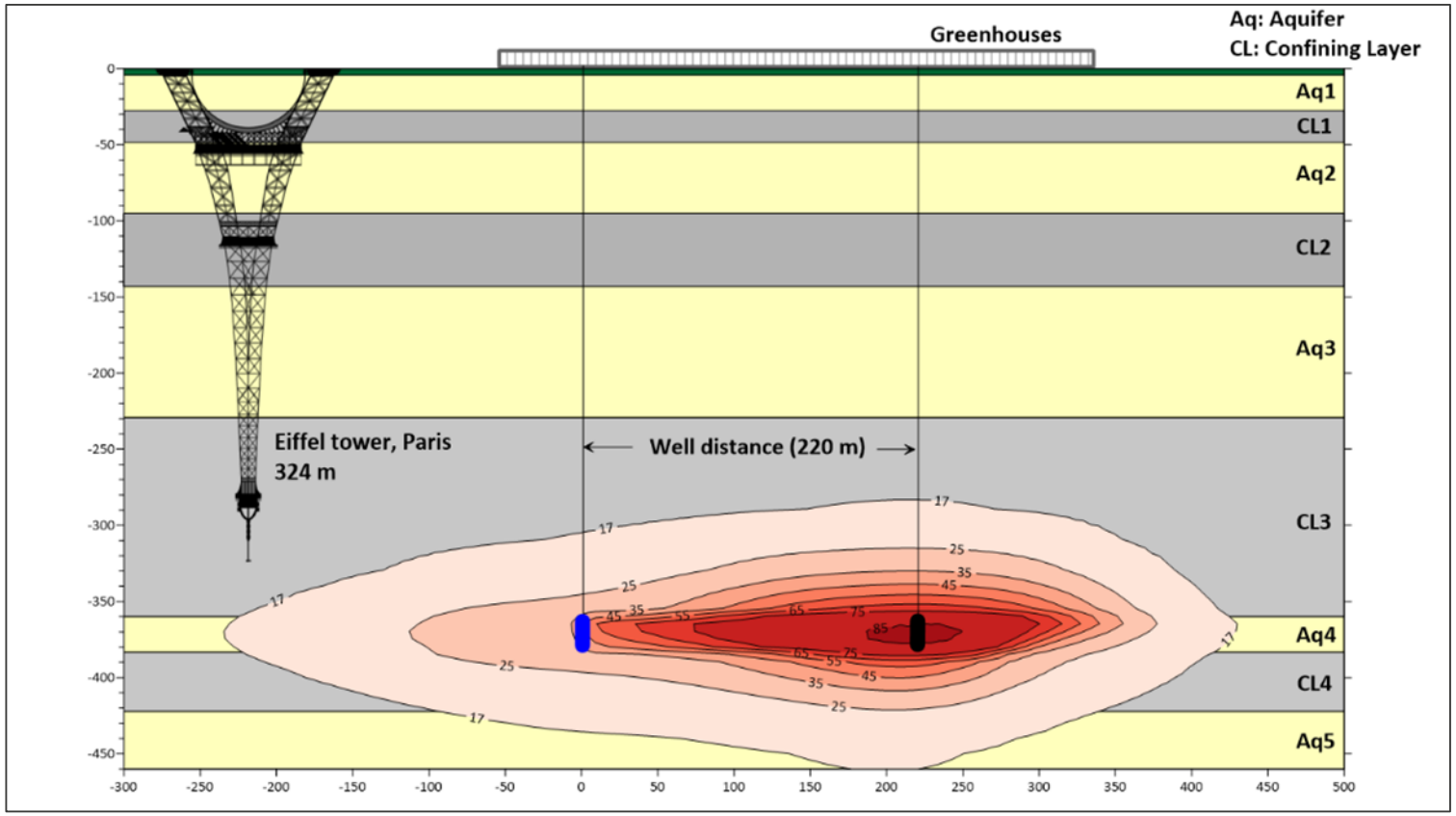
65 – 80 % per year



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

3. Feasibility of (pilot) license → thermal impact

Simulation of maximal thermal effects after 20 year for the Middenmeer HT-ATES system



Oerlemans et al. (2022)

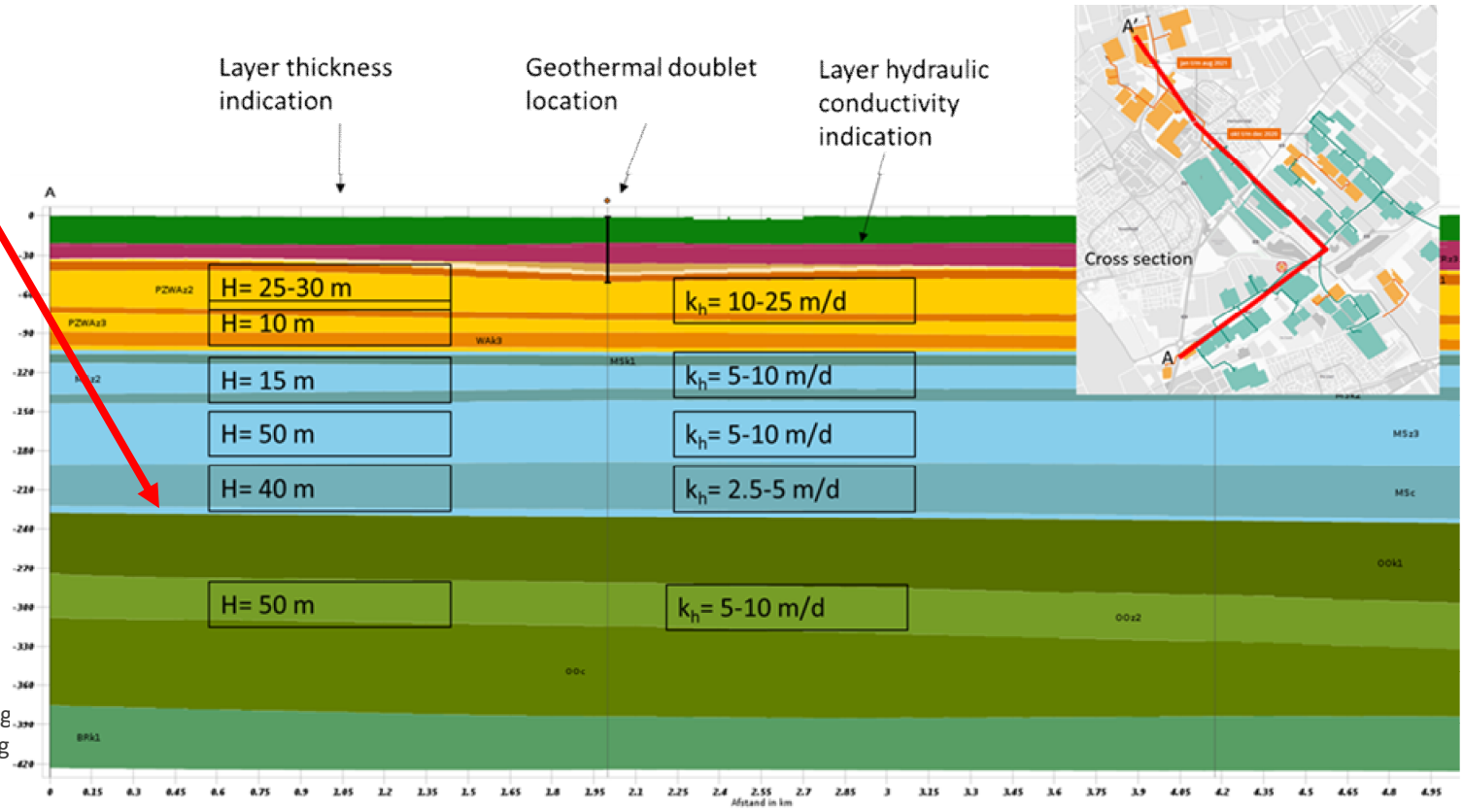
The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

3. Feasibility of (pilot) license for TRIAS

Subsurface characteristics

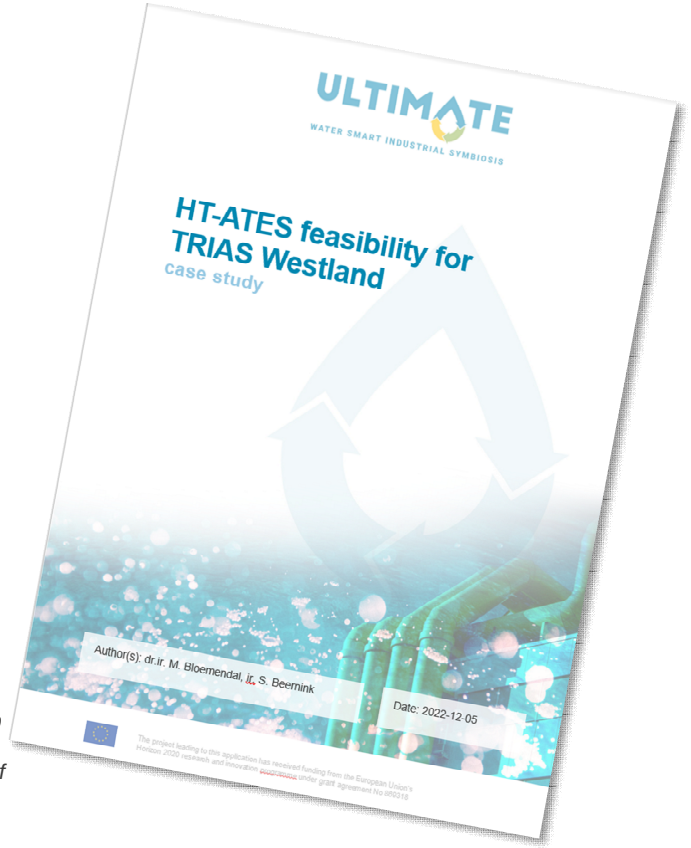
- Storage aquifer >200m depth
- Saline groundwater
- No other systems closeby

→ Pilot license is possible when no other interests are harmed
Impact study and monitoring needed



The project leading to this application has received funding
Horizon 2020 research and innovation programme under g

HT-ATES good feasibility for TRIAS Westland case



Read more →

https://mp.watereurope.eu/media/publications/KWR2022.125_HT-ATES_triasWestland_feasibility.pdf

General:

1. Heat storage potential ✓
2. Subsurface conditions ✓
3. Policy: pilot permit seems possible ✓

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

Potential for HT-ATES in Europe (and beyond)

(seasonal) storage potential

- → Increase availability renewables
- → Relieve electricity grid
- → …







Subsurface potential

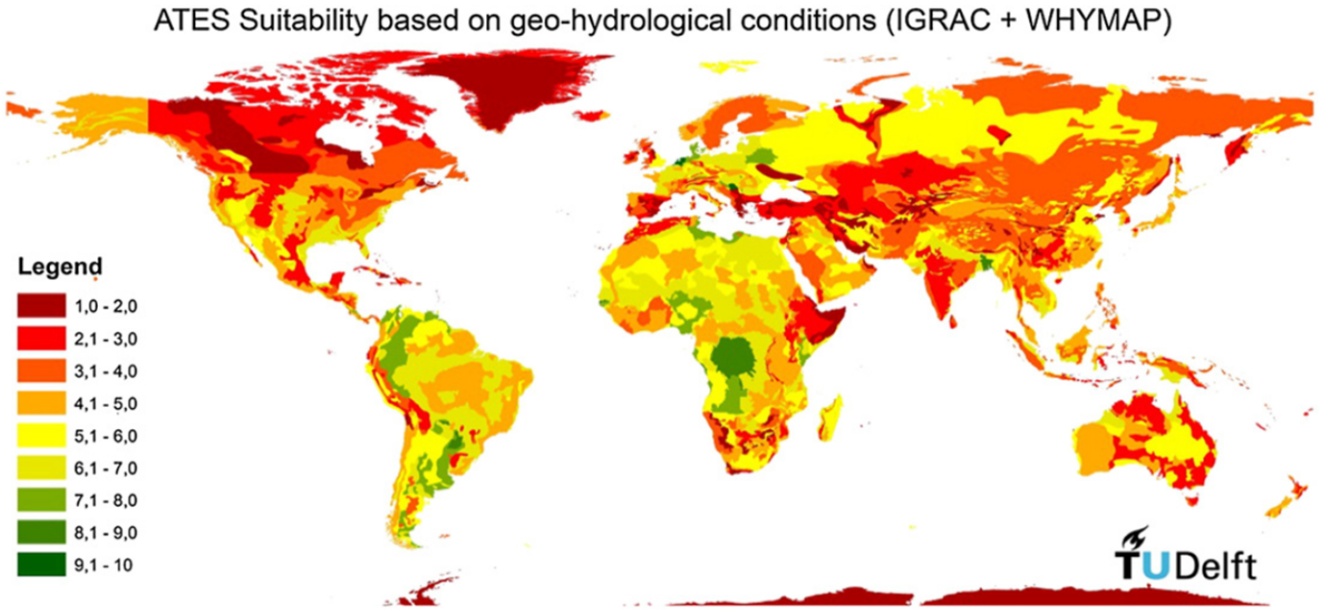


Fig. 5. ATES suitability based on WHYMAP & IGRAC data.

Bloemendal et al. (2015)

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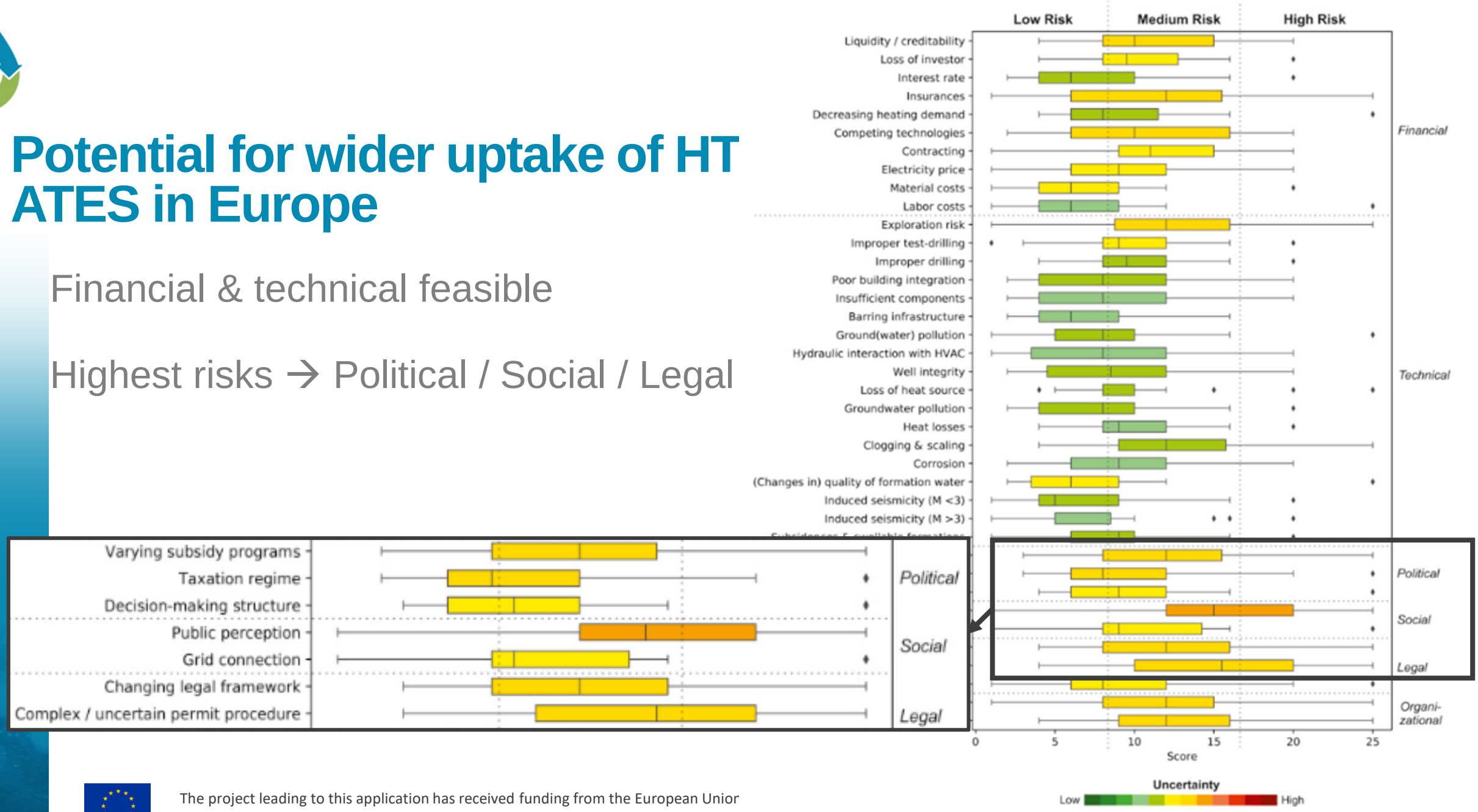
Potential for wider uptake of HT ATES in Europe

Financial & technical feasible

Highest risks → Political / Social / Legal



The project leading to this application has received funding from the European Unior Horizon 2020 research and innovation programme under grant agreement No 86931

Fleuchaus et al. (2020)

Increasing the further uptake of HT-ATES in the coming years

Learning by doing

- Design and build pilot systems
- Monitor performance and impact

Develop policies

WarmingUPGOO
Geothermie & Opslag Opschaling

PUSH IT

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

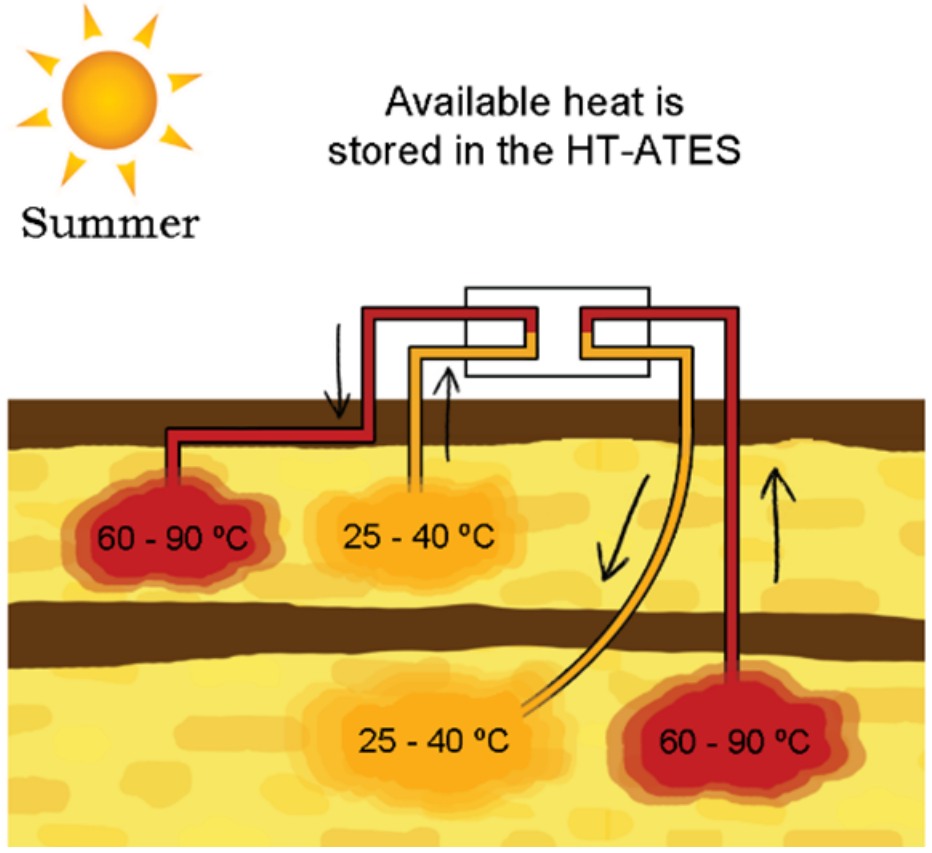
Conclusions

1. HT-ATES: potential for implementation in Europe (and beyond) to increase CO_2 emissions reduction.

2. It has potential when:

- (yearly) mismatch in renewable energy
- Local suitable subsurface conditions
- Potential for licensing

3. Coming years → increasing further uptake by learning by doing!



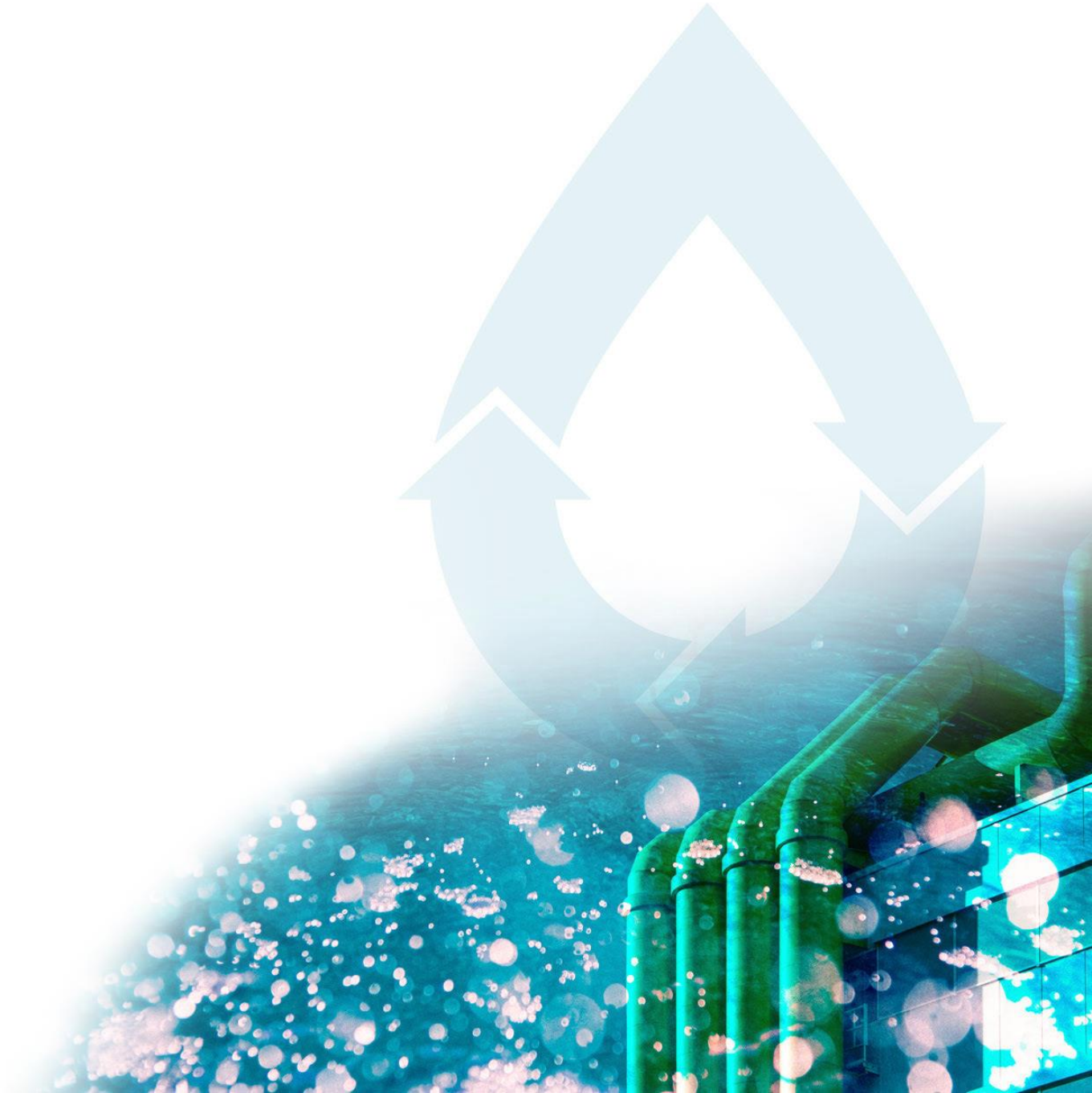
The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

Life Cycle Assessment for HT-ATES

Christian Remy (KWB), 14.05.2024



Agenda

- Motivation
- Definitions
- Input data
- Results of LCA

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

Motivation

Concept: increase efficiency of geothermal well by seasonal storage of heat in HT-ATES

Goal: assess environmental impacts of system and show benefits

Method: Life Cycle Assessment (ISO 14040)

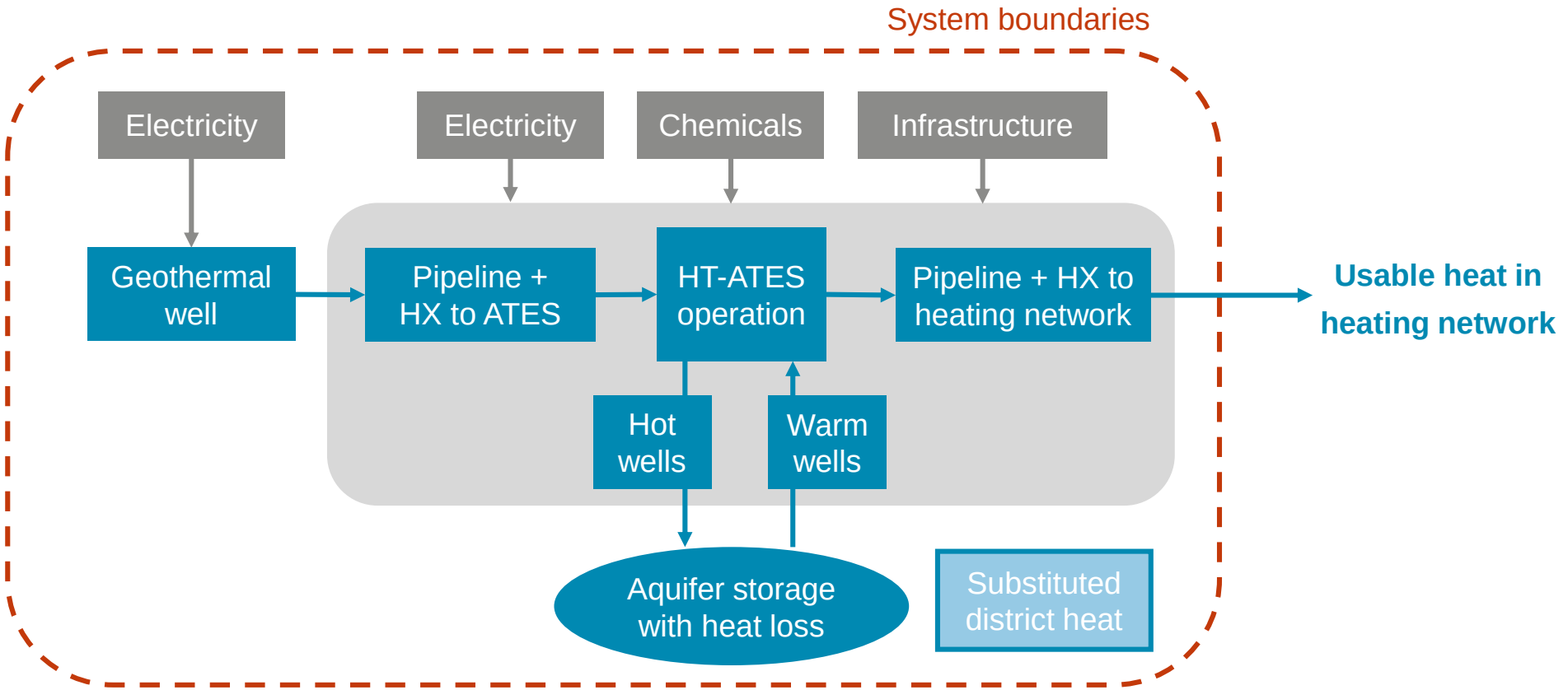
- Direct and indirect impacts
- Compare to district heating
- Focus: fossil energy demand and greenhouse gas emissions

Input data → feasibility study



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

System boundaries for LCA



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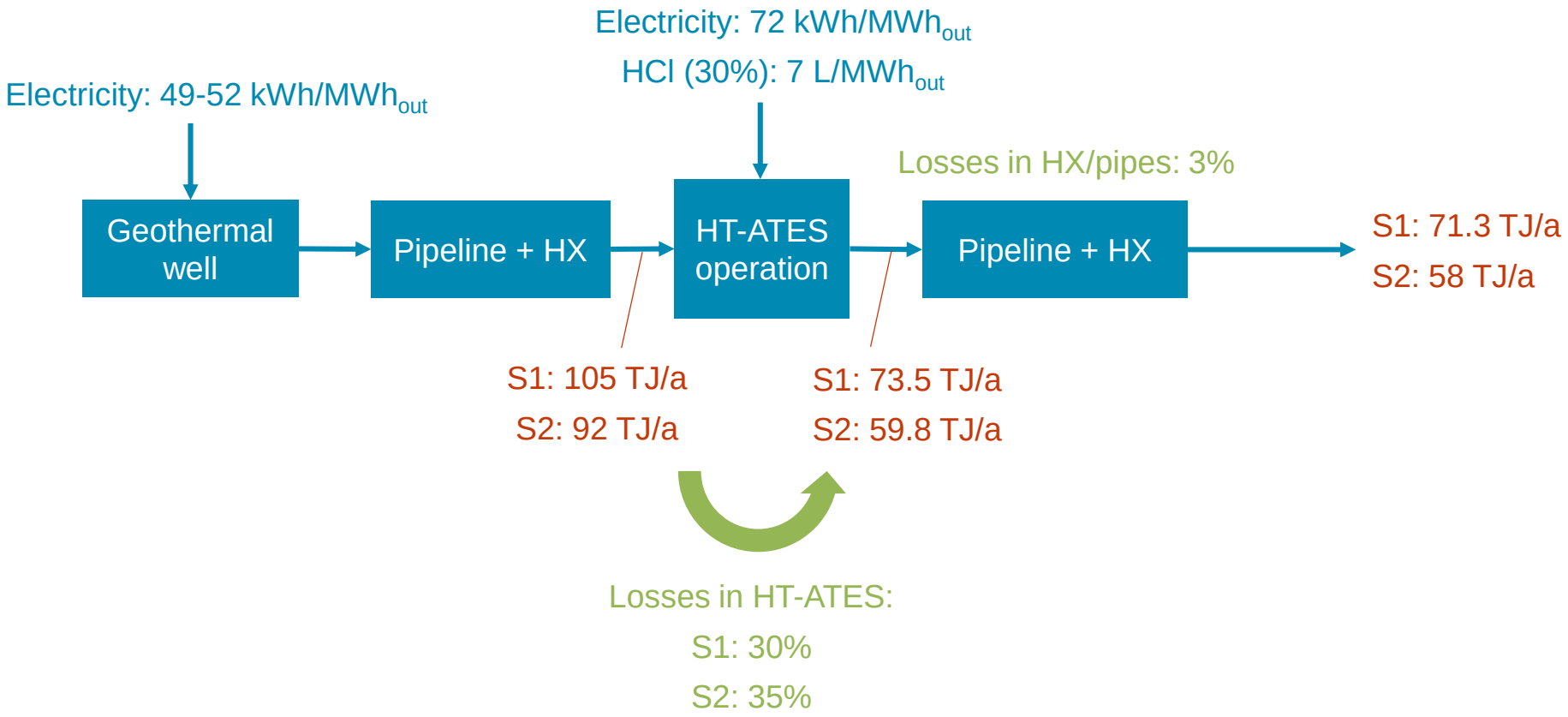
Operational data for two scenarios (S1 + S2)



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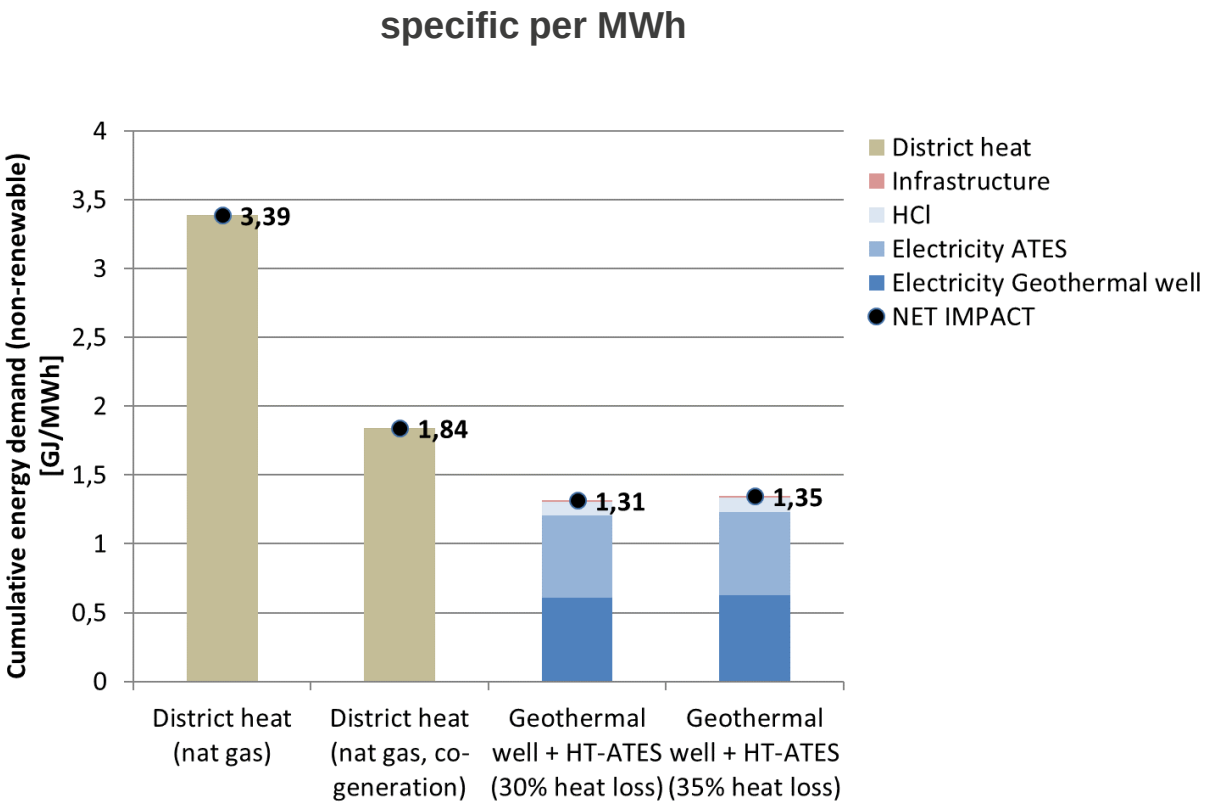
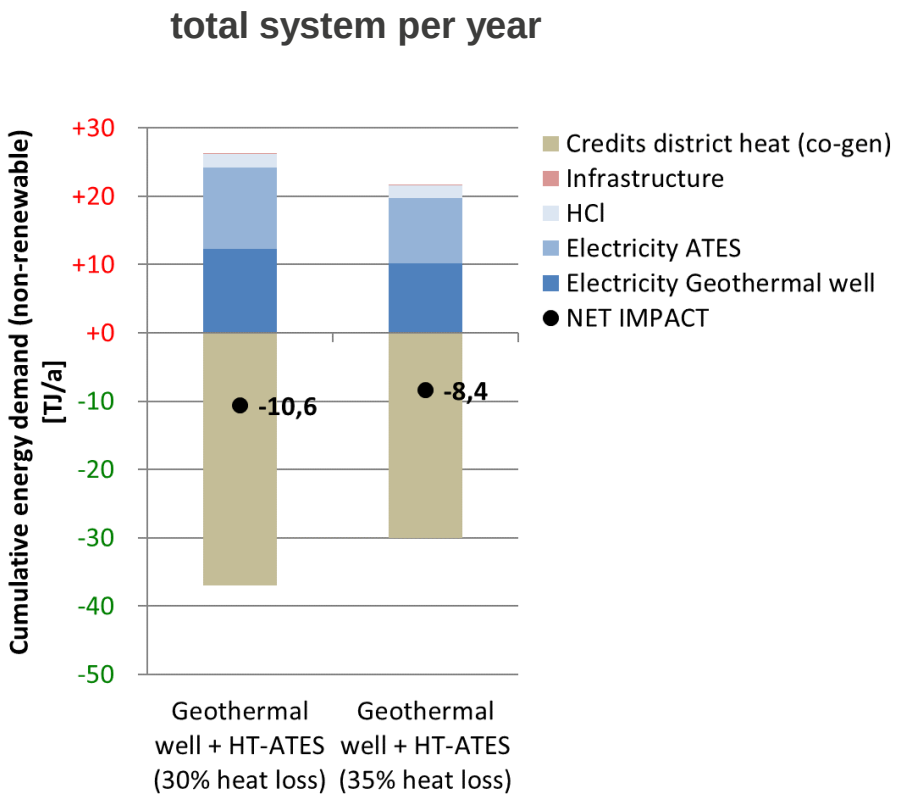
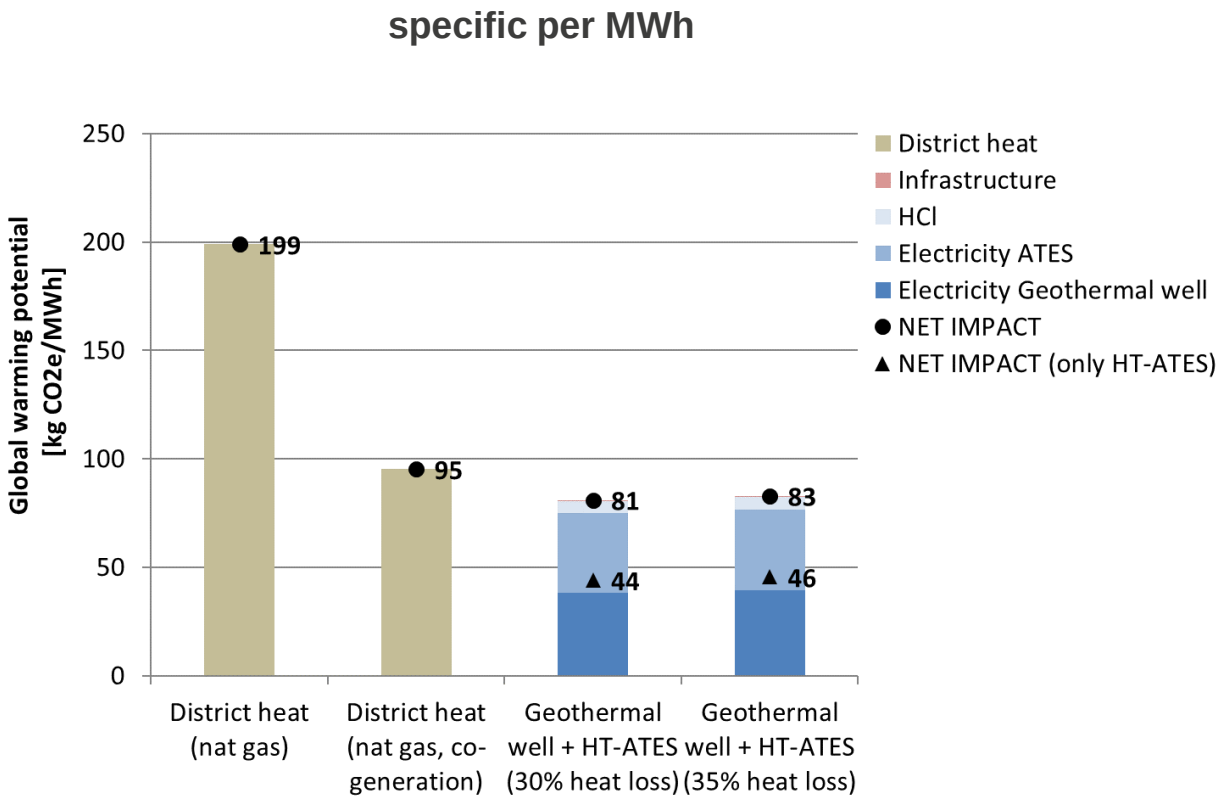
Results: fossil energy demand

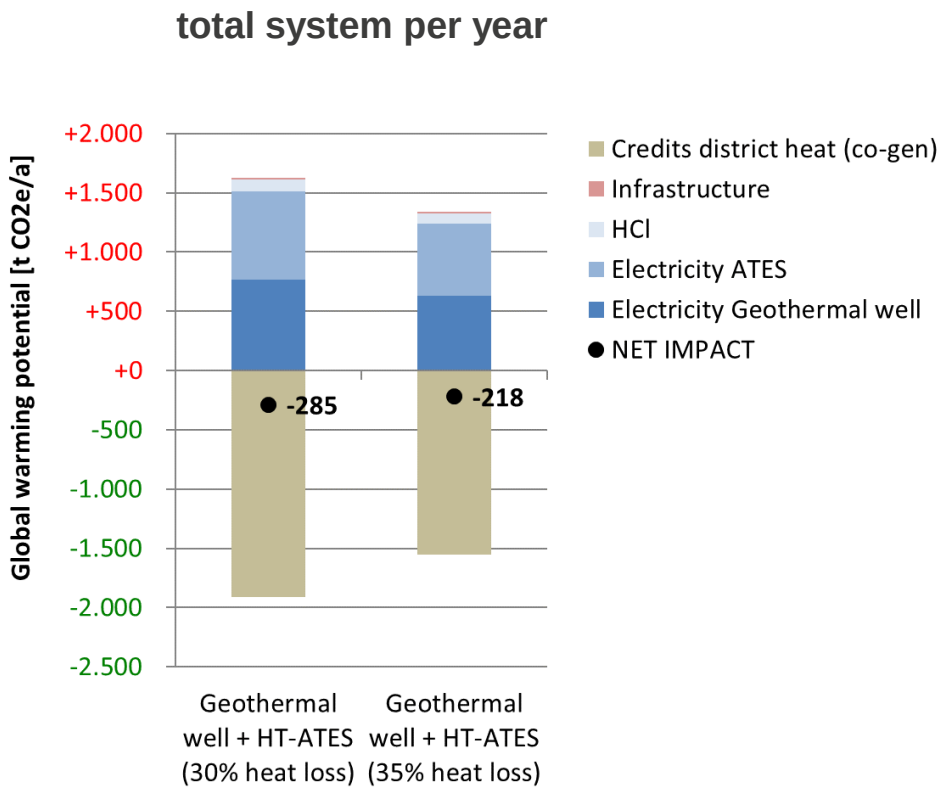




The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

Results: greenhouse gas emissions





Power mix (NL 2019): 505 g CO_2e/kWh (LCA database ecoinvent 3.9.1)

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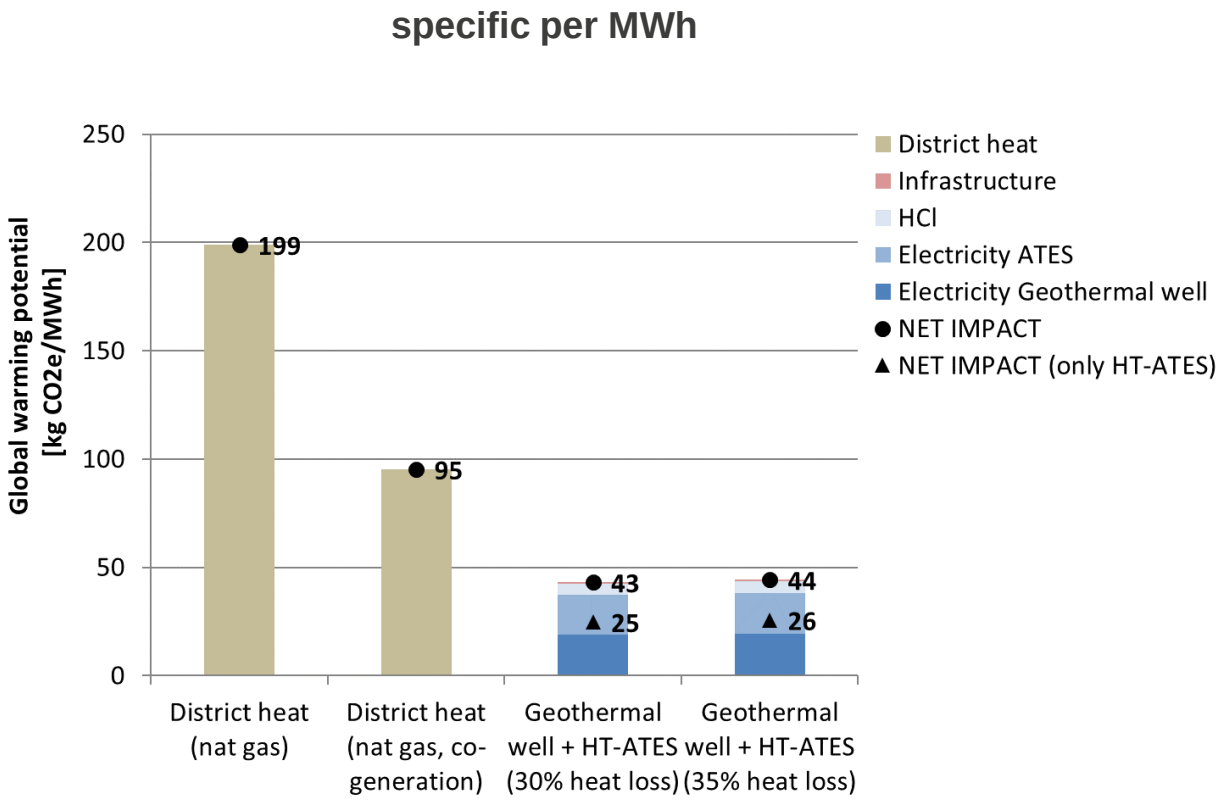
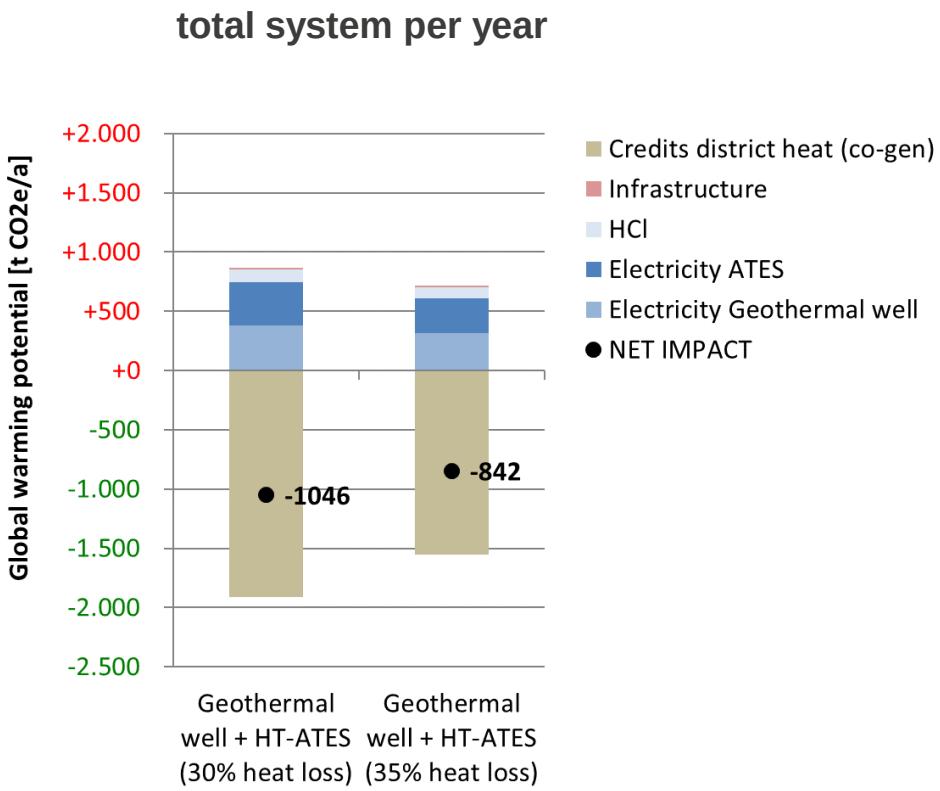
Results: greenhouse gas emissions (2030)





Power mix (NL 2030): 250 g CO_2e/kWh (estimate)

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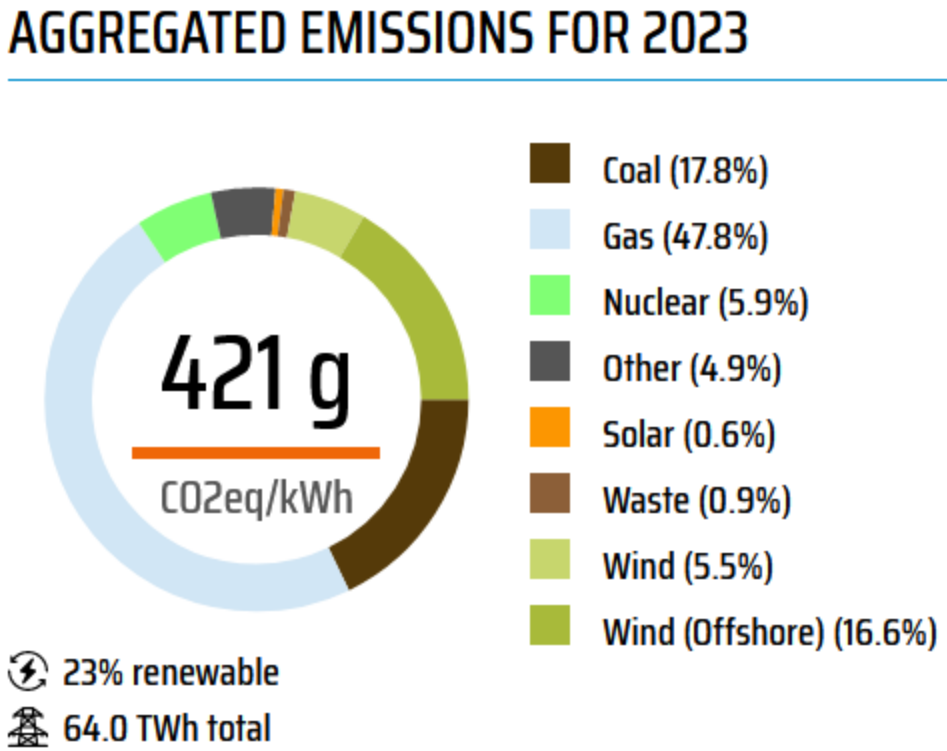
Power mix NL (2023)



https://www.nowtricity.com/country/netherlands/

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Conclusions

Main environmental impacts:

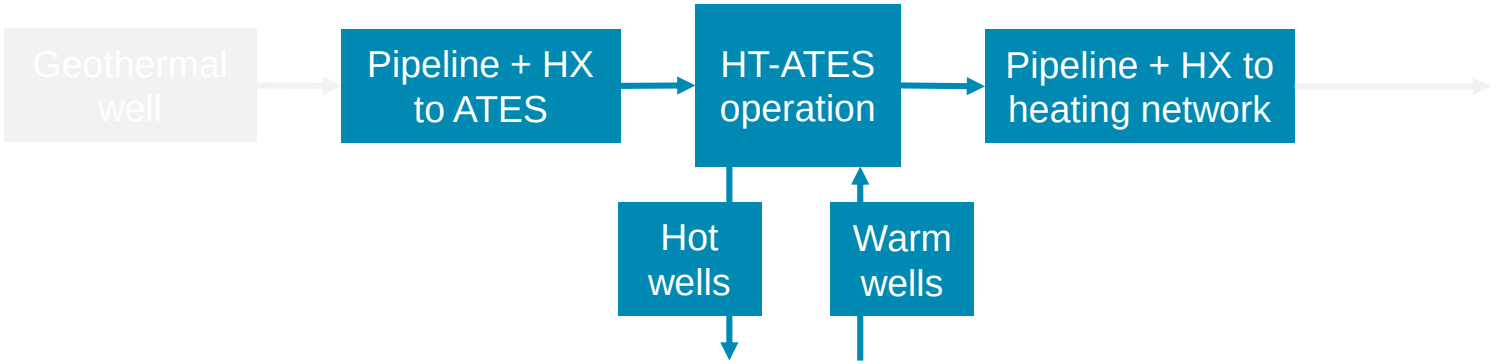
- Electricity for geothermal well and HT-ATES
- Infrastructure: negligible

Geothermal well + HT-ATES reduce CO_2e emissions of heat supply:

- - 60% to heat from natural gas
- - 15% to heat from co-gen power plant
- 218 – 258 t CO_2e saved per year (vs power plant)
- With more renewable power, savings will increase in the future (> 1000 t CO_2e/a)

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

Backup: infrastructure data



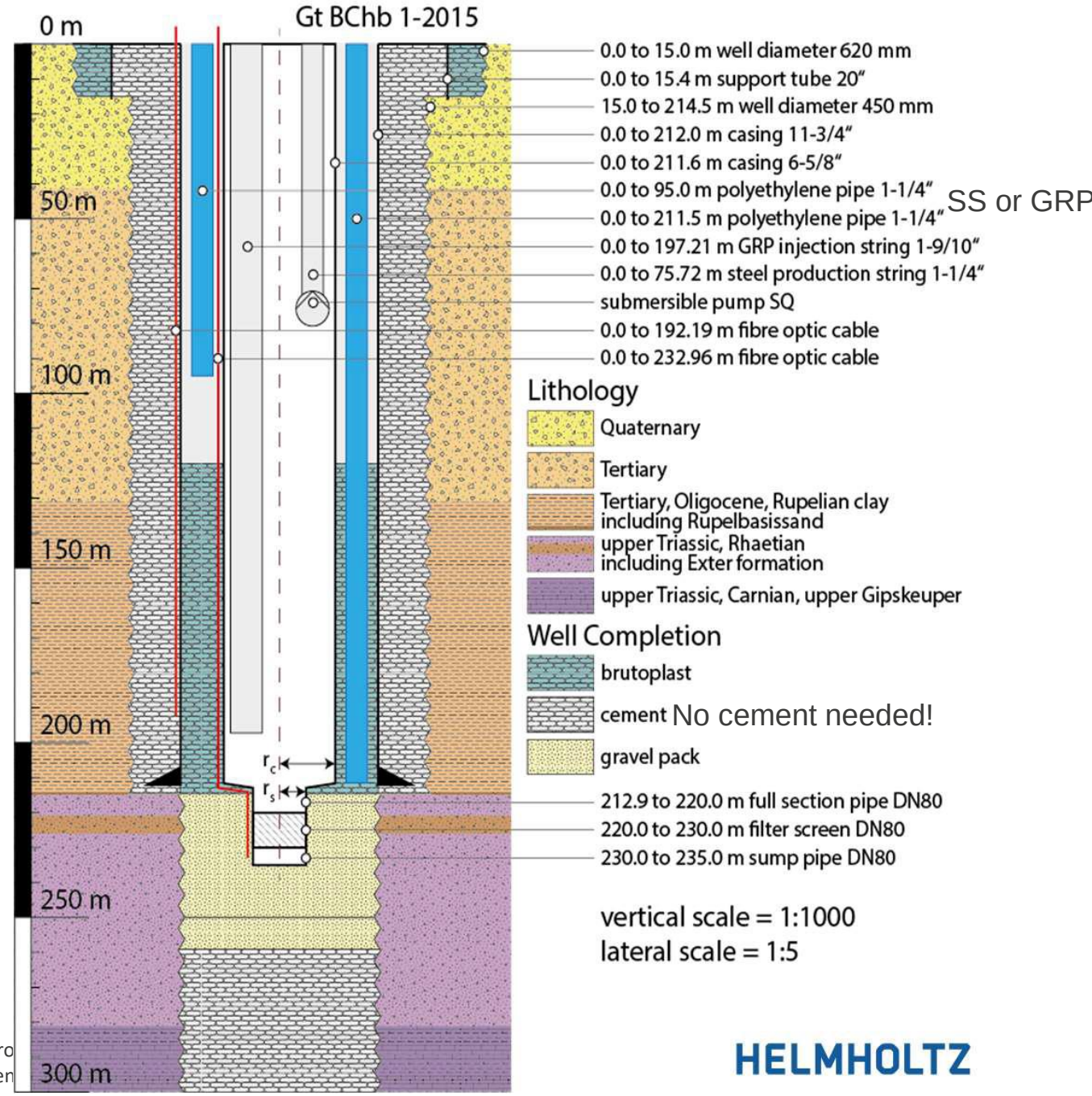
System	S1	S2	Source	Lifetime [a]
Piping + HX to ATES	Yes	Yes	Supplier	15 + 30
HT-ATES station	Yes	Yes	Estimate	50
Hot wells (220m)	5	3	Literature	50
Warm wells (220m)	10	6	Literature	50
Piping + HX to heating network	Yes	Yes	Supplier	15 + 30

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

HT-ATES: wells

Well design: (depth: 220m)

- Borehole: DN 800 → 110 m³ excavated material
- Casing: DN 500
- Pipe: GRE (DN 200) @ 5 kg/m → 1500 kg
- Aux (well head, filter screen) → 1000 kg SS
- Submersible pump (production well): 100 kg cast iron
- Drilling: diesel (1 week)



The project leading to this application has received funding from the Euro
Horizon 2020 research and innovation programme under grant agreemen

ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

CS 6: Karmiel & Shafdan

K. Baransi-Karkaby, N. Massalha, M. Hassanin, A. Aharoni, H. Raanan Kiperwas,

D. Iossifidis, M. Touloupi, I. Sabbah



Workshop on energy recovery, 5th 2024

ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

TRANSITION FROM LINEAR TO CIRCULAR ECONOMY

in the nexus of the water sector & intensive water consuming industries.

CASE STUDY 6: KARMIEL & SHAFDAN, ISRAEL

NEW WAYS TO DEAL WITH WASTEWATER SHOCK LOADS

KARMIEL 6

SHAFDAN 6

Energy

Materials

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

Case study 6 - Karmiel and Shafdan

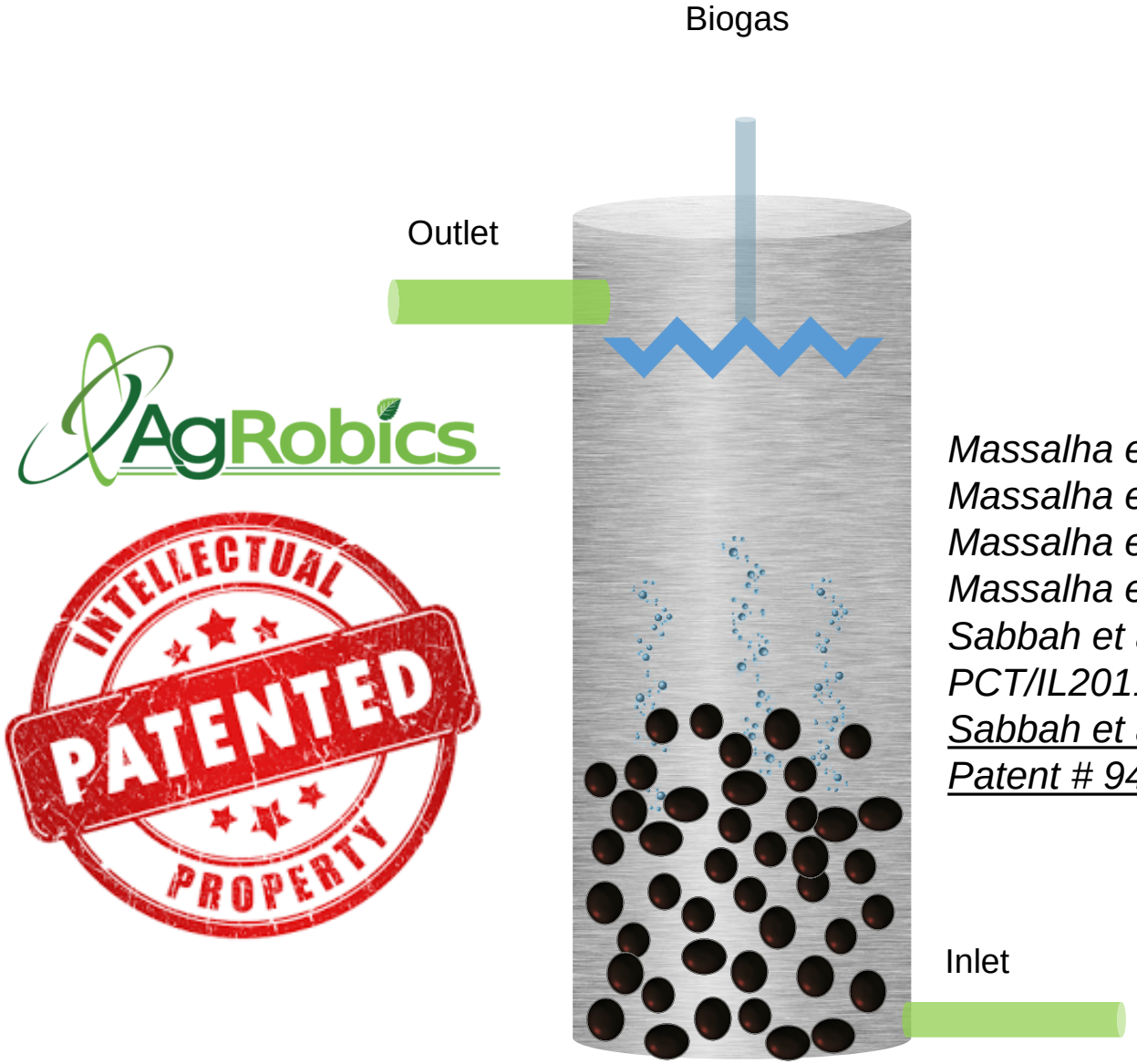
Lead partner:

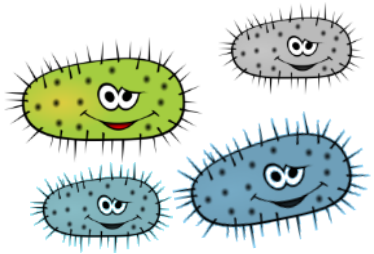
جمعية الجليل
אגודת הגליל
The Galilee Society



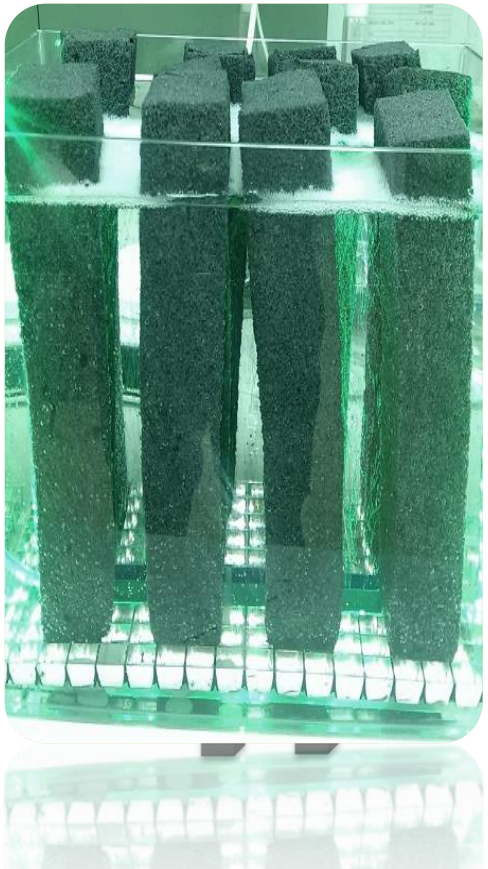
The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

AAT- Advanced Anaerobic Treatment

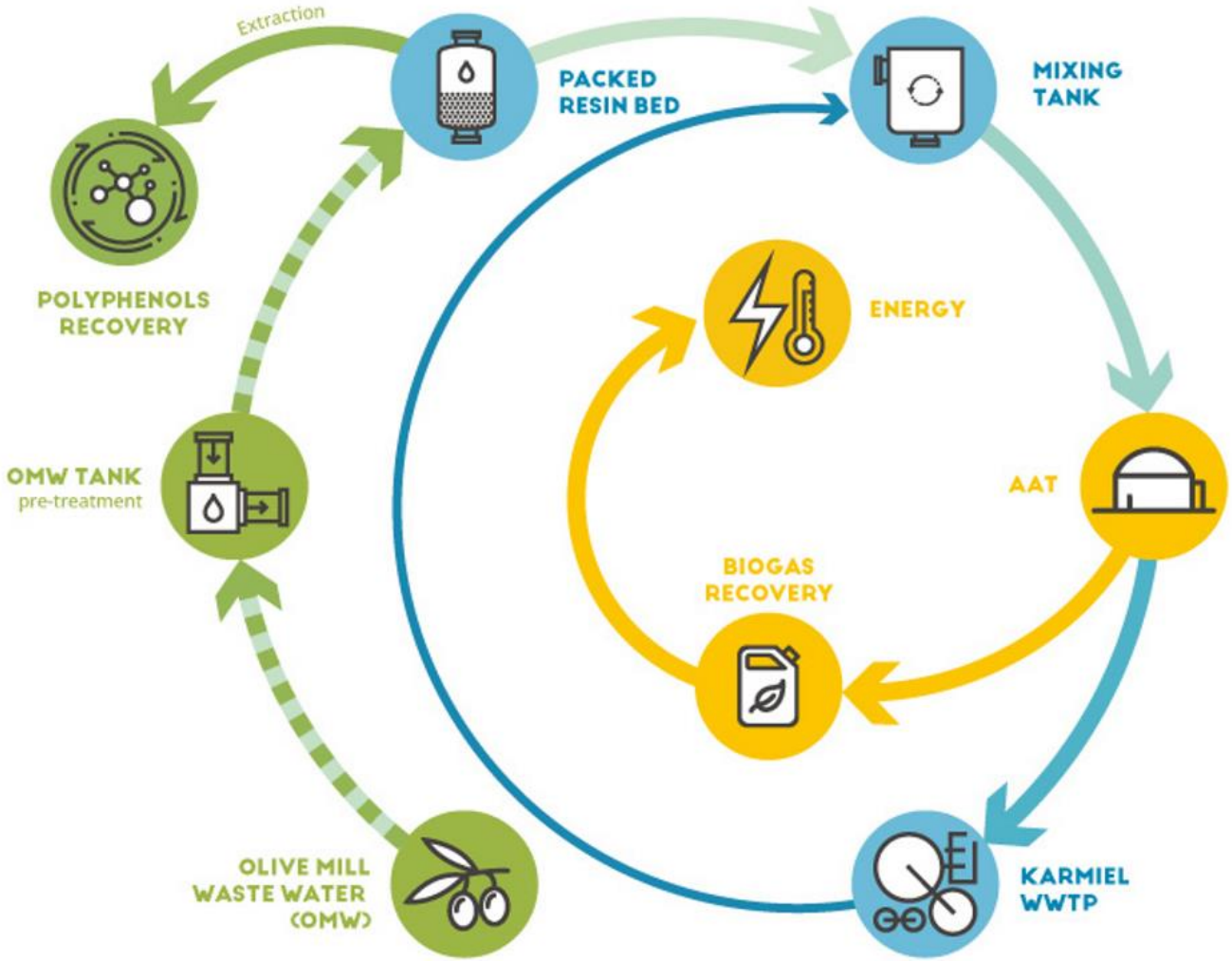




Massalha et al., Water Res., 2014,
Massalha et al., 2015- AD14,
Massalha et al., Biores. Technol., 2015
Massalha et al., Chem. Eng. J., 2015
Sabbah et al., 2011 , PCT: PCT/IL2011/000263
Sabbah et al., 2016, United States Patent # 9452458



Case study 6 - Karmiel





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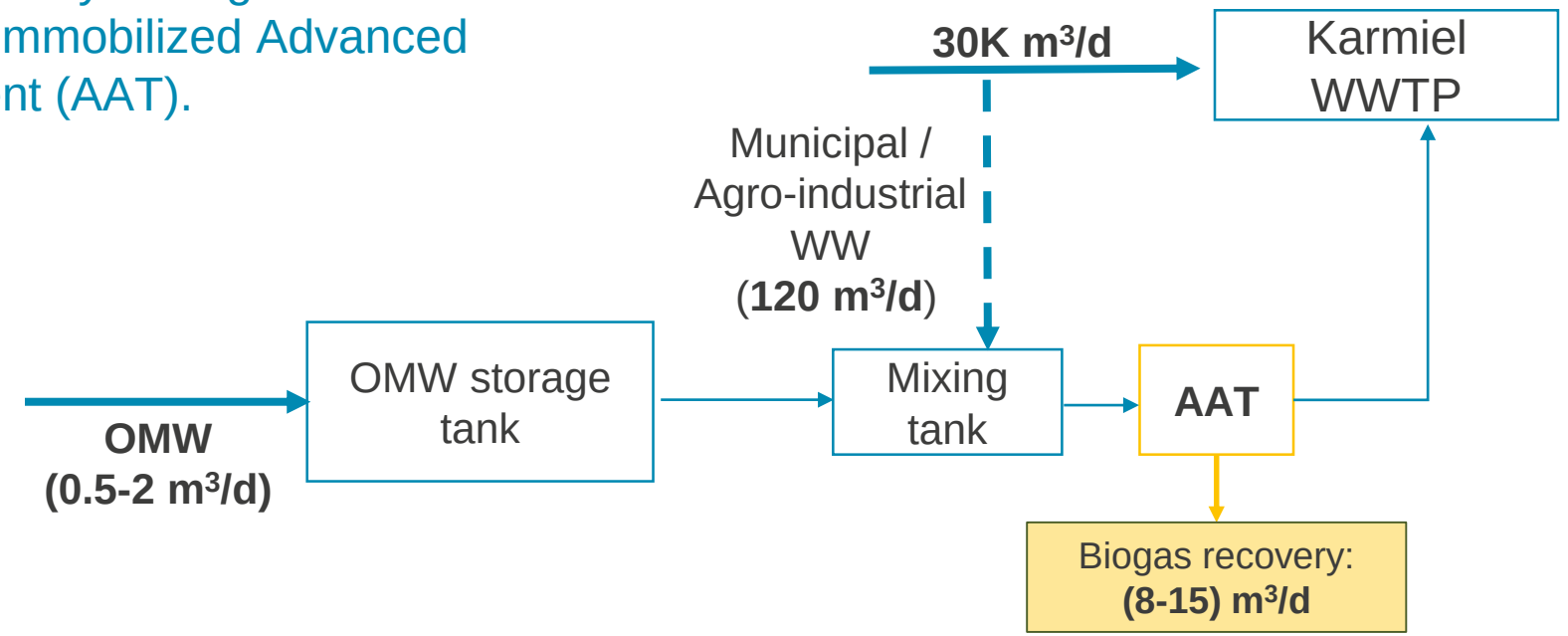
ENERGY - Task 1.3.3

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

OBJECTIVE:

Reducing the high organic load peaks in WWTP main stream, caused by mixing with olive mill wastewater, using immobilized Advanced Anaerobic Treatment (AAT).





TRL: 5 → 8

Quantifiable targets: 8-15 m³ biogas/d; 20-25% reduction of energy demand; 25% energy recovery

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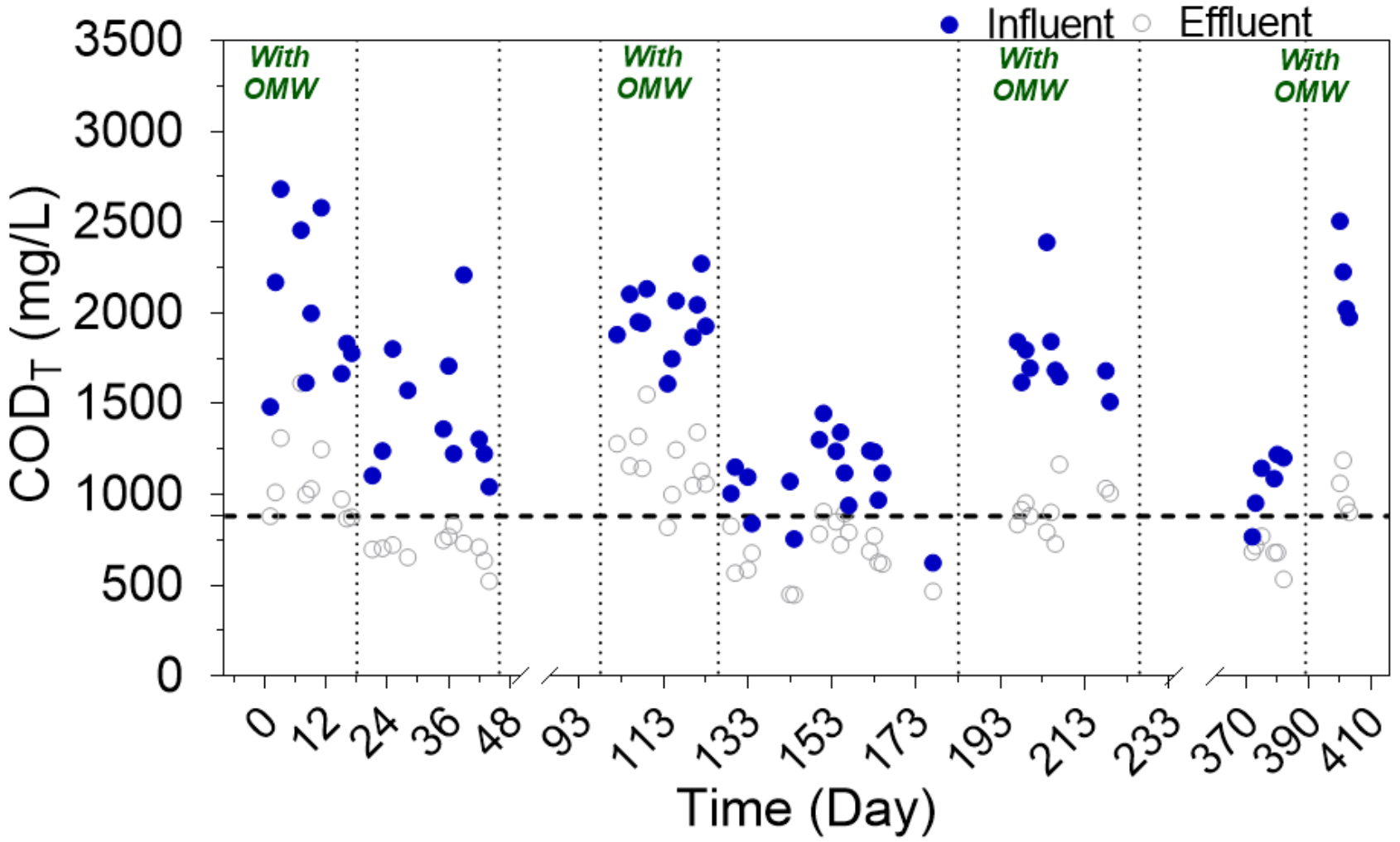
Case study 6 - Karmiel



The system tolerates the applied ratio of 0.5% of OMW to domestic wastewater with a stable COD in the effluent (of 900 mg/L)

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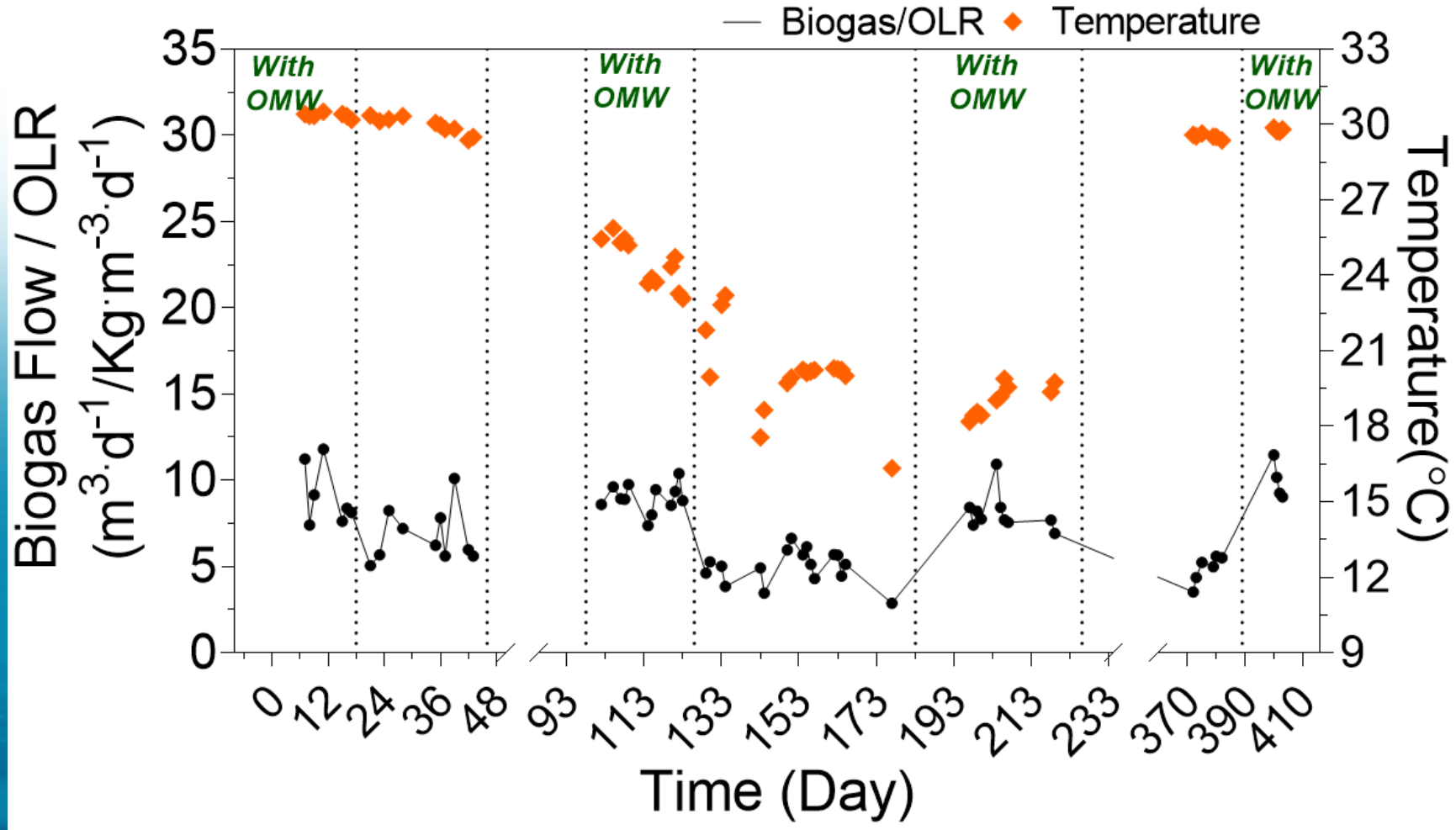
Case study 6 - Karmiel



AAT produces biogas throughout its operation.
In summer, biogas production is at its maximum rate, and is highly dependent on the influent COD and high temperature.

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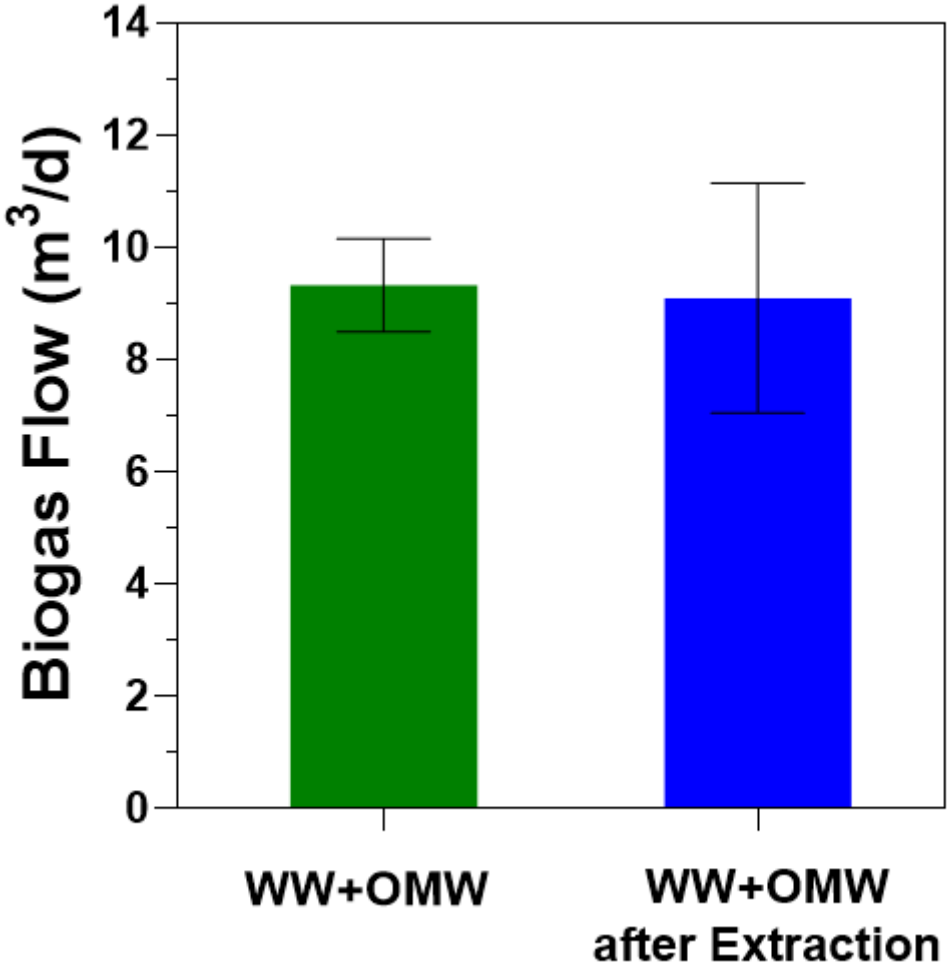
Case study 6 - Karmiel



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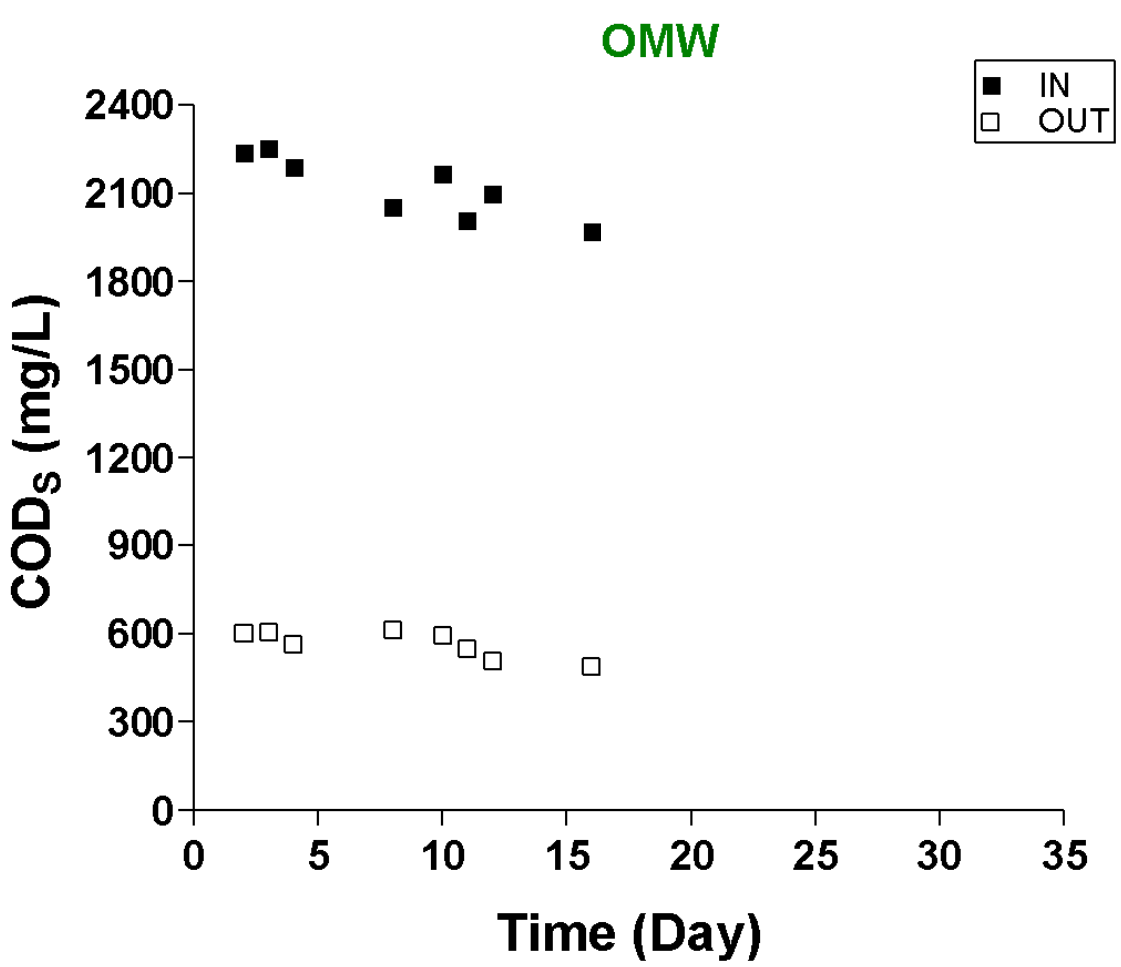
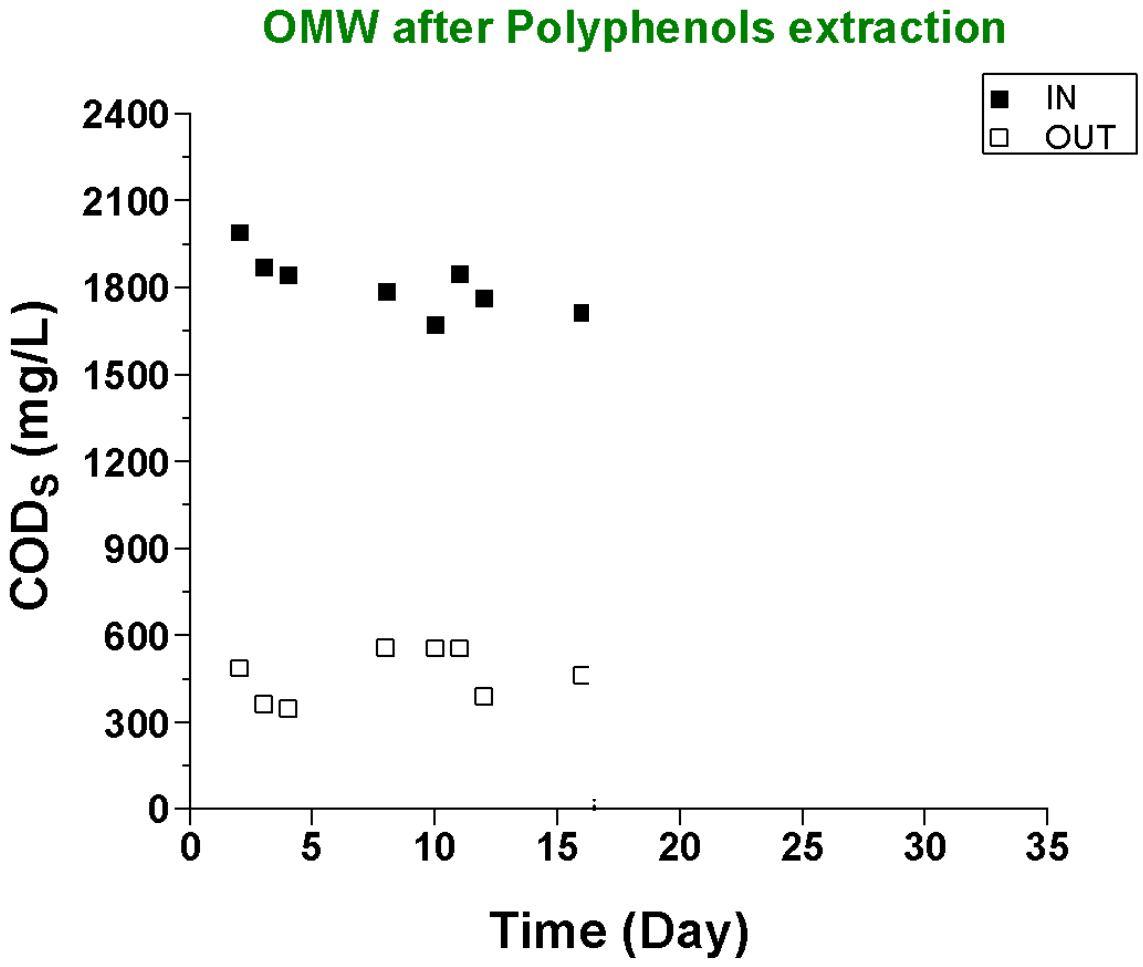
CS6: ENERGY-Lab scale AAT performance





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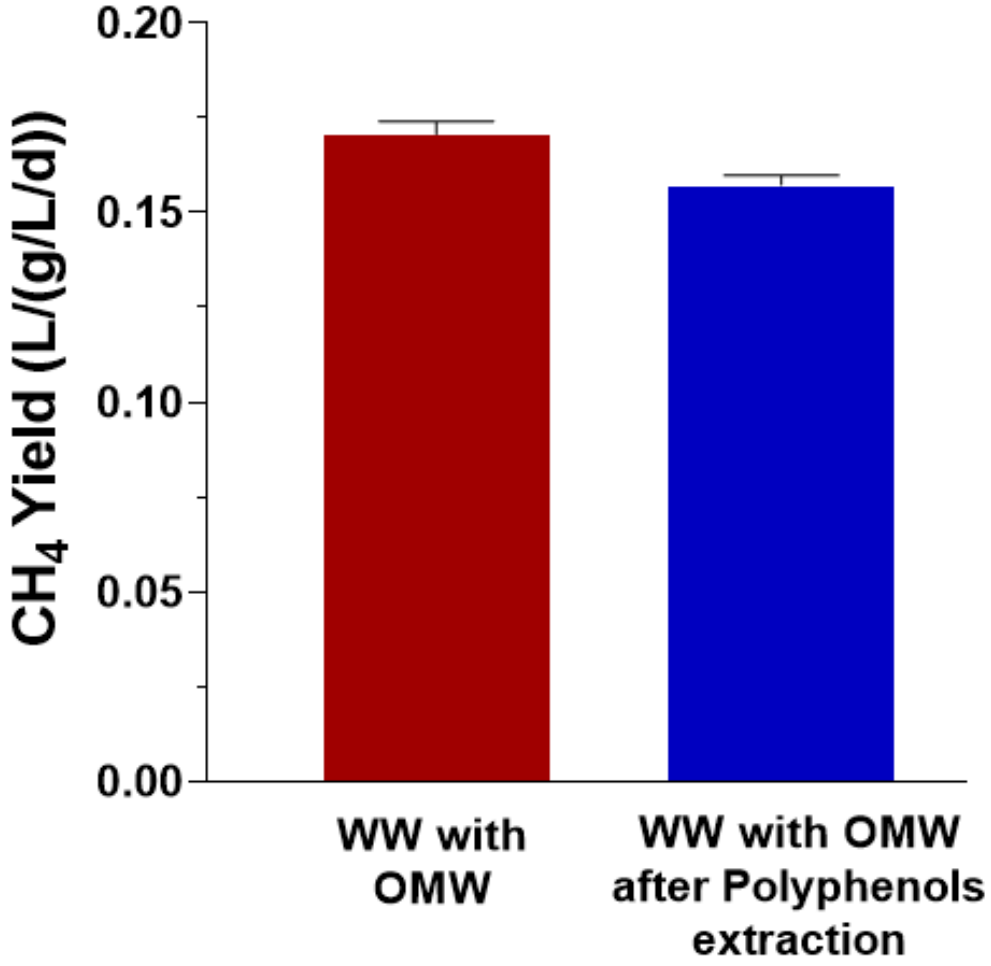
CS6: ENERGY-Lab scale -AAT performance



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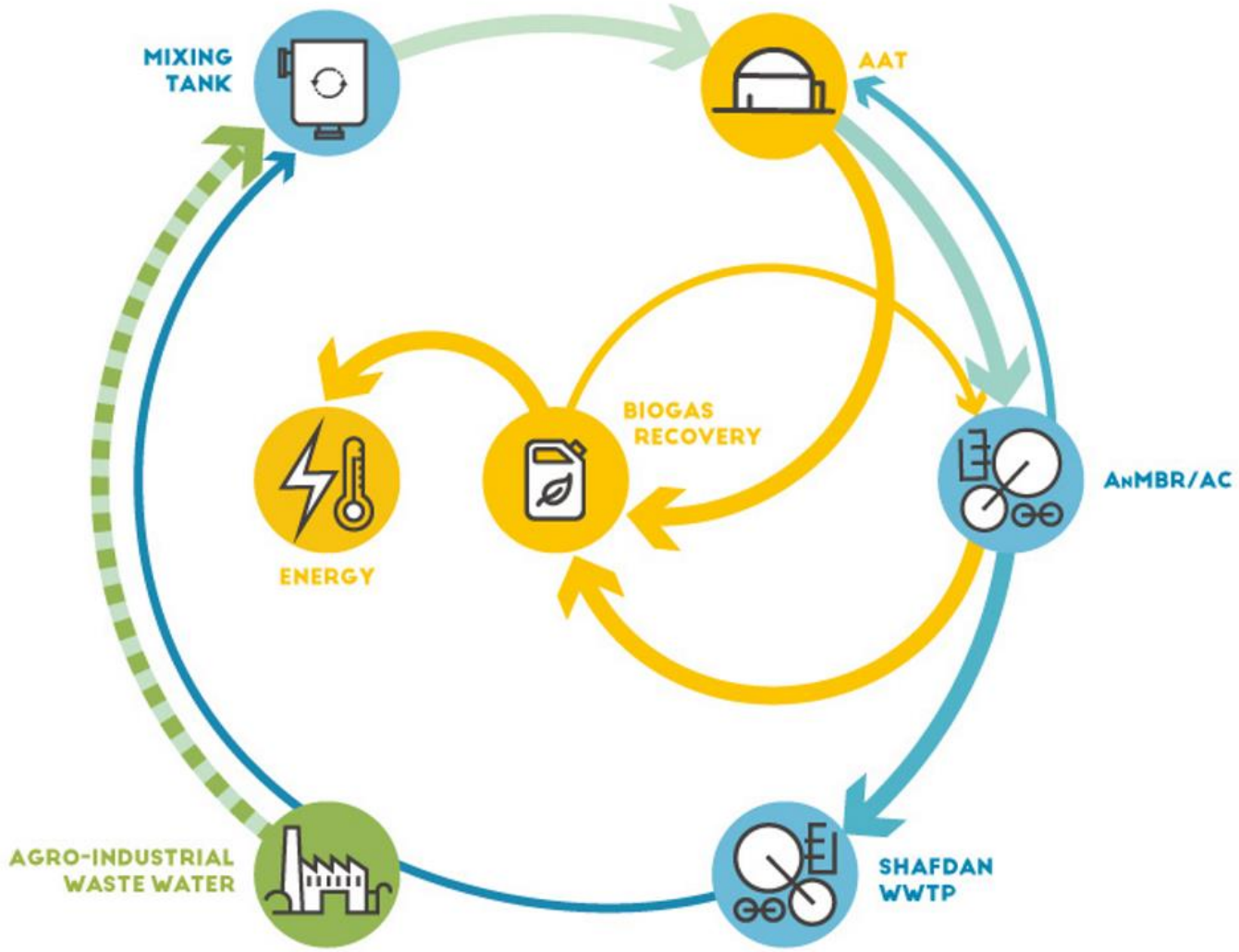
Case study 6 - Shafdan





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

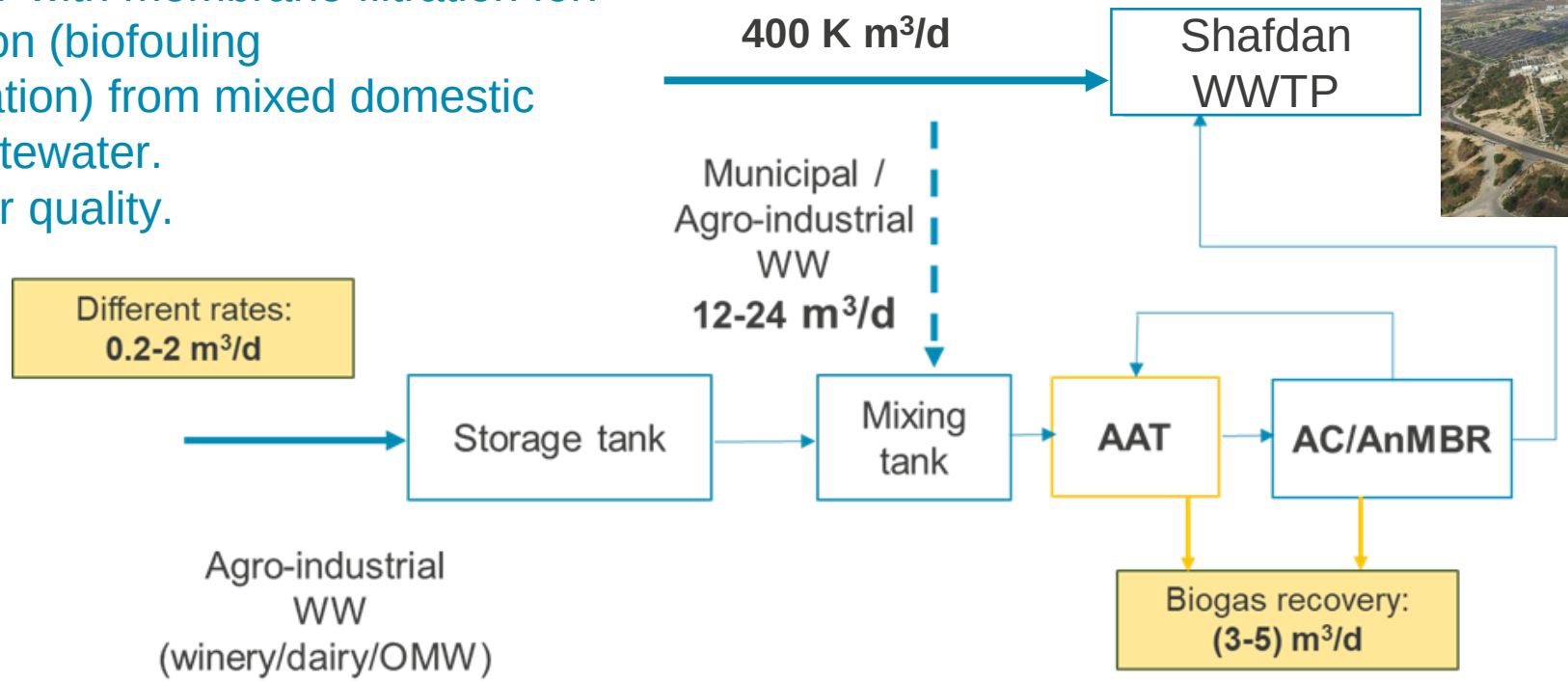
ENERGY - Task 1.3.4

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

OBJECTIVE:

Testing the efficiency of AnMBR based on combining immobilized biofilm AAT with membrane filtration for:
Higher biogas production (biofouling reduction/optimal operation) from mixed domestic and agro-industrial wastewater.
Improving effluent water quality.





TRL: 5 → 7

Quantifiable targets: : 3-5 m³ biogas/d; 20-25% reduction in energy demand; 25% energy recovery

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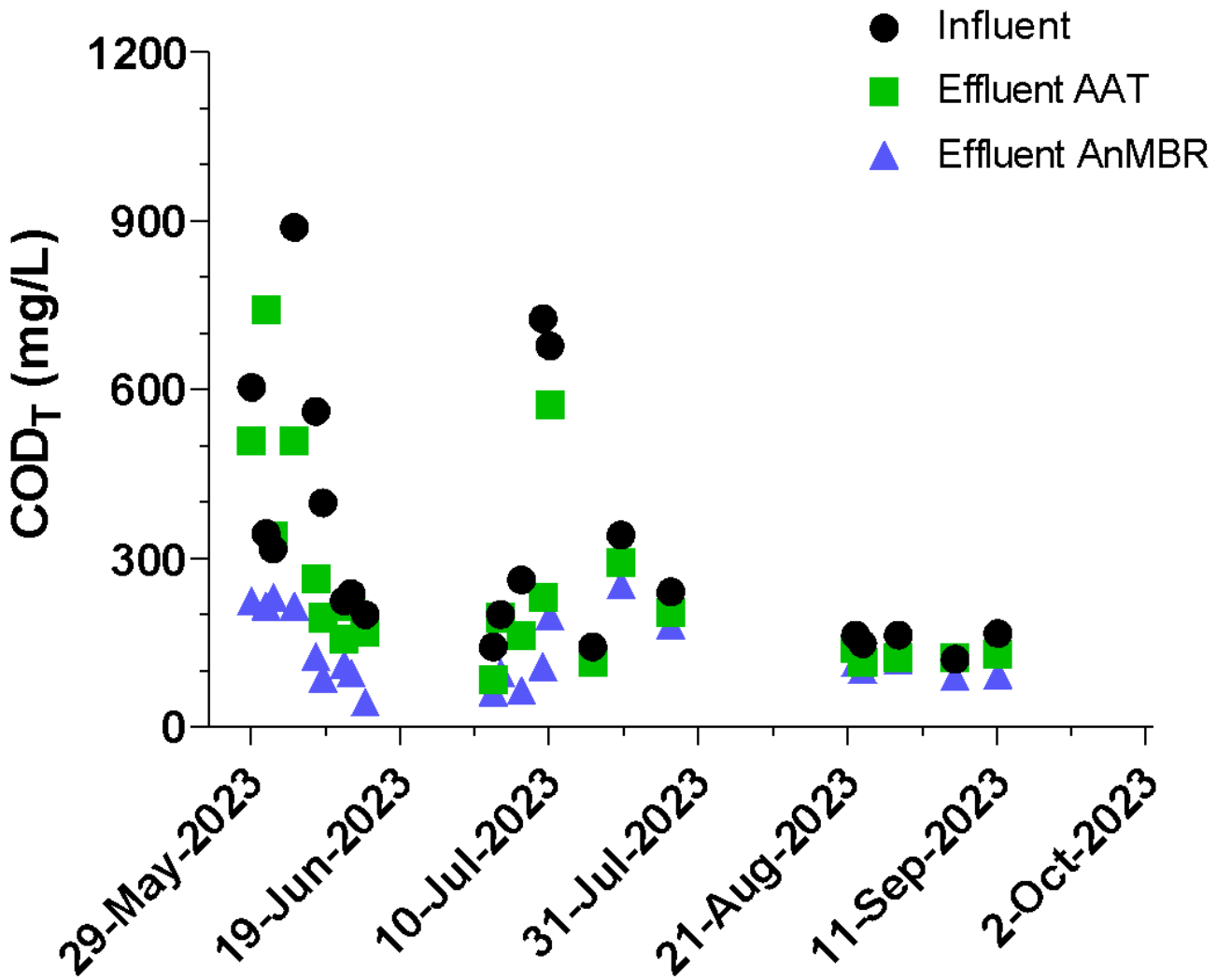
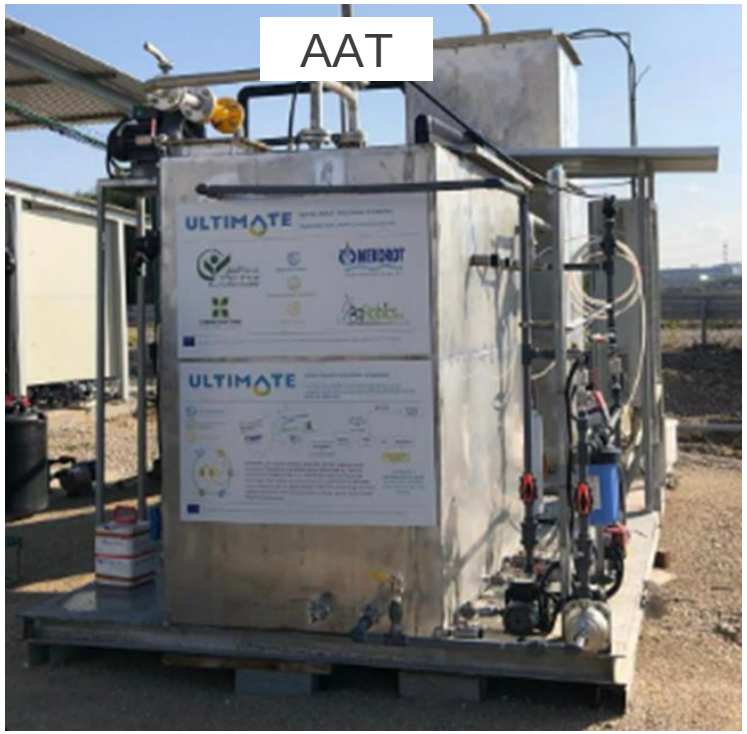
Case study 6 - Shafdan







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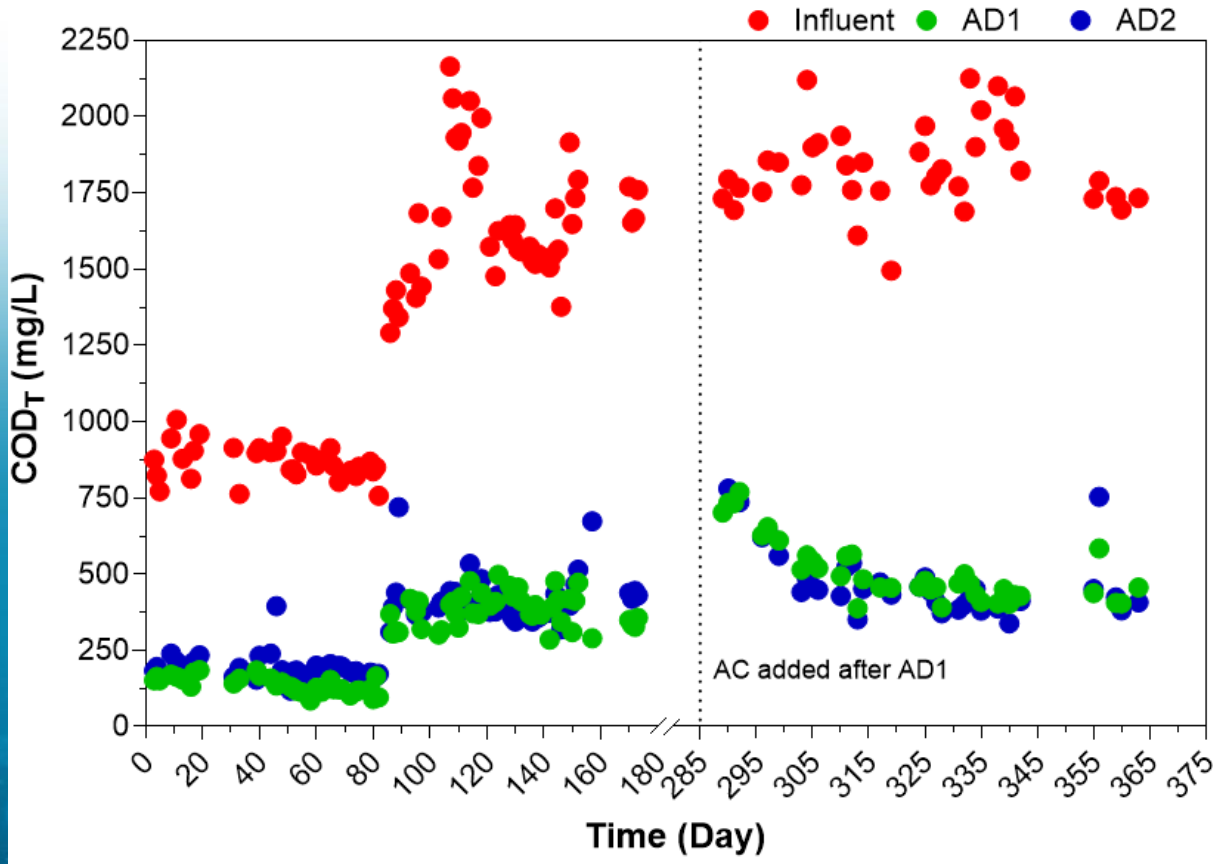
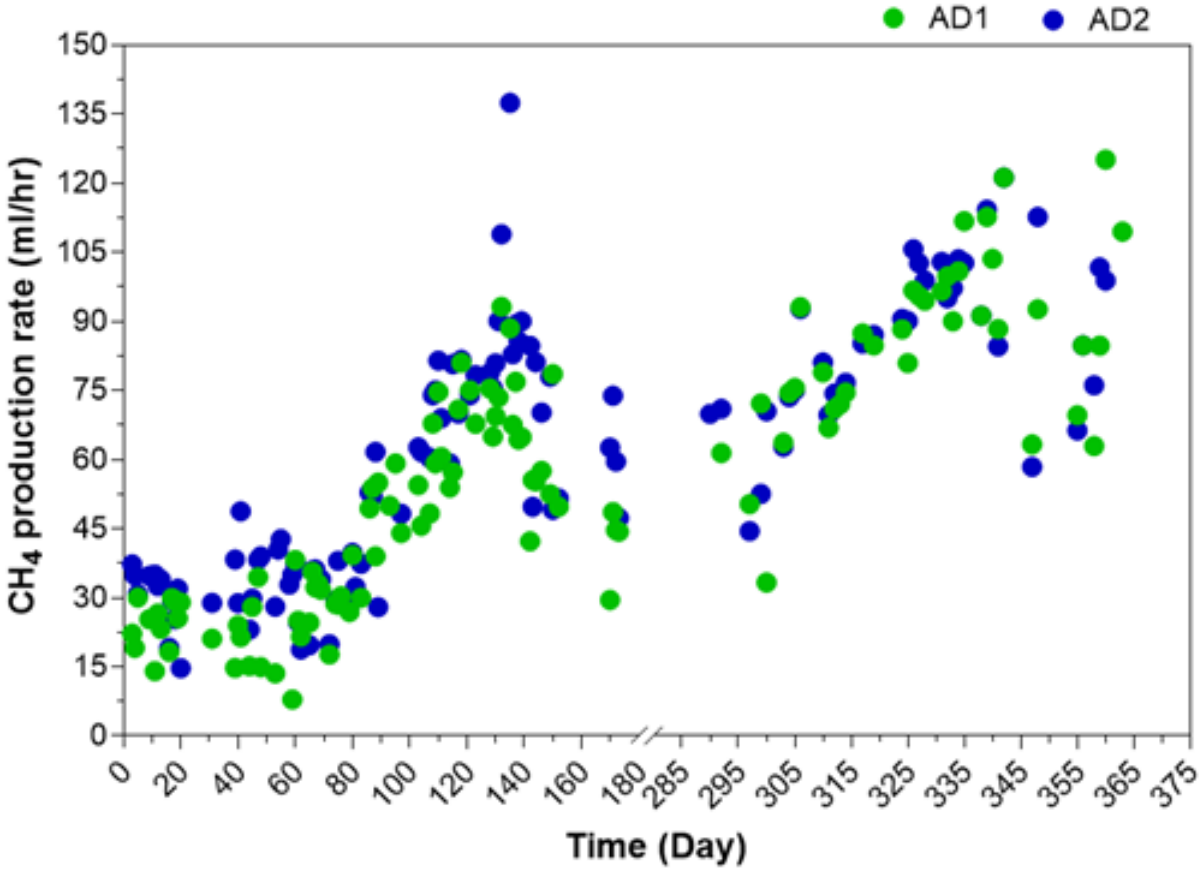
Lab scale AnMBR





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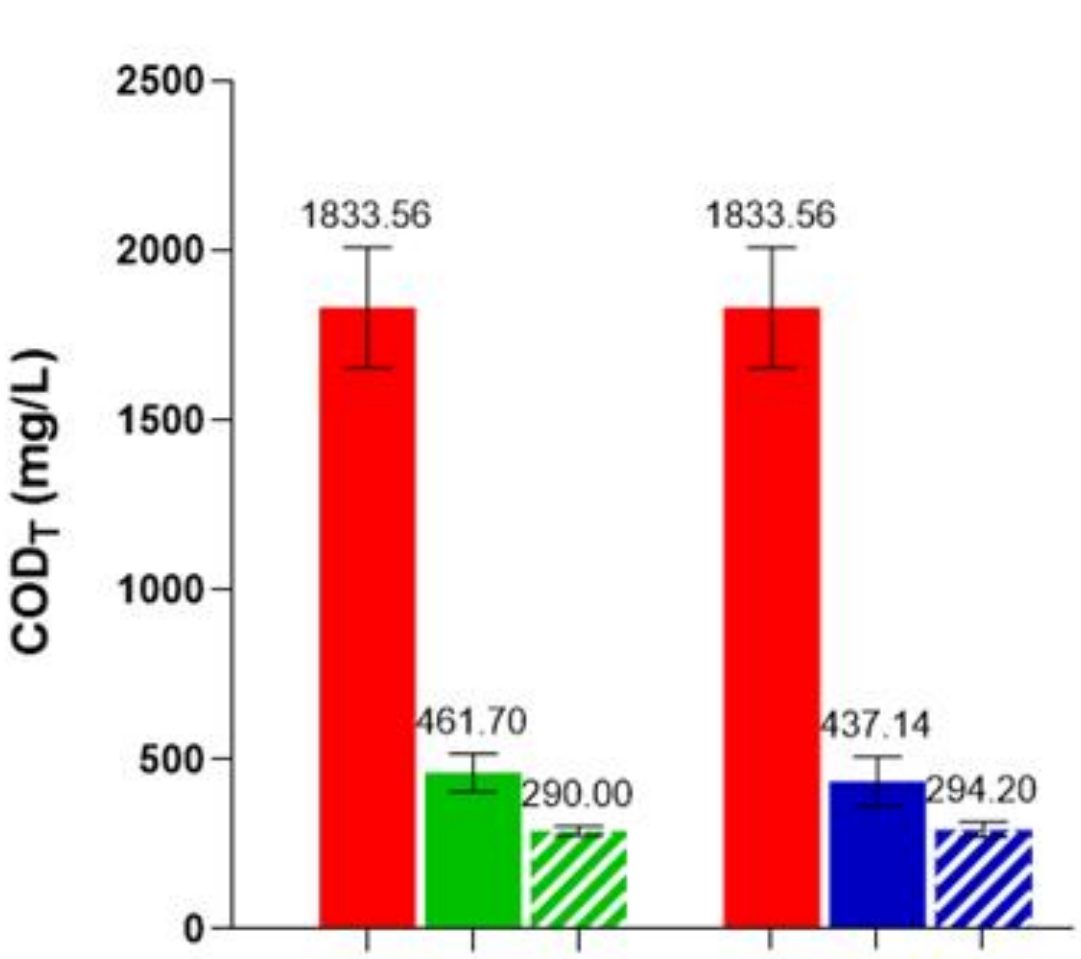
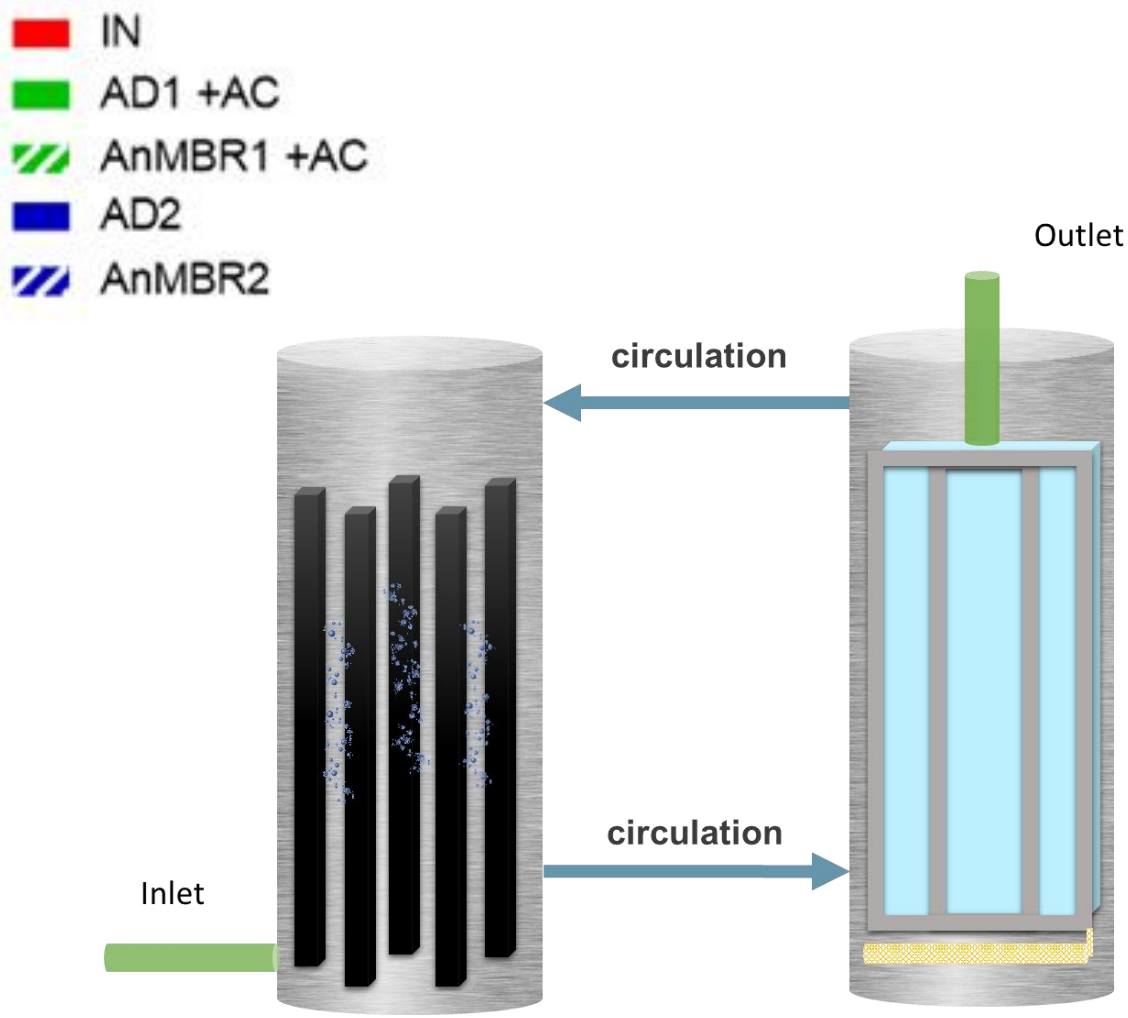
Lab scale AnMBR





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Isam Sabbah



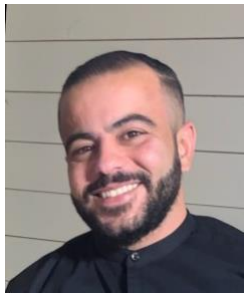
Katie Baransi Karkaby



Khalid Farah



Nedal Massalha
CTO



Mahdi Hassanin



Avi Aharoni



Hadas Raanan Kiperwas



Saleh Zatme



Sari Musa



Stav Shimshoni
M.Sc. Student



Dimitri Iossifidis



Myrto Touloupi

Thank you for your attention!

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

Biogas production and valorization in CS5 Lleida:

AnMBR vs. ELSAR® & SOFC, using biogas to produce electricity and heat

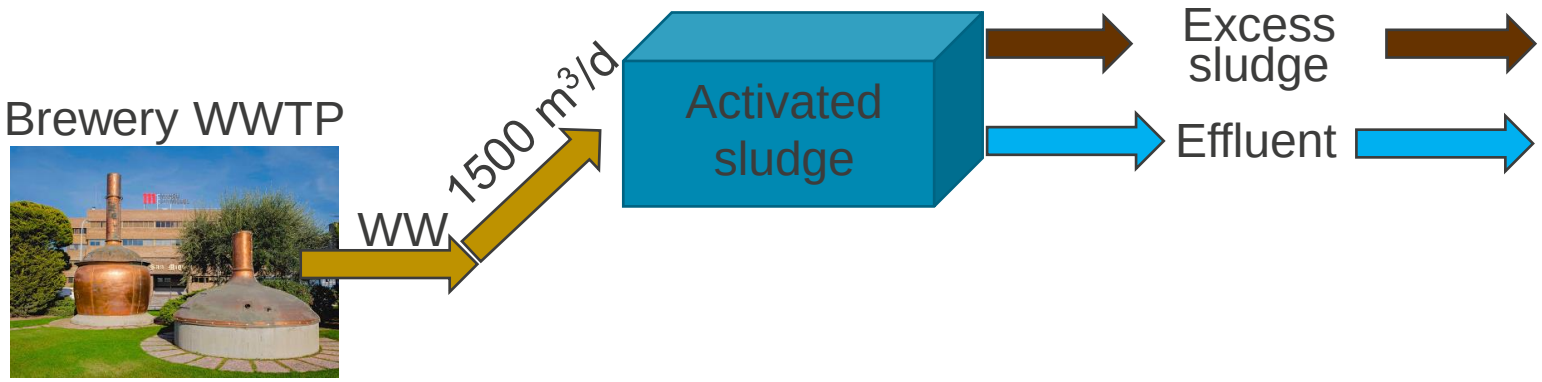
A. Giménez-Lorang

aqualia



14.05.2024

Case study nr. 5: baseline conditions



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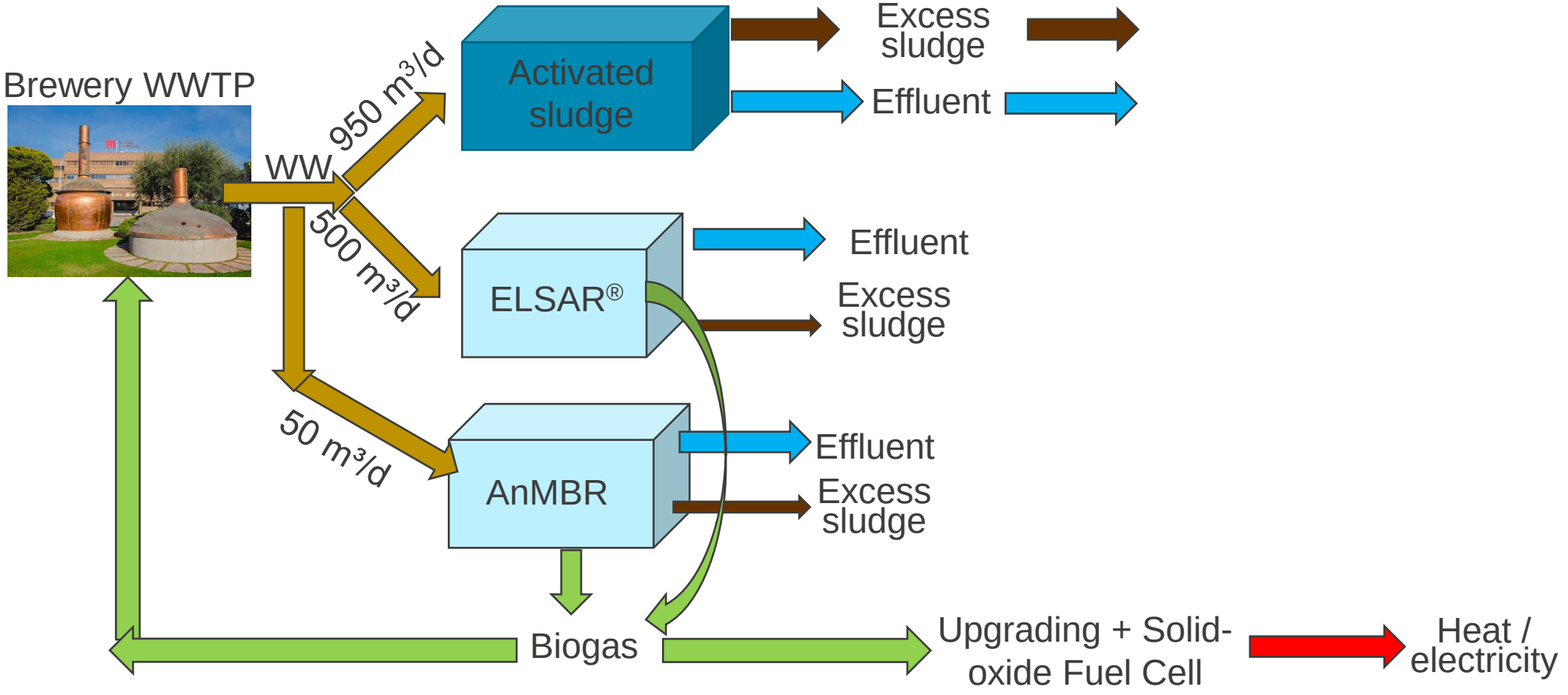
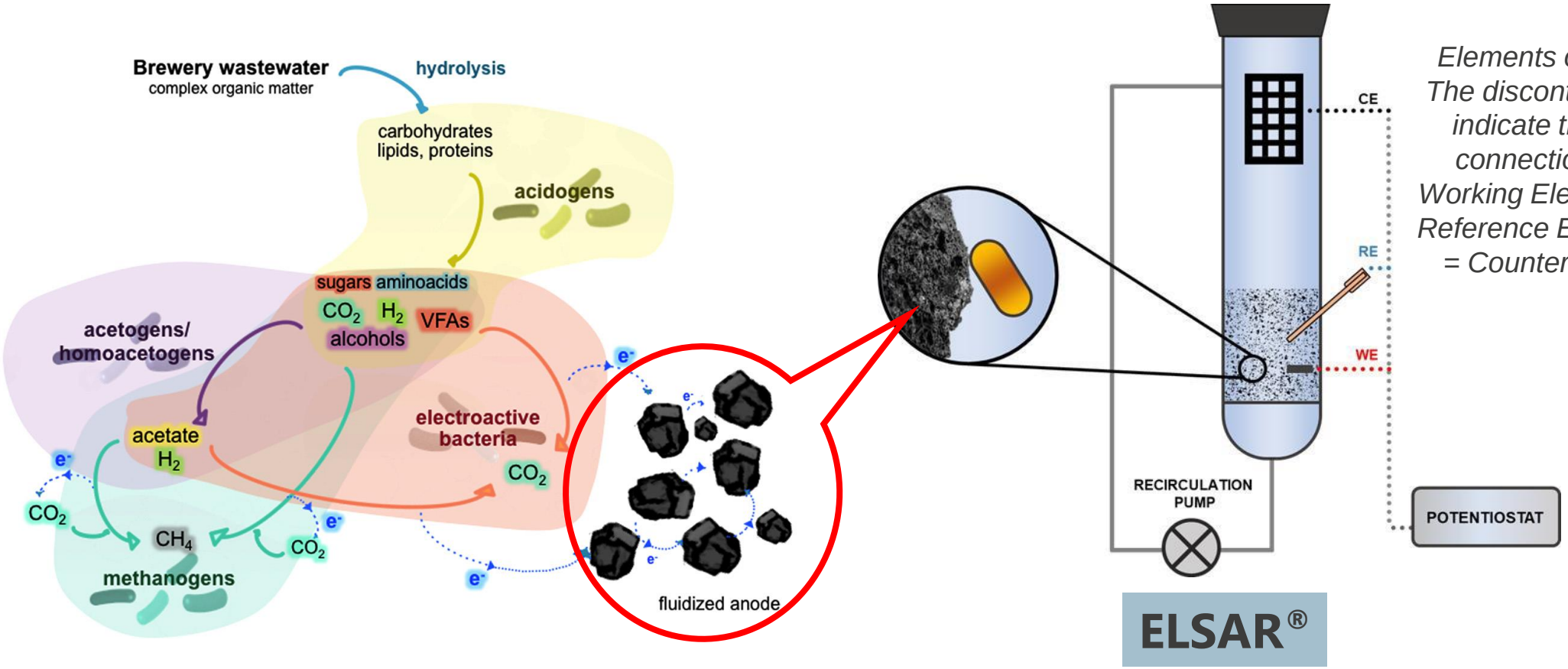
Case study nr. 5: ULTIMATE water-smart solution



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

Definition of ELSAR®



Elements of ELSAR®. The discontinuous lines indicate the electric connections. WE = Working Electrode. RE = Reference Electrode. CE = Counter Electrode.

Schematic of the different anaerobic communities that might coexist within the ELSAR® and the possible competitive reactions among them for the electron donors. Adapted from Tejedor-Sanz *et al.*, 2018

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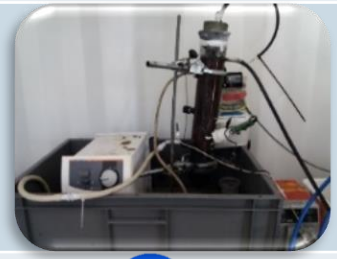
The path to market of ELSAR®*

**Method for treating wastewater in a fluidized bed bioreactor* (Ref. EP 2927196 A1).

	Lab-scale FBBR	Pre-pilot	Prototype	Demo	Pre-industrial
Technical features	• **TVR 1,2L** • Brewery WW • CC: graphite plate + SS mesh / SS sponge	• **TVR 5,4L** • Brewery WW • CC: graphite plate + SS sponge	• **TVR 450L** • Brewery WW	• **TVR 1m^3** • Urban WW • CC: carbon fiber structure + SS sponge	• **TVR 140m^3** • Brewery WW • CC: carbon fiber structure + SS structure • Q 20 $m^3 \cdot h^{-1}$; • OLR 2.000 $kgCOD \cdot L^{-1}$
Running years	2013-2014	2018	2019	2020-2021	2024
Picture					
Financing Project	ITACA	ANSWER	ANSWER	ADVISOR	ULTIMATE
Main goal	Optimization of operational para-meters and design	ELSAR® vs. AFBR. Competitive advantages	Long-term operation (20 months)	Operational environment and low-strength WW.	Operational environment and high-strength WW.

*TVR = **T**otal **V**olume **R**eactor; ELSAR = **EL**ectro-**S**timulated **A**naerobic **R**eactor; WW = wastewater; FBBR = **F**luidized **B**ed **B**io-**R**eactor ; AFBR = **A**naerobic **F**luidized **B**ed **R**eactor; CC = current collector*

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aqualia

Competitive advantages of ELSAR® vs. conventional anaerobic fluidized bed reactor (AFBR)



Highlights

- ELSAR® improves the wastewater treatment capacity of conventional AFBR.
- ELSAR® overcome the most common operational issues related to AFBR units in real WWTP.
- ELSAR® showed a high performance and robustness treating real brewery wastewater.
- ELSAR® has been operated during one year with high COD and nutrients removal rates.
- ELSAR® recovered more energy from wastewater than conventional AFBR.

Under steady conditions

1. COD overload
2. Presence of biocides
3. Starving periods
4. Sudden temperature changes

More H_2, more biogas/kg removed COD

Extracted conclusions from Asensio *et al.*, 2021.
AFBR = Anaerobic fluidized bed reactor

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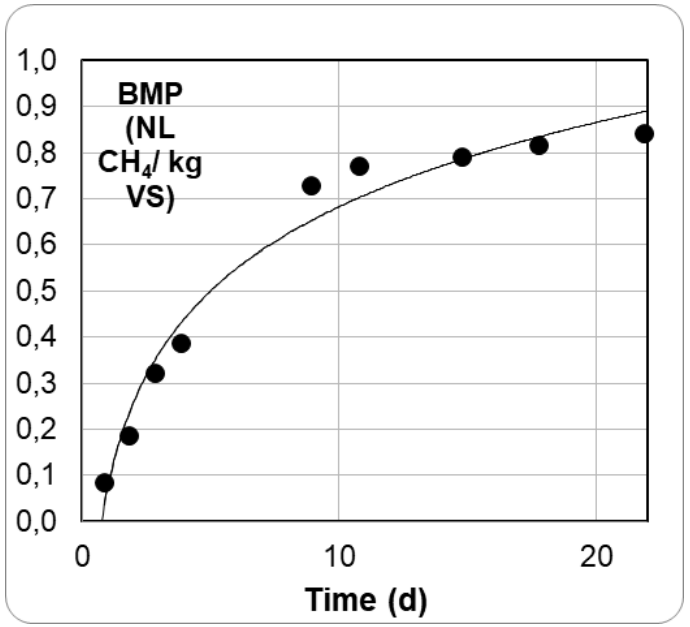
The next step: pre-industrial ELSAR®. Preliminary results.

- Exhaustive brewery wastewater characterization (1 month long)
- Biochemical methane potential (BMP) tests showing adequate anaerobic biodegradability. A potential of 0,31 Nm^3 CH_4/ removed kg COD was found. This result is consistent with other sources.
- Preliminary geotechnical study & basic design projects shows no technical limitations for proposed solutions (but certain need for foundation & civil works)



PARAMETER	AVERAGE ± STANDARD DEVIATION	UNITS
COD (stirred sample)	5586±1732	mg/L
COD (settled sample)	4674±1765	mg/L
NH4	3±3	mg/L
NO3	2±1	mg/L
Total N	64±23	mg/L
Total P	17±4	mg/L
Sulphates	158±32	mg/L
Sulphur	<1	mg/L
Conductivity	2551±627	µS/cm
Total alkalinity	19,3±6,6	meq/L
Partial alkalinity	8,8±4,4	meq/L
Intermediate alkalinity	12,9±3	meq/L
Volatile fatty acids	15±3,6	mg Ac/L
pH	6,67±0,96	-log[H^+]
Total suspended solids	199±99	mg/L
Volatile suspended solids	124±51	mg/L
% SSV	0,67±0,16	%
Settled solids	40±30	mg/L

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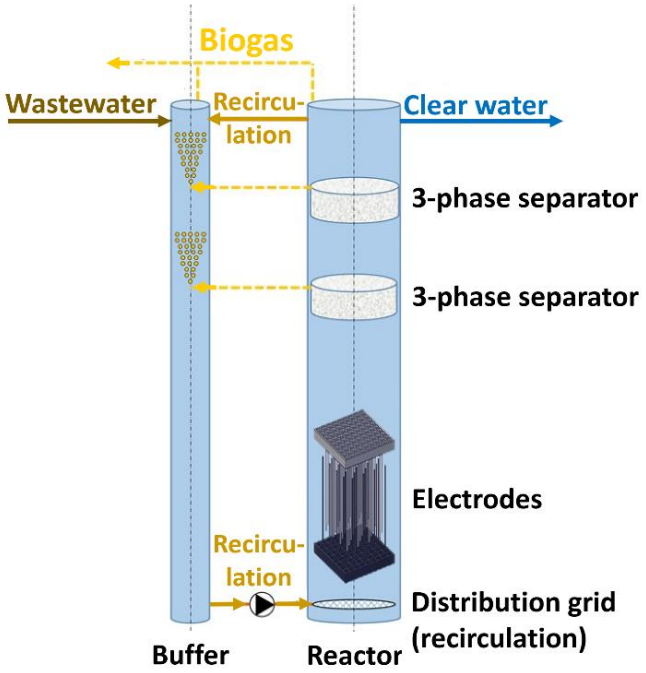
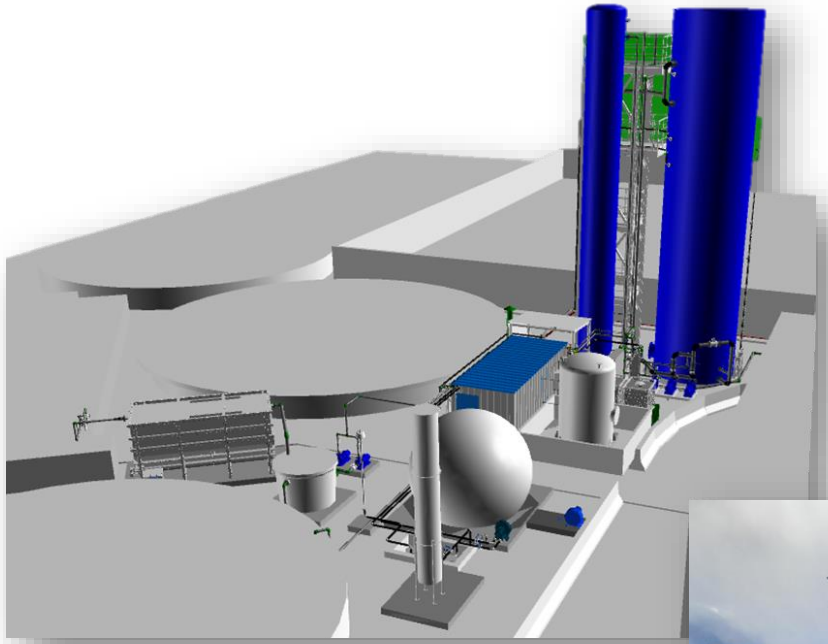
The next step: pre-industrial ELSAR®









- *Features*
  - *Flow 20 m^3/h; 30 Nm^3 biogas/h*
  - *OLR 2.000 kg COD/d*
  - *Mesophilic range (30 - 37ºC)*
- *Materials:*
  - *Tank: Glass-Fiber Reinforced Plastic*
  - *Anodic collector: carbon fiber*
  - *Cathodic collector: stainless steel*

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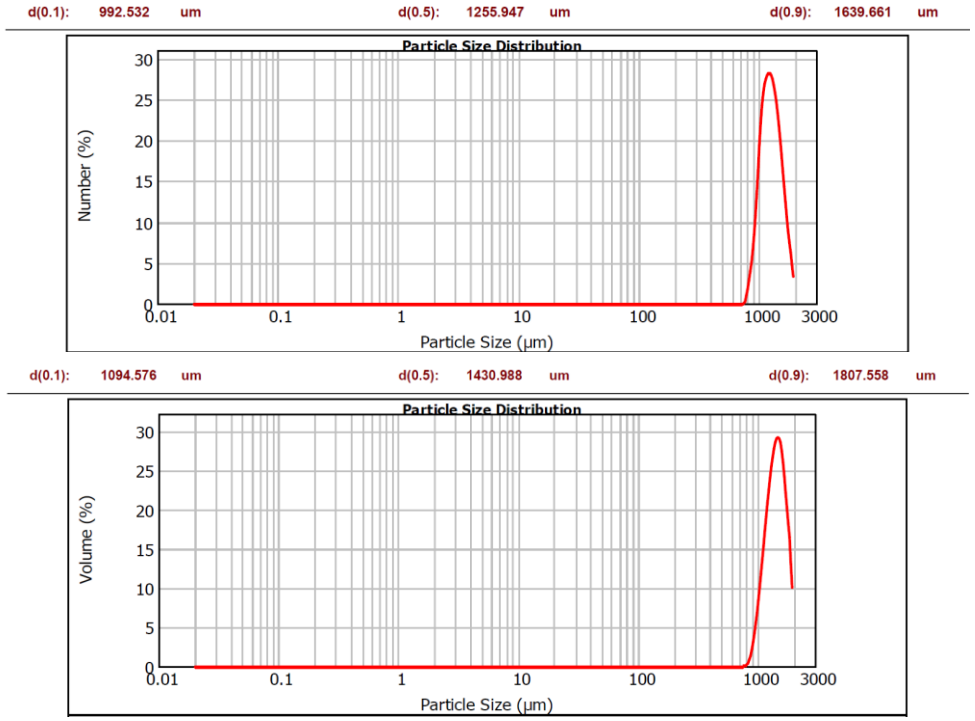
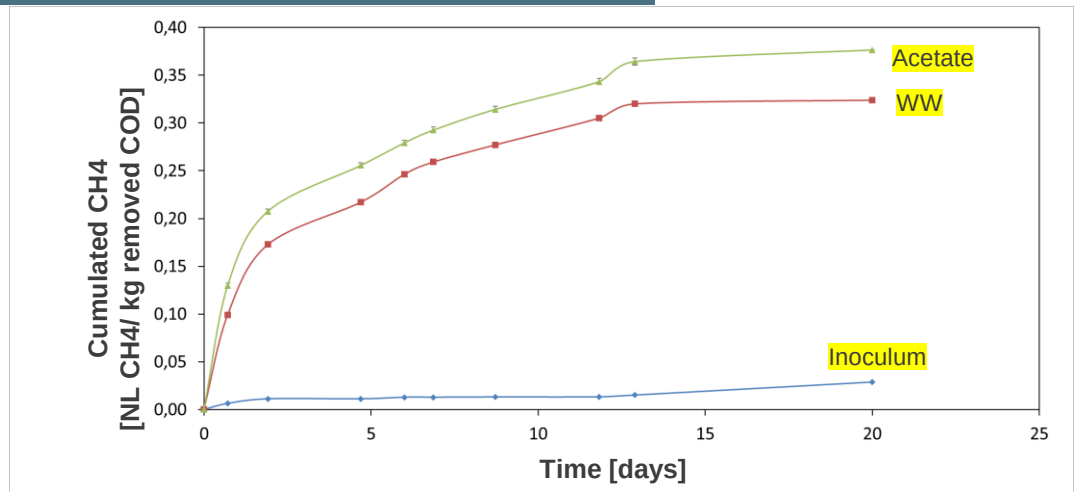
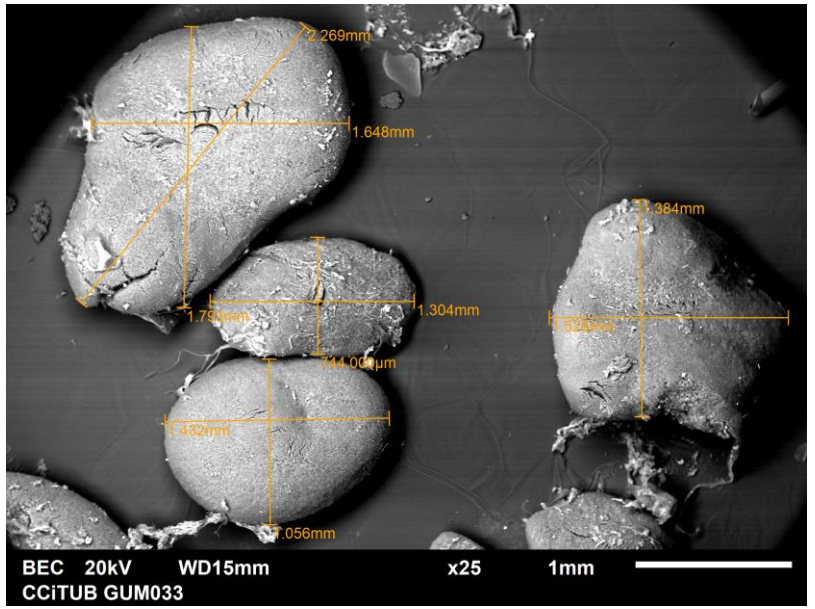
Results of ELSAR®

- Inoculum:
  - Granular sludge from HRAR treating brewery WW
  - 2000 kg VSS
  - Optimum SMA and settleability
  - Good shape and size (ca. 1mm)





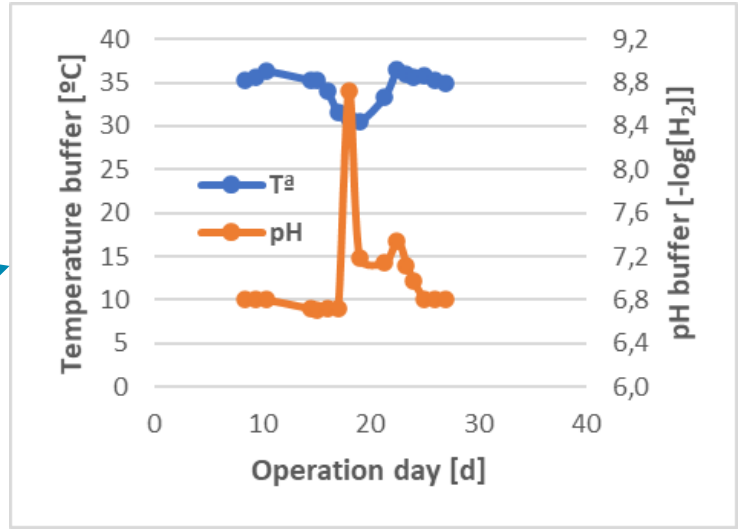


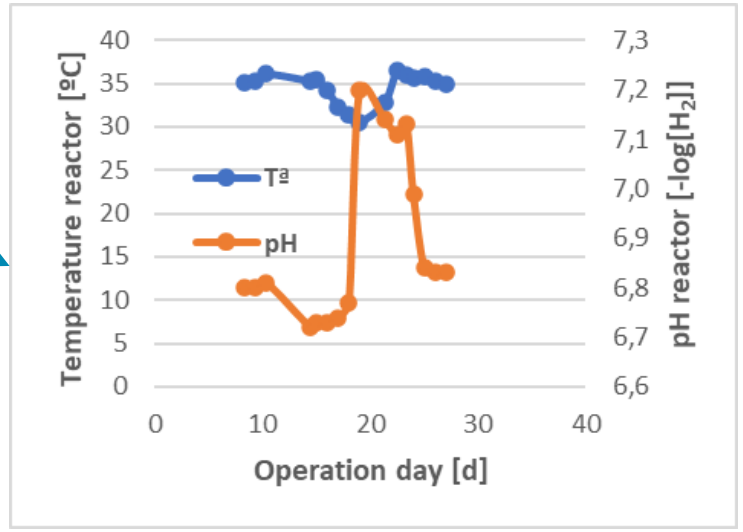
The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

Results of ELSAR®

So far, so good…

- Commissioning with no electrostimulation.
- Conservative OLR in startup 1-2 kg COD/m^3/d the 1st month. Upflow velocity 3,3 m/h.
- Extrem pH fluctuations forced to decrease OLR. But: high buffer capacity
- COD removal > 96%
- %CH4 in biogas > 70%
- Stable process. IA/TA = 0,2 (<0,3)
- Next step: increase OLR up to > 25 kg COD/ m^3/d





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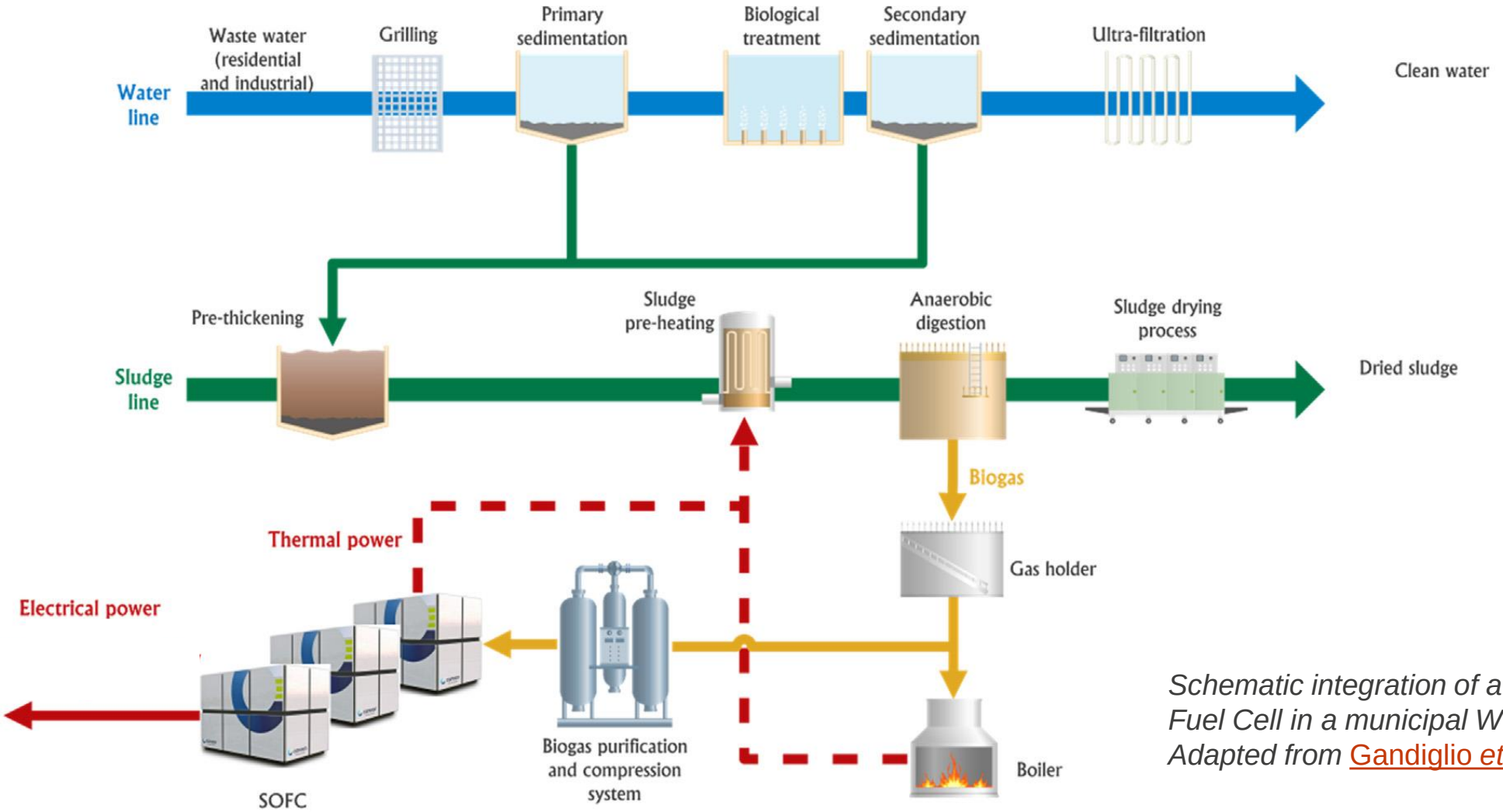
Solid Oxide Fuel Cells: an efficient way to obtain energy from biogas



Schematic integration of a Solid Oxide Fuel Cell in a municipal WWTP. Adapted from Gandiglio *et al.*, 2020

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Solid Oxide Fuel Cells: fundamentals & potential

- Steam reforming

$$CH_4 + H_2O \rightleftharpoons 3H_2 + CO, \quad \Delta H^0_{298} = 206.3\,{}^{kJ}/_{mol}$$

$$CO + H_2O \rightleftharpoons H_2 + CO_2\,, \quad \Delta H^0_{298} = -41.1\,{}^{kJ}/_{mol}$$

- Partial oxidation → requires oxygen
- Dry reforming → requires high operating temperature (800–1000 °C) & higher proportion of CO_2

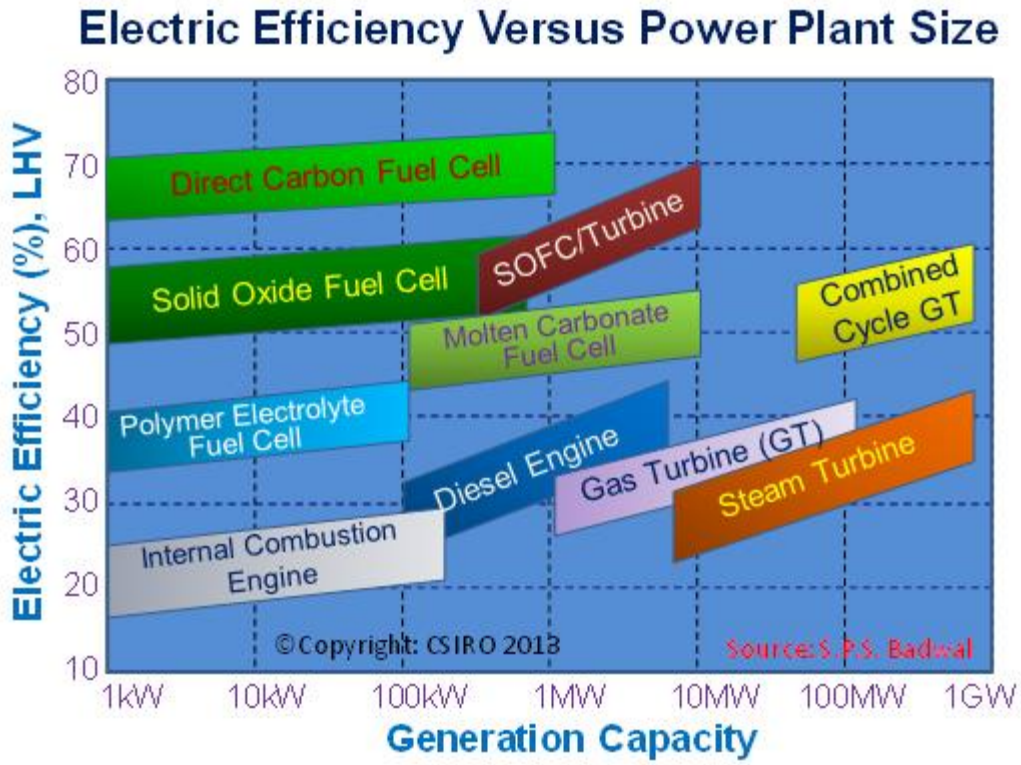

Figure. The electric efficiency versus power plant size for different power generation technologies. Source: https://csiropedia.csiro.au/ceramic-fuel-cells/

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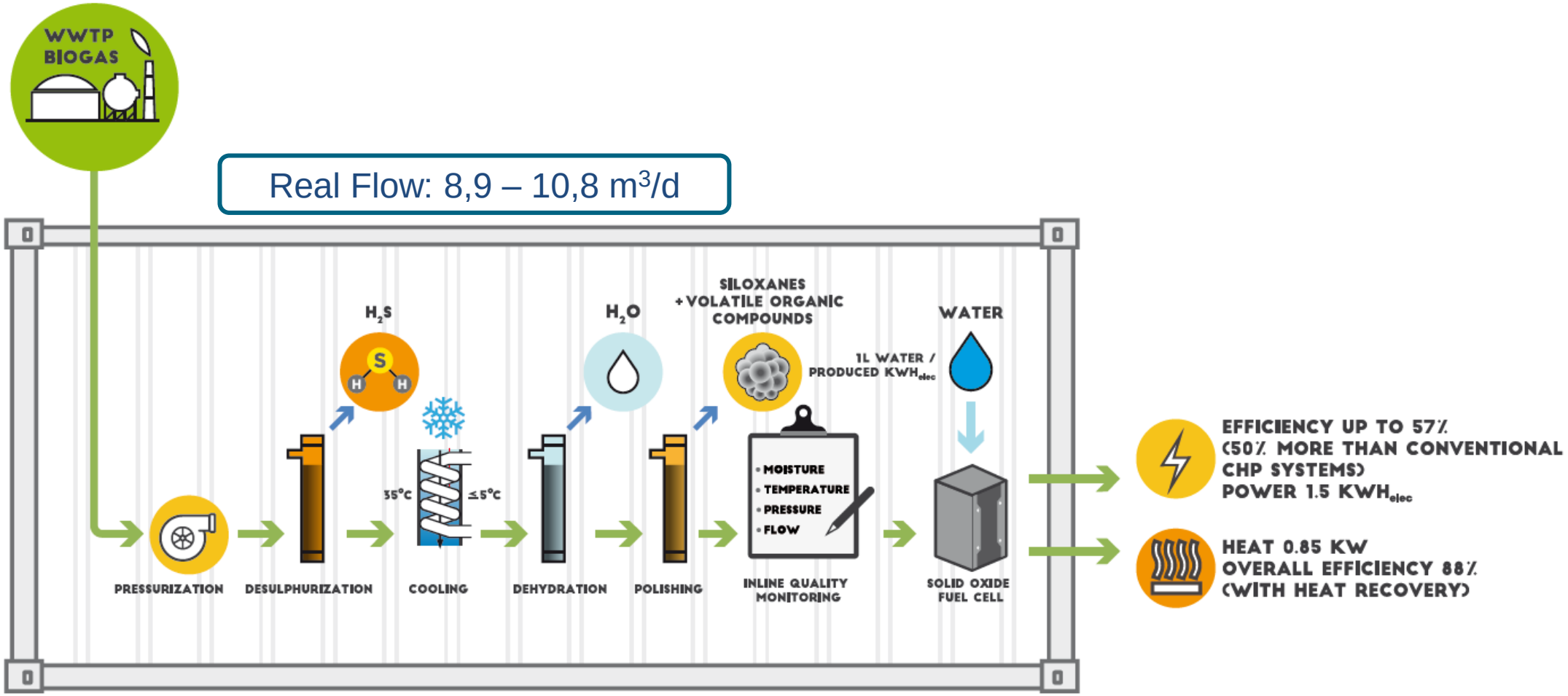
Solid Oxide Fuel Cells: experience in CS5



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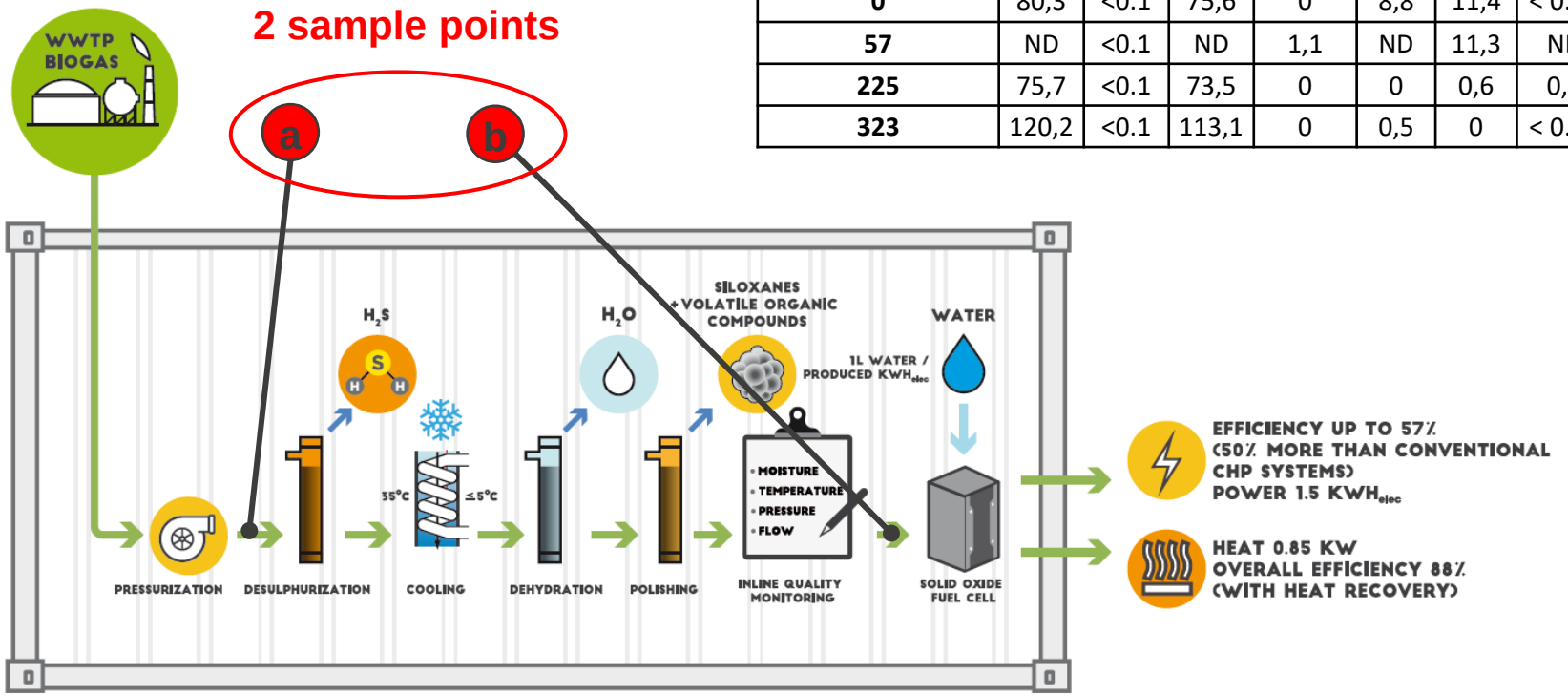
Solid Oxide Fuel Cells: experience in CS5

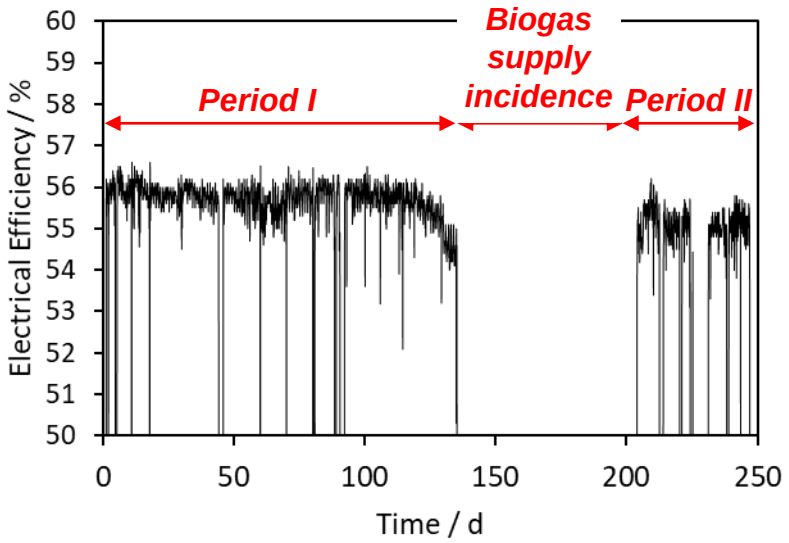
Day (since commissioning)	H_2S (mg/Nm³)		Total S (mg-S/Nm³)		NH_3 (mg/Nm³)		VOC (mg/Nm³)		Siloxanes (mg-Si/Nm³)	
	a	b	a	b	a	b	a	b	a	b
0	80,3	<0.1	75,6	0	8,8	11,4	< 0.02	1	< 0.05	< 0.05
57	ND	<0.1	ND	1,1	ND	11,3	ND	< 0.02	ND	0,66
225	75,7	<0.1	73,5	0	0	0,6	0,8	< 0.02	0,21	< 0.05
323	120,2	<0.1	113,1	0	0,5	0	< 0.02	< 0.02	< 0.05	< 0.05



→ **Pre-treatment of biogas before entering the SOFC has been validated.**

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

Solid Oxide Fuel Cells: experience in CS5



Parameter	Period I	Period II	Supplier specifications
Electrical efficiency	55,6 ± 0,5 %	55,1 ± 0,5 %	57,0 %
Power output	1298 ± 18 W	1226 ± 18 W	1300 W
Water consumption	18 ± 8 L/d	16 ± 7 L/d	Up to 32 L/d
Produced energy	4 MWh	2 MWh	-

- → First year of operation show a constant and expected output's behavior:
  - → Constant electrical efficiency between 55.1±0,5% and 55.6±0,5%, confirming ca. +50% vs. conventional CHP
  - → Produced power 1,3 kW (>6 MWh produced, so far)
  - → Biogas pre-treatment validated
  - → Learned lessons:
    - → No dehydration is needed. adjustments for optimization are still to be done: automatization, measuring, etc. Technical-economic market study for 60-250 kW FC

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ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

Biogas production and valorization in CS5 Lleida:

AnMBR vs. ELSAR® & SOFC, using biogas to produce electricity and heat

A. Giménez-Lorang

aqualia



14.05.2024

ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

CS5: Environmental impact of anaerobic treatment of brewery wastewater

ULTIMATE final workshop on energy recovery

Lea Conzelmann (KWB) 14.05.2024



San Miguel brewery



Wastewater

Volume: 1350 m^3/d

COD: 4000 mg/L

TP: 20 mg/L

TN: 15 mg/L

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Wastewater treatment

Today

Surface aerators



Future

Aerobic system with modern membrane diffuser

Benefits/ disadvantages regarding CO_2-footprint?

Anaerobic treatment with EGSB or ELSAR®

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

Measuring the environmental footprint

Life-cycle assessment (LCA) based on ISO 14040/44

- Environmental impacts with holistic view
- Systematic comparing of different scenarios
- Different environmental indicators, here: CO_2 footprint (CO_2-eq)
- Goal: Treatment of brewery wastewater
- Functional unit: Annual CO_2-eq per 500,000 m^3 WW

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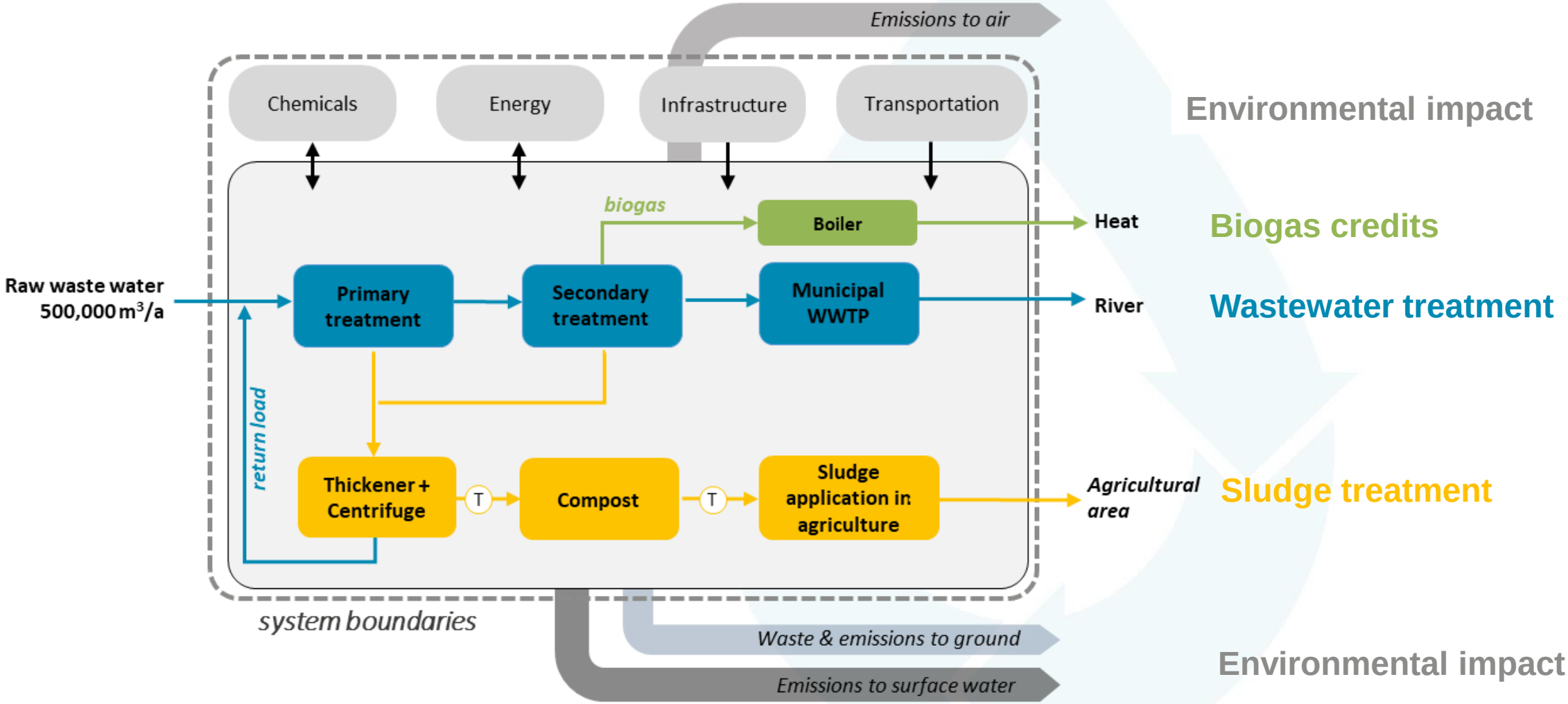
System boundaries



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Scenarios

Scenarios for secondary treatment

1. Activated sludge
2. Expanded Granular Sludge Bed (EGSB)
3. ElectroStimulated Anaerobic Reactor (ELSAR ®)

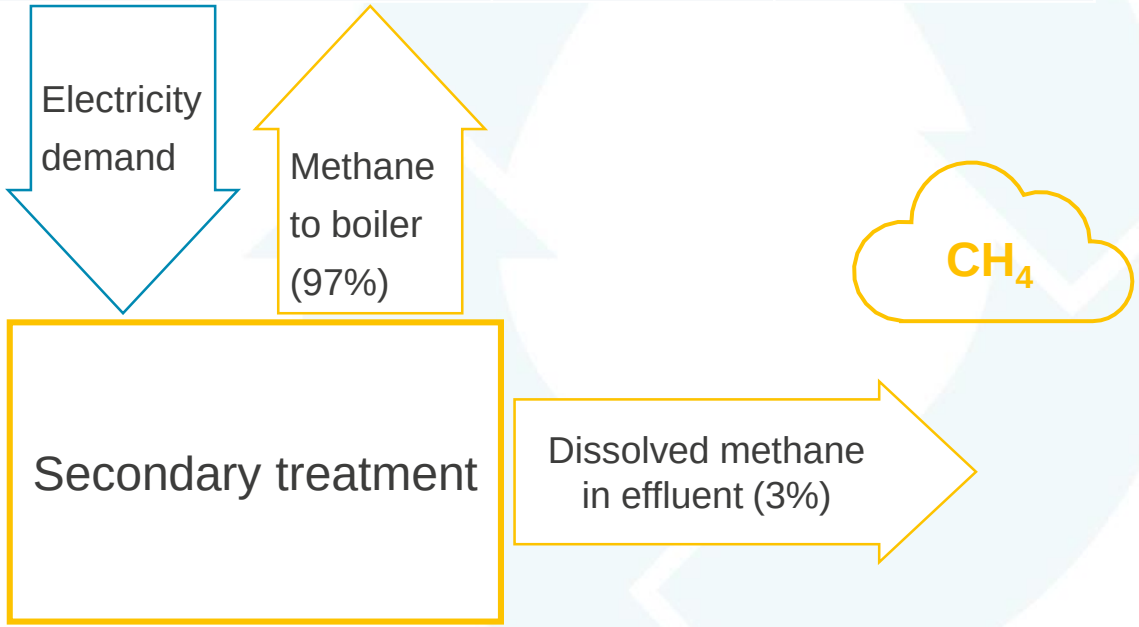
The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

Important data for LCA

Parameter	Unit	Activated sludge + clarifier	EGSB	ELSAR®
Electricity demand	Wh/ m^3 WW	1,530	220	220
Methane yield (75% of biogas)	L CH_4/ kg $COD_{removed}$	-	350	385
Dissolved methane in effluent	mg/L	-	18 (at 35°C)	18 (at 35°C)
Methane to boiler | dissolved methane	L CH_4/ m^3 WW	-	887 | 27	966 | 27
TS | COD | TN | TP removal to sludge	%	97 | 97 | 40 | 10	63 | 90 | 8 | 10	63 | 92 | 8 | 10

→ **Higher methane yield**

→ **Higher COD, TN and TP load to WWTP**



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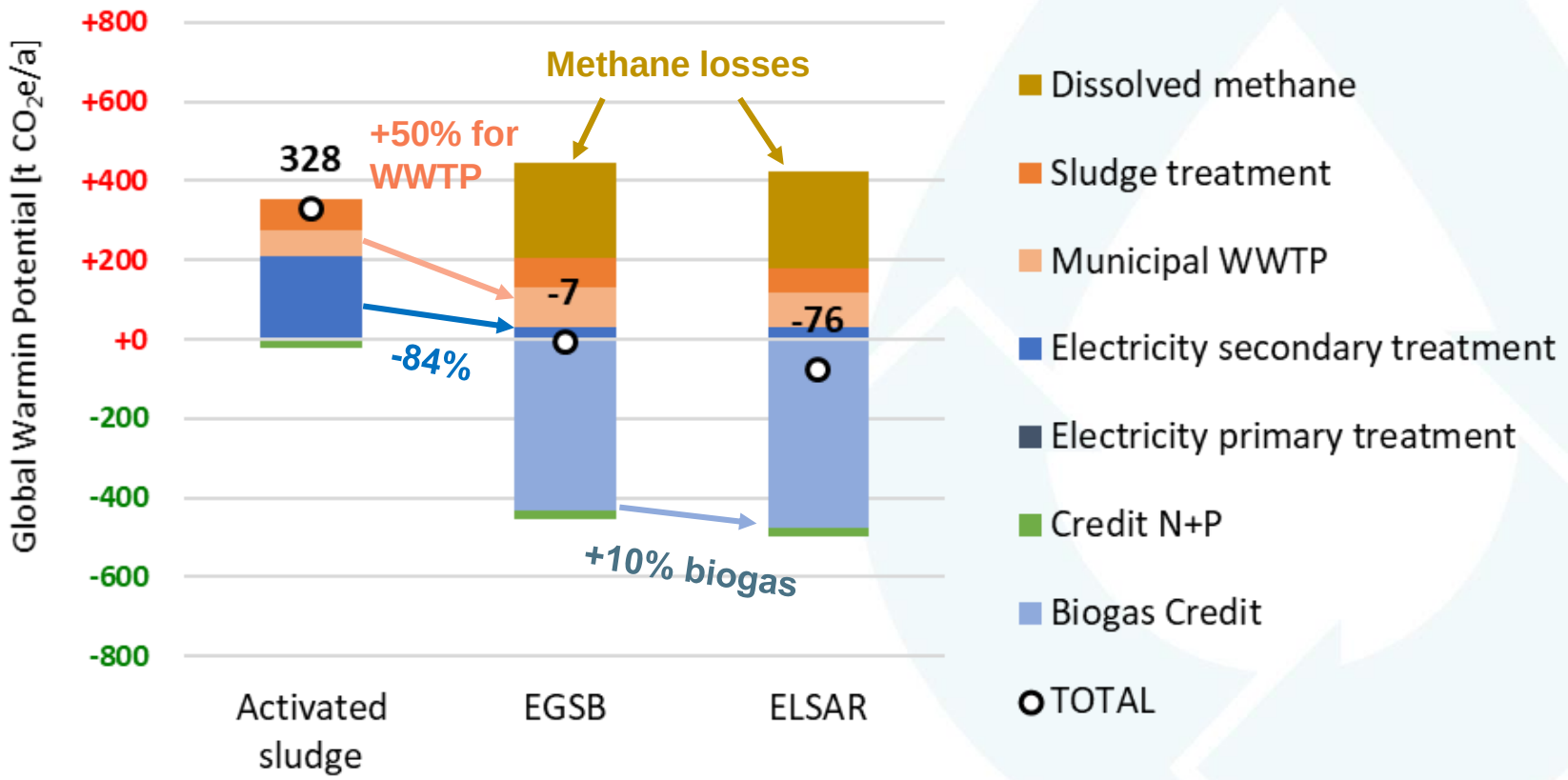
Results „CO_2 footprint“



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Conclusions

- Anaerobic treatment has a better CO_2 footprint than aerobic treatment
- Dissolved methane: main CO_2e impact of anaerobic treatment
- ELSAR® is better than EGSB due to higher methane yield (+10%)
- Less nutrient removal in anaerobic treatment → higher nutrient load to municipal WWTP

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Back-up

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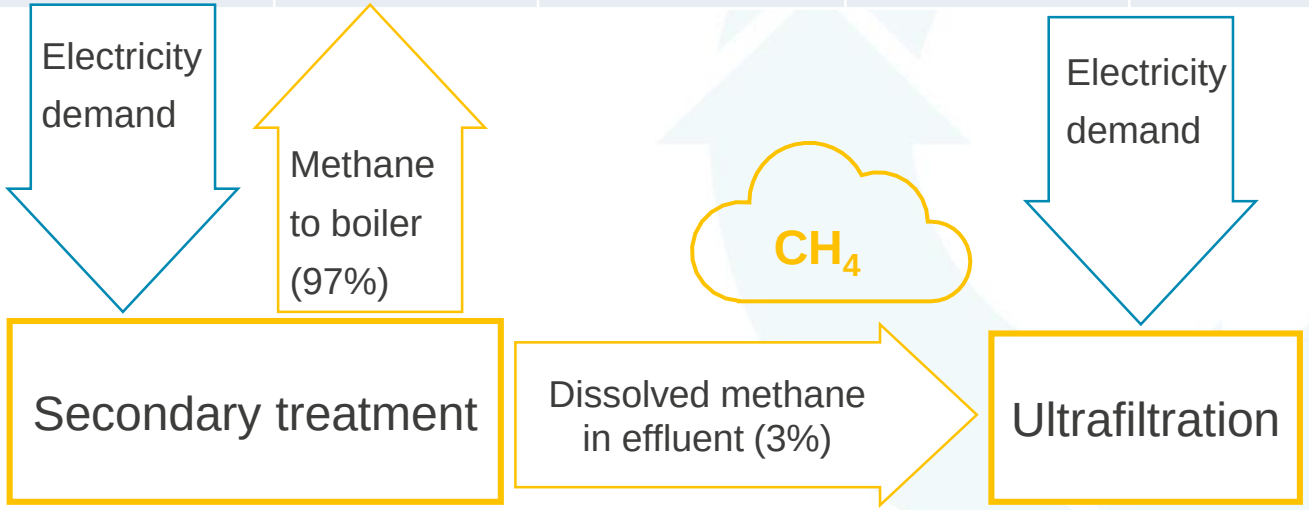
LCA B: Important data for LCA

Parameter	Unit	Activated sludge + UF	AnMBR	ELSAR + UF
Electricity secondary treatment	Wh/m³ WW	1,530	2,600	220
Electricity UF (yield 85%)	Wh/m³ WW	180	-	180
Total electricity	**Wh/m³ WW**	**1,710**	**2,600**	**400**
Methane yield (75% of biogas)	L CH_4/ $COD_{removed}$	-	350	385
Dissolved methane in effluent	mg/L	-	18 (at 35°C)	18 (at 35°C)
Methane to boiler | dissolved in effluent	L CH_4/ m³ WW	-	871 | 27	966 | 27



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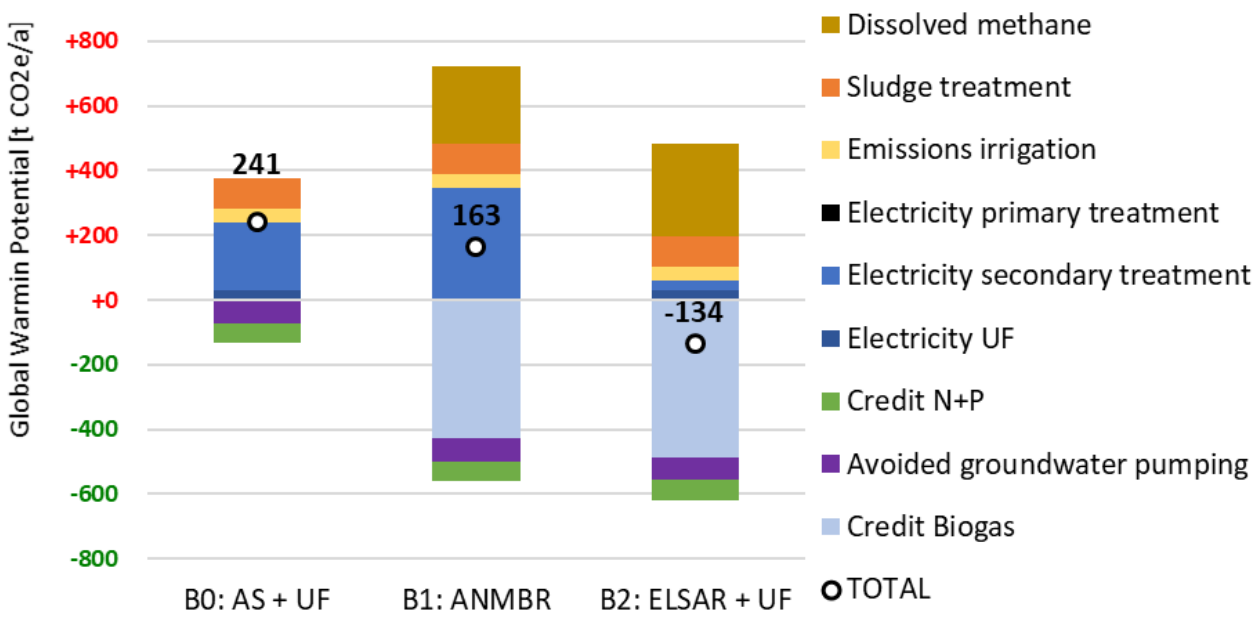
Preliminary results – CO_2 Footprint



Emissions fertigation (N2O)

Credit N+P includes nutrients in irrigation water and sludge

- AnMBR increases electricity demand by 70%, however overal GWP can be reduced by 40%
- Small credit for avoided groundwater pumping (70 t CO_2e/a)

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

LCA A: Selected data

Parameter	Unit	Activated sludge	EGSB	ELSAR
Primary treatment	**m^3/a**	**500,000 + 31,000 return load**	**500,000 +21,000 return load**	**500,000 + 21,000 return load**
Electricity	Wh/m^3 WW	5	5	5
Sludge volume	%	4	4	4
Secondary treatment	**m^3/a**	**565,000**	**501,000**	**501,000**
Electricity	Wh/ kg $COD_{removed}$	420* + circulation	71,4	71,4
Total electricity	Wh/m^3 WW	1,530	220	220
TS | COD | TN | TP removal to sludge	%	97 | 97 | 40 | 40	63 | 90 | 8 | 10	63 | 92 | 8 | 10
Methane yield (75% of biogas)	L CH_4/ kg $COD_{removed}$	-	350	385
Dissolved methane in effluent	mg/L	-	18 (at 35°C)	18 (at 35°C)
Methane to boiler | dissolved in effluent	L CH_4/ m^3 WW	-	536 | 18	590 | 18
Communal WWTP	**m^3/a**	**496,000**	**500,000**	**500,000**
Emissions NH_3 | N_2O	% of influent N	0.6 | 0.8	0.6 | 0.8	0.6 | 0.8
Electricity[#]	Wh/m^3 WW	127	260	240
Removed COD | Nitrified N | removed P	%	90 | 99 | 96	90 | 99 | 96	90 | 99 | 96
Iron chloride for P elimination	Mol Fe/ mol P	0,27	0,27	0,27

*** Electricity for aeration** (0.6 kg O2 per kg COD removed and 0.7 kWh/kg O2 generated)

[#]**Sewer:** Energy consumption recicurlation pumping (denitrification): 1 kWh/kg N, **0**.6 kg O2 per kg COD removed and 0.7 kWh/kg O2 generated

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

LCA A: Inventory

Parameter	Unit	Activated sludge	EGSB	ELSAR
Sludge treatment	**m^3/a**	**PS: 21.000 + SS: 13,000**	**PS: 21.000 + SS: 2,500**	**PS: 21.000 + SS: 2,500**
TS content PS | SS	%	PS: 1,5 SS: 1,5	PS: 1,5 SS: 5	PS: 1,5 SS: 5
Gravity thickening | dewatering	Wh/m^3 sludge	50 | 66	50 | 66	50 | 66
Polymere for dewatering	g/kg TS	4	4	4
TS after thickening | dewatering	%	5 | 20	5 | 20	5 | 20
Transportation sludge to composting	km	15	15	15
Composting	**t/a**	**2,900**	**1,900**	**1,900**
Emissions NH_3 | N_2O	% of TN load	24 | 0.04	24 | 0.04	24 | 0.04
Emissions CH_4 | VOC	mg/kg TS	272 | 3,100		
Diesel for turning of compost	L/t	0.44	0.44	0.44
Electricity for sieving	kWh/t	22	22	22
Dry matter after composting	%	54	54	54
Mass increase after bulking material	%	12	12	12
Transportation compost to agriculture	km	15	15	15

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LCA A: Inventory

Parameter	Unit	Activated sludge	EGSB	ELSAR
Agricultural application (54% DM)	**t/a**	**1,204**	**790**	**790**
Efficiency of mineral N | P fertilizer substitution	%	25 | 60	25 | 60	25 | 60
Emissions NH_3 | N_2O | NOx	g/ kg N	130 | 16 | 40	130 | 16 | 40	130 | 16 | 40
Mass compost	t / a			
Mass TN | TP	t / a			

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

LCA B: Inventory

Parameter	Unit	Activated sludge	AnMBR	ELSAR+ UF
Primary treatment	**m^3/a inflow**	**500,000 +120,000 return load**	**520,000 +20,000 return load**	**500,000 +115,000 return load**
Electricity	Wh/m^3 WW	5	5	5
Secondary treatment	**m^3/a inflow**	**600,000**	**500,000**	**590,000**
Electricity	Wh/ kg $COD_{removed}$	420* + circulation	not defined	71,4
Total electricity	Wh/m^3 WW	1,530	220	220
TS | COD | TN | TP removal to sludge	%	97 | 97 | 40 | 10	99 | 90 | 44 | 52	63 | 92 | 8 | 10
Methane yield (75% of biogas)	L CH_4/ $COD_{removed}$	-	350	385
Dissolved methane in effluent	mg/L	-	18 (at 35°C)	18 (at 35°C)
Methane to boiler | dissolved in effluent	L CH_4/ m^3 WW			
Ultrafiltration	**m^3/a inflow**	**586,000**	**(497,000)**	**586,000**
Electricity	Wh/m^3 WW	180	-	180
Yield	%	85	-	85
TS | COD | TN | TP removal to return load	%	99 | 40 | 12 | 9	-	99 | 78 | 55 | 9

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LCA B: Inventory

Parameter	Unit	Activated sludge	AnMBR	ELSAR
Sludge treatment	**m^3/a**	**PS: 21.000 + SS: 13,000**	**PS: 21.000 + SS: 4,200**	**PS: 26.000 + SS: 2,900**
TS content PS | SS	%	PS: 1,5 SS: 1,5	PS: 1,5 SS: 5	PS: 1,5 SS: 5
Gravity thickening | dewatering	Wh/m^3 sludge	50 | 66	50 | 66	50 | 66
Polymere for dewatering	g/kg TS	4	4	4
TS after thickening | dewatering	%	5 | 20	5 | 20	5 | 20
Transportation sludge to composting	km	15	15	15
Composting	**t/a**	**3,100**	**3,100**	**3,100**
Emissions NH_3 | N_2O	% of TN load	24 | 0.04	24 | 0.04	24 | 0.04
Emissions CH_4 | VOC	mg/kg TS	272 | 3,100		
Diesel for turning of compost	L/t	0.44	0.44	0.44
Electricity for sieving	kWh/t	22	22	22
Dry matter after composting	%	54	54	54
Mass increase after bulking material	%	12	12	12
Transportation compost to agriculture	km	15	15	15

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LCA B: Inventory

Parameter	Unit	Activated sludge	AnMBR	ELSAR
Agricultural application (54% DM)	**t/a**	**1,320**	**1,220**	**1,250**
Efficiency of mineral N | P fertilizer substitution	%	25 | 60	25 | 60	25 | 60
Emissions NH_3 | N_2O | NOx	g/ kg N	130 | 16 | 40	130 | 16 | 40	130 | 16 | 40
Mass compost	t / a	1,300	1,200	1,200
Mass TN | TP	t / a	14 | 10	14 | 10	14 | 10
Avoided groundwater pumping	**m^3/a**	**491,000**	**497,000**	**497,000**
Electricity	kWh/m^3	0,36	0,36	0,36

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Data quality

Process	Parameters	Data source	Responsible Partner	Data quality
primary treatment, sewer, sludge treatment, activated sludge	Electricity, chemicals, volume & loads	Average data of full-scale WWTPs, DWA A 216	KWB	medium-high
EGSB	Electricity, water/ biogas quality and quantity		aqualia/ KWB	medium
AnMBR	Electricity, water/ biogas quality and quantity	Berghof 2022, estimations	aqualia/ KWB	medium-high
ELSAR	Electricity, water/ biogas quality and quantity	Pilot trials	aqualia	medium-high
Composting	Emissions and volume	Remy 2020	KWB	high
Fertiliser production and application	Emissions to air, soil and water	Literature	KWB	medium
	Background data	Ecoinvent v 3.9.	KWB	medium-high

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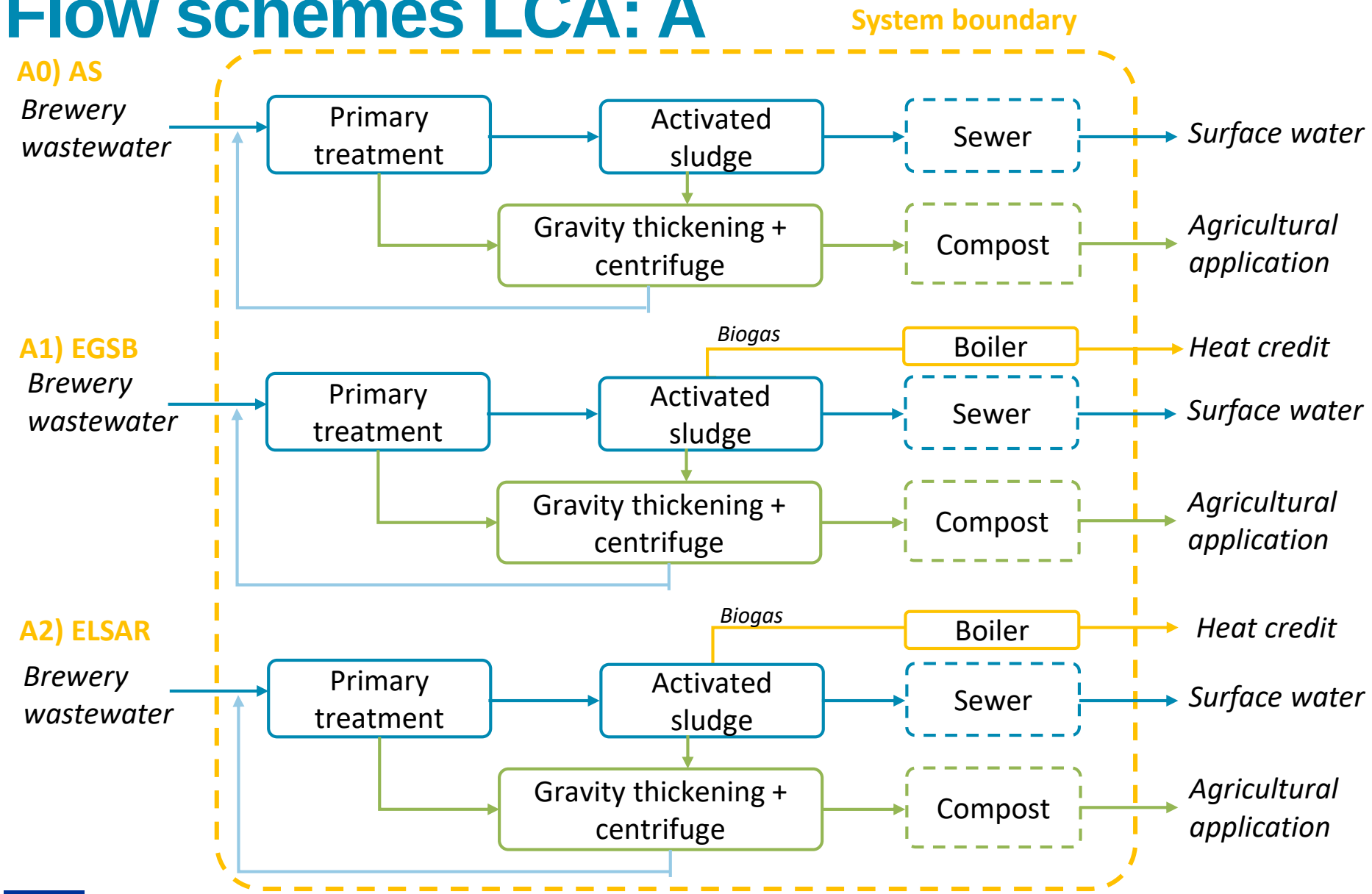
Flow schemes LCA: A



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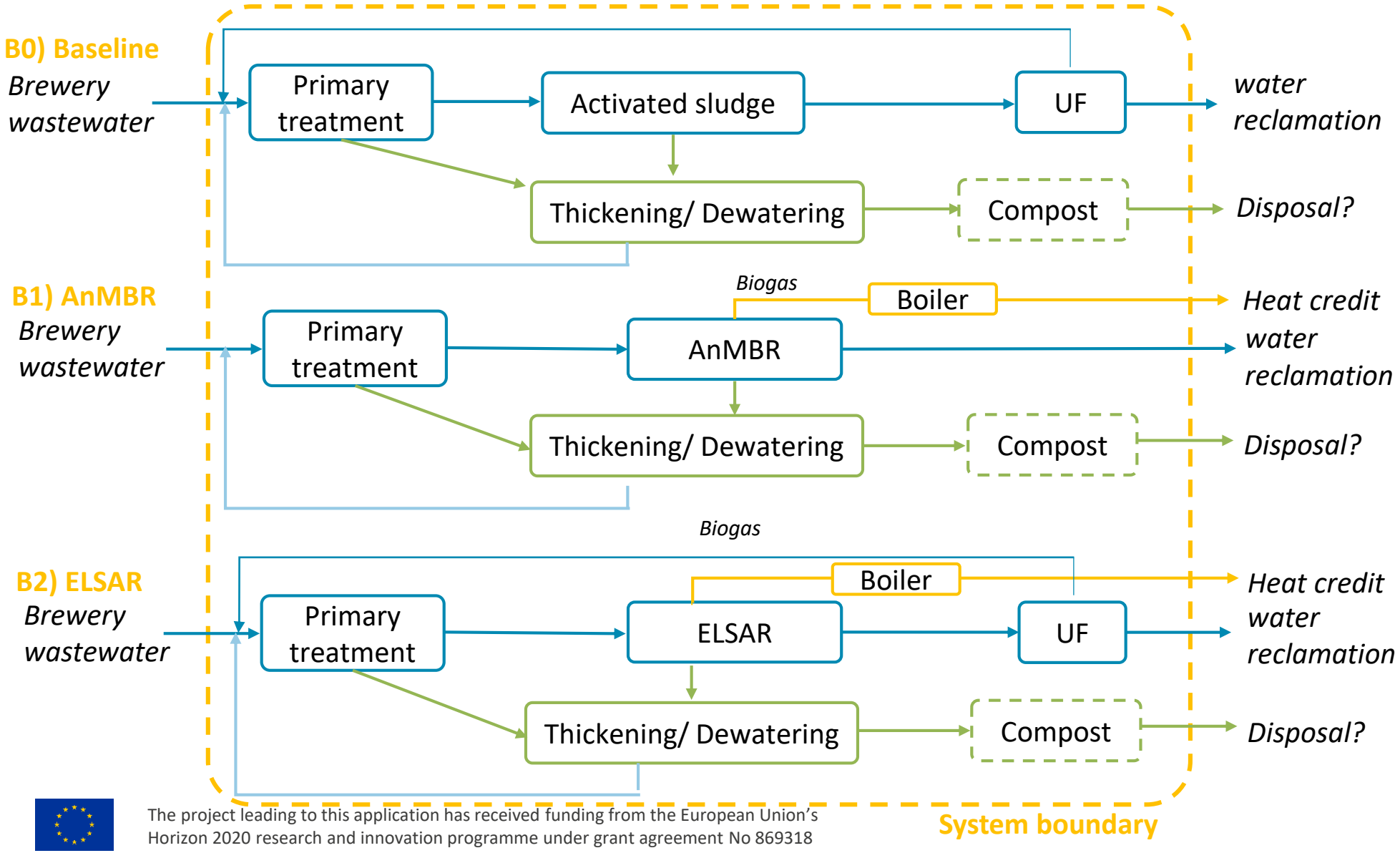
Flow schemes LCA B



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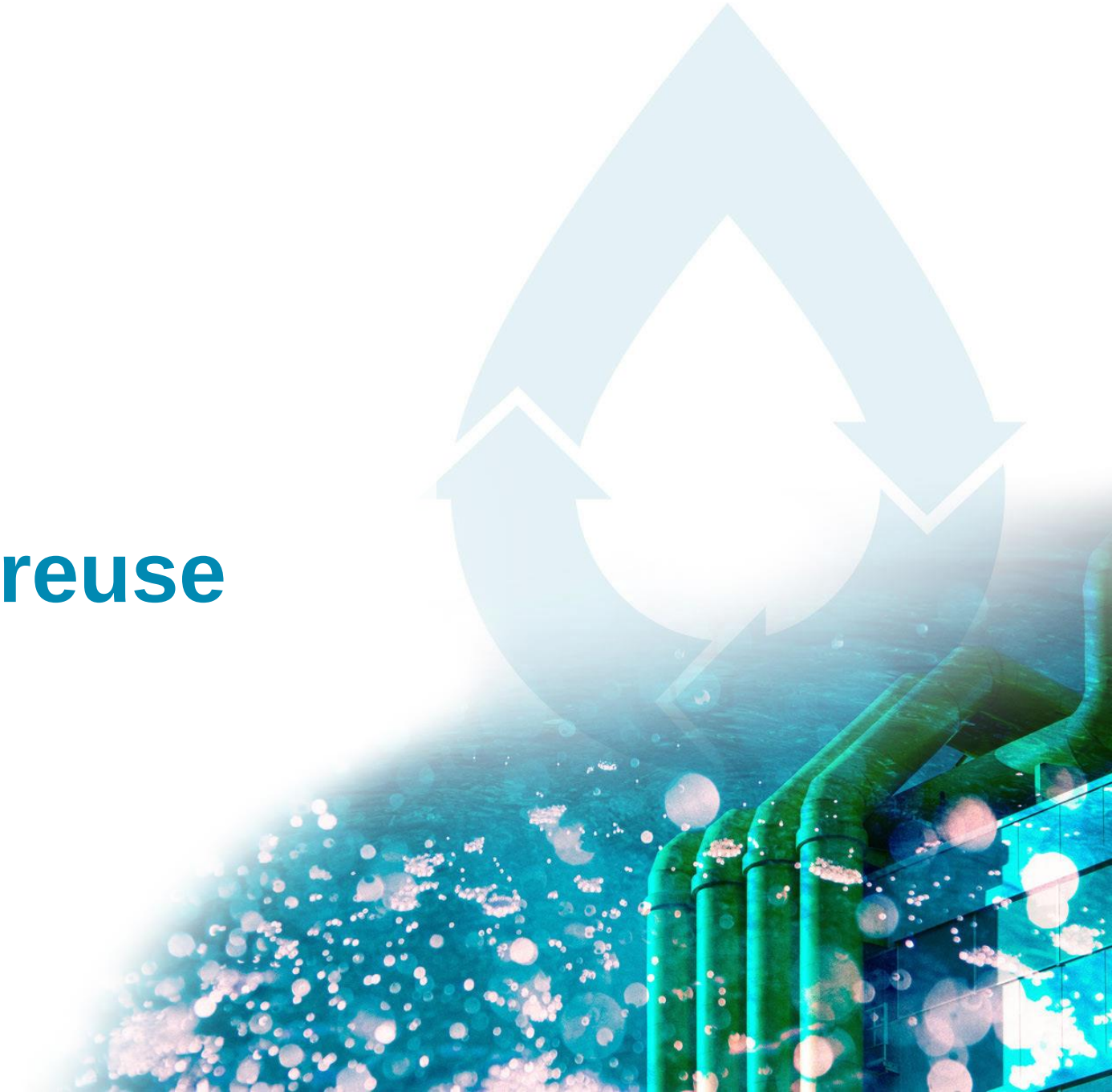
ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

Online seminar
Material recovery & reuse

F. Fatone, J. González Camejo

May, 2nd 2023.



Agenda

ULTIMATE
WATER SMART INDUSTRIAL SYMBIOSIS

CS meeting: Material Recovery on June 4th, 2024

Teams link:
Fai clic qui per partecipare alla riunione

15:30h	**Welcoming** *Circular water vision within the context of new EU directives: presentation of the Green Week partner event* *Prof. Francesco Fatone (UNIVPM)*
15:40h	**CS3 Rosignano:** Potential use of by-products from local chemical industry for circular wastewater treatment *Massimiliano Sgroi (UNIVPM)*
15:55h	**CS4**: Recovery of antioxidants from fruit processing wastewater *Myrto Touloupi (GTG TECH)*
16:10h	**CS8**: *Recovery of sulphur and metals at Chemical Platform Roussillon* *Anne Reguer (SUEZ)*
16:25h	**Break**
16:30h	**CS7**: *Recovery of nutrients from distillery wastewater after AnMBR treatment* *Marc Pidou (Univ. Crainfield)*
16:45h	**CS7 Tain:** Quantitative chemical risk assessment for the recovery of fertilizers *Malte Zamzou and Johannes Koslowski (KWB)*
17:00h	Relevant scale-up of materials recovery in the CIRCULAR BIOCARBON flagship project *Placido Aurensanz Tena (URBASER)*
17:30	**Discussion: nutrient recovery and reuse** • Status of end-of-waste criteria • What are the main challenges/barriers to replicate your technology (technological, economical, legal, environmental, social) and why? • What might help to tackle these challenges? • From your perspective, how can EU policy support you to make your business case a success?
16:45h	**End**

Grant Agreement No 869318

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

CS3 Rosignano – Potential use of by-products from local chemical industry for circular wastewater treatment



Massimiliano Sgroi (UNIVPM)

04 June 2024

ULTIMATE Project

H2020 ULTIMATE:
Industry water-utility symbiosis for a smarter water society

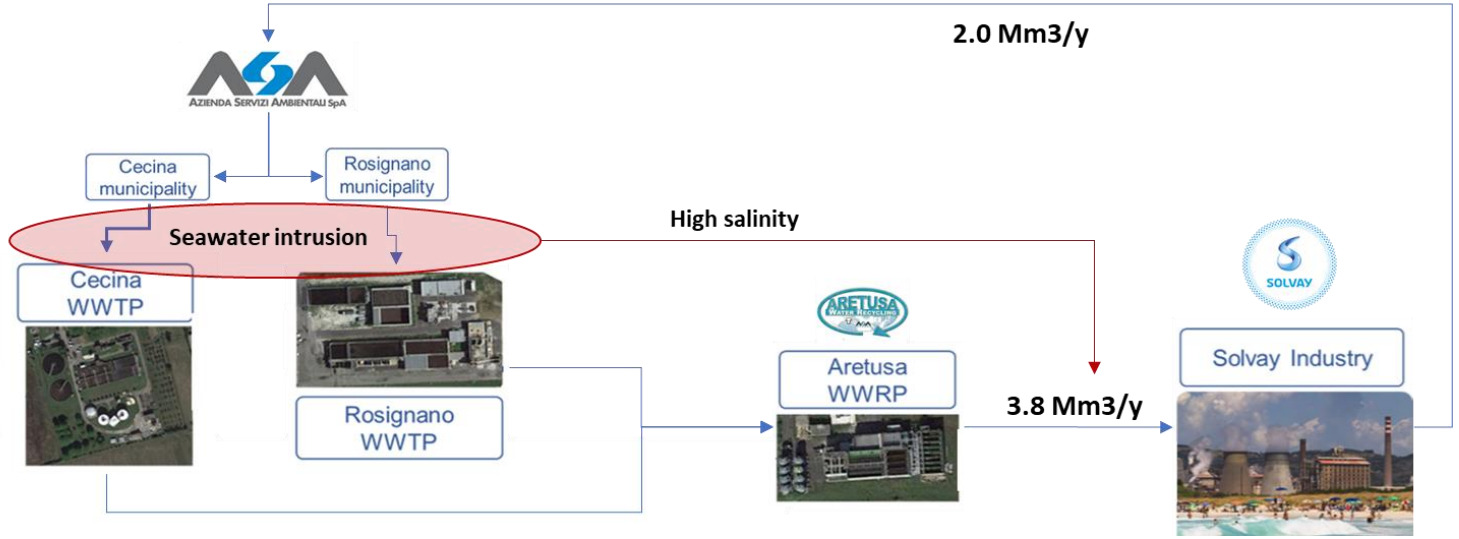
ULTIMATE
WATER SMART INDUSTRIAL SYMBIOSIS

Promote, establish and extend **water smart industrial symbiosis between service providers from the water sector and the industrial sector** by implementing circular economy **solutions for water, material and energy recovery**.

- 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



Rosignano case study



ARETUSA Water Recycling · WEST Systems · AZIENDA SERVIZI AMBIENTALI SpA · CPTM Consorzio Polo Tecnologico Magona · Termomeccanica Ecologia · Termomeccanica Group · SOLVAY

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

WWEE LAB Water and Waste Environmental Engineering · ARETUSA Water Recycling · CPTM · WEST Systems

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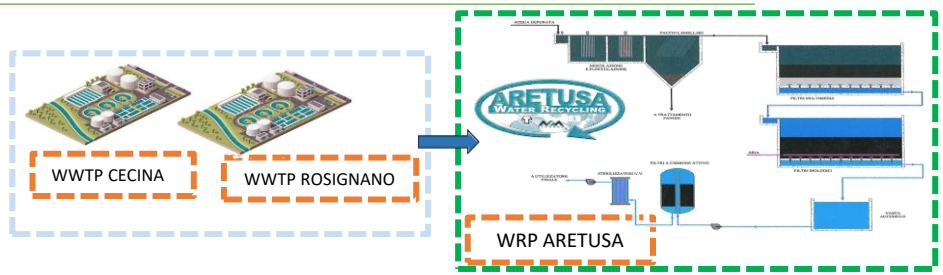
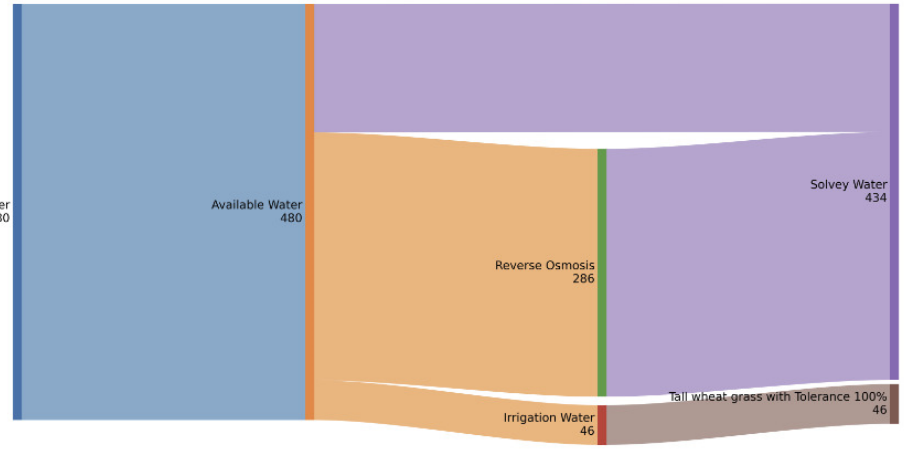
FRAMEWORK OF THE REGIONAL SYMBIOSIS SISTEM



Water



Water

By products for water treatments

Industrial sites in the area



Freshwater



Match-Making TOOL for water reuse in the area (agricolture)

On-line sensors for water quality monitoring in real-time



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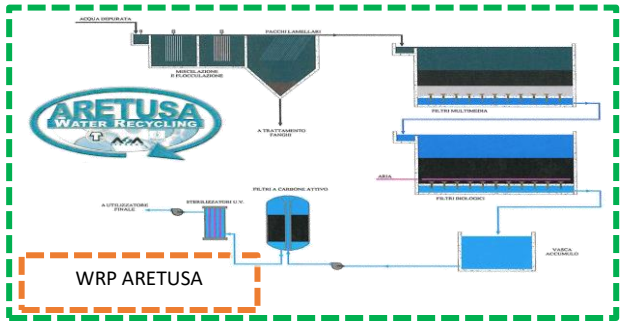
ULTIMATE Project



Water

Industrial sites in the area



Limits for industrial reuse – cooling water

N°	Description	Unit of measure	Specific	Maximum value
1	Cl-	ppm	≤ 500	500
2	NH4	ppm	≤ 8	8
3	Sospended solids	ppm	≤ 2	2
4	**Conducibility**	**microS.**	**≤1.030**	**1030**
5	Alkalinity	ppm CaCO3	≤ 340	340
6	**Ca**	**ppm Ca**	**≤ 160**	**160**
7	**Mg**	**ppm**	**≤ 45**	**45**
8	SO_4	ppm	≤ 140	140
9	Fe	ppm	≤ 0,1	0.1
10	Si	ppm SiO2	≤ 30	30
11	Mn	ppm	≤0,4	0.4
12	PO_4	ppm	≤ 3	3
13	Al	ppm	≤ 0,1	0.1
14	As	ppm	≤ 0,2	0.2
15	Ba	ppm	≤ 2,5	2.5
16	Fluorides	ppm F	≤ 0,1	0.1
17	Vegetable and animal oils	ppm	≤ 1	1
18	**COD**	**ppm O2**	**≤ 10**	**10**
19	Surfactants	ppm	≤ 0,5	0.5
20	BOD	ppm	≤10	10
21	**Esch. Coli**	**CFU/100ml**	**≤ 250**	**250**
22	Coli Tot.	CFU/100ml	≤ 250	250
23	Strep. Coli	CFU/100ml	≤ 20	20
24	Filamentous bacteria		absent	0

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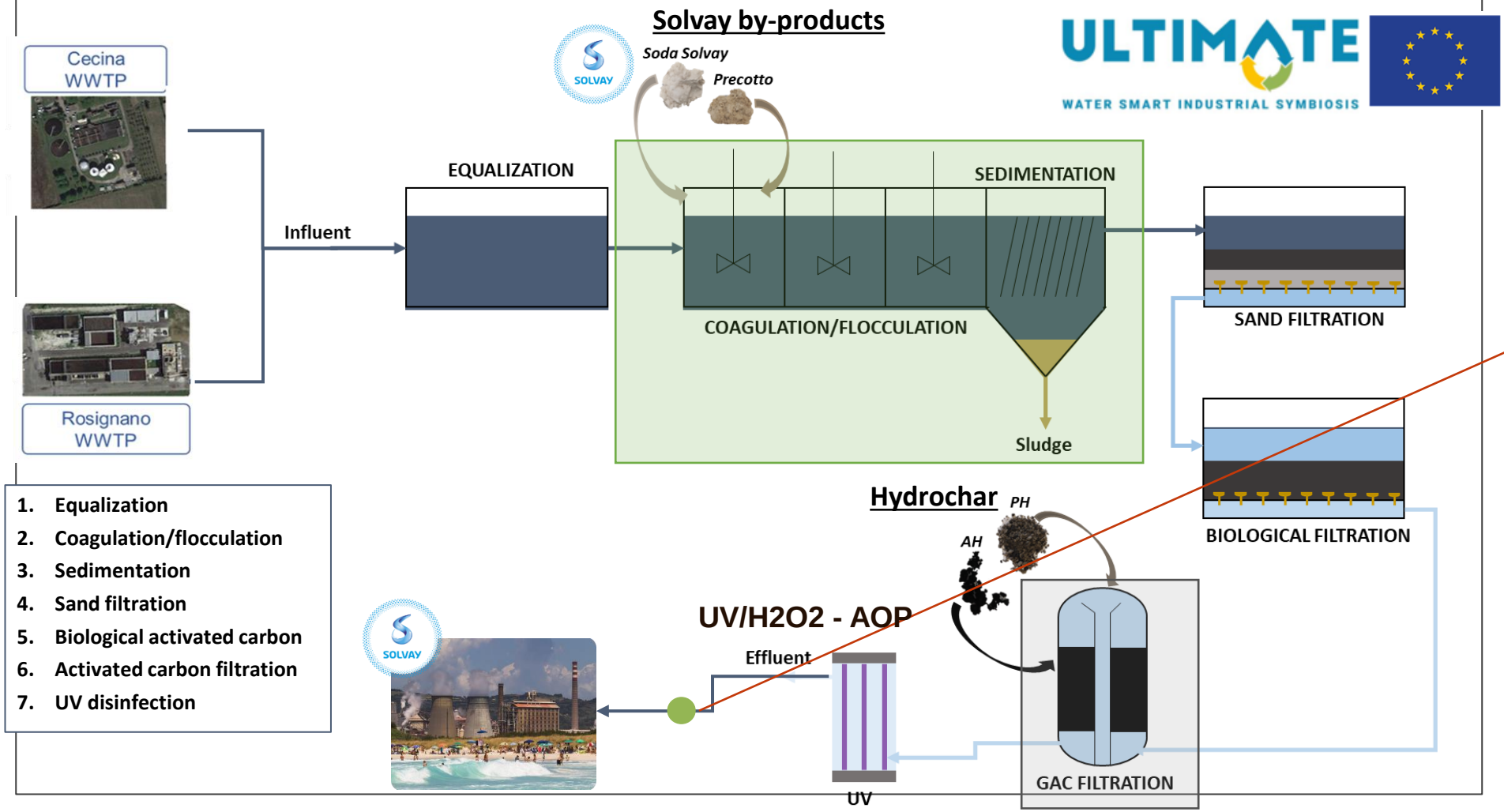
ULTIMATE Project

WATER SCARCITY and RESOURCE DEPLETION – WATER REUSE – INDUSTRIAL SYMBIOSIS

BY-PRODUCTS reuse in ADVANCED TREATMENT PROCESSES for water reuse in industries



Digital tools for water quality monitoring and support system

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 Project

WATER SCARCITY and RESOURCE DEPLETION – WATER REUSE – INDUSTRIAL SYMBIOSIS

TESTED BY-PRODUCTS

GRANULATED LIMESTONE ROCKS ONLY PARTIALLY CALCINATED (PRECOTTO)



"PRECOTTO": GRANULATED LIMESTONE ROCKS ONLY PARTIALLY CALCINATED AND SLACKED, WITH A DECLARED CONTENT OF $Ca(OH)_2$ OF ABOUT 9%.

SOLVAY CHIMICA ITALIA SPA BY-PRODUCTS TESTED

SOLVAY

Na_2CO_3 "Soda Solvay® Light" OUT OF SPECIFICATION



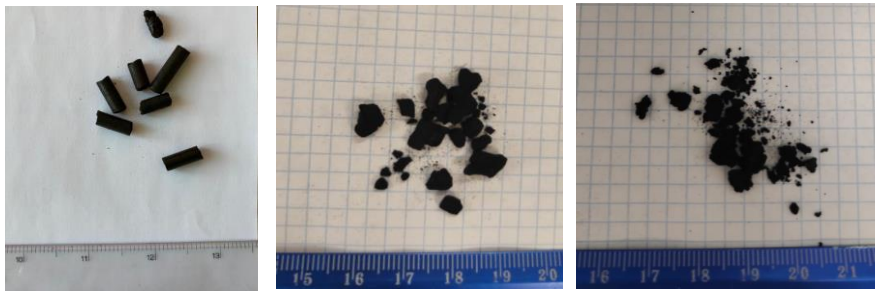
Na_2CO_3 "Soda Solvay® Light" PRODUCT THAT RESULTED TO BE OUT OF SPECIFICATION

SOLVAY CHIMICA ITALIA SPA BY-PRODUCTS TESTED

SOLVAY

HYDRO-CHAR FROM MUNICIPAL SEWAGE SLUDGE

HYDROCHAR ACTIVATED WITH DIFFERENT PROCESSES



BY-PRODUCT	PRODUCTION PROCESS	Description	POSSIBLE USES
Hydrochar	Hydrotermal Carbonization (HTC) of sewage sludge or biomass	Carbon-rich porous material	- Soil amendment - Energy production - Adsorbent
Soda Solvay out of specification	Soda production line (washing process)	Soda Solvay with "foreign bodies" (e.g. screws, pieces of wood), "pollutants" (e.g. oil stains), or dust.	- Chemical industrial process - Coagulant and Softening agent
Precotto	Soda production line	Partially cooked limestone	- Construction sector - Cement production - Concrete, brick - Ceramic production - Coagulant and softening agent

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 Project

WATER SCARCITY and RESOURCE DEPLETION – WATER REUSE – INDUSTRIAL SYMBIOSIS

BY-PRODUCTS reuse in ADVANCED TREATMENT PROCESSES for water reuse in industries

By-products for softening process

Materials characterization

Soda Solvay
Out of specification Na2CO3



Collected during the maintenance and cleaning operations of the Solvay plants which do not meet the required standard

Precotto
Granulated limestone rocks



Partially cooked limestone, residual from the production line of Soda in Solvay industry

SOFTENING TESTS to reduce hardness
Batch tests with pH of 8.5-9-9.5-10 at different dosages of the by-products (0.1-0.4 g).

Laboratory Tests



TREATMENT GOAL:

Concurent removal of COD and Hardness

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ULTIMATE Project

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BY-PRODUCTS reuse in ADVANCED TREATMENT PROCESSES for water reuse in industries

By-products for softening process

Softening agent	PAC	Alluminium Sulphate	Flocculant	Target pH	Final pH	Conductivity	TSS	COD	Mg	Ca	COD Removal	Mg Removal	Ca Removal
-	ml	mg	ml	-	-	µS/cm	mg/l	mg/l	mg/l	mg/l	%	%	%
INFLUENT WASTEWATER - ARETUSA WWTP (By-products solution at 40 mg/l)					**8.6**	**1597**	**4.8**	**64.5**	**55.5**	**178**	-	-	-
-	-	-	1	-	8.5	1910	10	64.5	54.2	175	0.00	2.29	1.7
-	-	98	1	-	7.3	1844	5	25.8	52.6	165	60.00	5.16	7.6
Precotto	-	-	1	9	8.9	1895	8	34.4	49.2	168	46.67	11.38	5.7
Precotto	-	-	1	9.5	9.4	1849	4	60.2	50.3	162	6.67	9.32	9.1
OoS Soda Solvay	-	-	1	9	9.0	1934	13	34.4	50.8	162	46.67	8.42	9.0
OoS Soda Solvay	-	-	1	9.5	9.5	2000	19	17.2	55.3	135	73.33	0.27	23.9
Mix	-	-	1	9	9.0	1993	4	8.6	52	178	86.67	6.24	0.3
Mix	-	-	1	9.5	9.5	1998	15	12.9	53.3	135	80.00	3.86	24.3
INFLUENT WW - ARETUSA WWTP (direct dosage of solid by-products)					**8.0**	**2130**	**50**	**23.9**	**46.1**	**164**	-	-	-
Precotto	-	-	1	9	8.7	1920	30	13	42.4	152	45.45	8.13	6.8
Precotto	-	-	1	9.5	9.1	1964	30	8.7	42.1	162	63.64	8.64	1.0
OoS Soda Solvay	-	-	1	9	9.0	2180	20		48.5	157		-5.26	4.3
OoS Soda Solvay	-	-	1	9.5	9.2	2310	10	6.52	52.3	89.7	72.73	-13.44	45.2
Mix	-	-	1	9	8.9	2180	10	8.26	46.6	154	65.45	-1.13	6.0
Mix	-	-	1	9.5	9.3	2270	0	10.9	49.6	130	54.55	-7.49	20.3
INFLUENT WW - ARETUSA WWTP (OoS Soda Solvay solution at 20 mg/l and Precotto solution at 10 mg/l)					**8.0**	**2130**	**50**	**23.9**	**46.1**	**164**	-	-	-
OoS Soda Solvay	-	-	1	9	9.2	2030	20	4.35	47.2	144	81.82	-2.29	12.0
OoS Soda Solvay	-	-	1	9.5	9.5	2480	60	8.7	53.5	77.5	63.64	-15.97	52.6
Precotto	-	-	1	9	9.1	2090	10	6.3	44.8	173	73.64	2.87	-5.9
Precotto	-	-	1	9.5	9.4	1946	10	10.9	41	128	54.55	11.06	21.5
Mix	-	-	1	9	9.3	2260	10	3.26	50.1	155	86.36	-8.73	5.5
Mix	-	-	1	9.5	9.8	2460	40	6.52	57.3	35.2	72.73	-24.24	78.5

OoS Soda Solavy dosed as solid is the preferable choice

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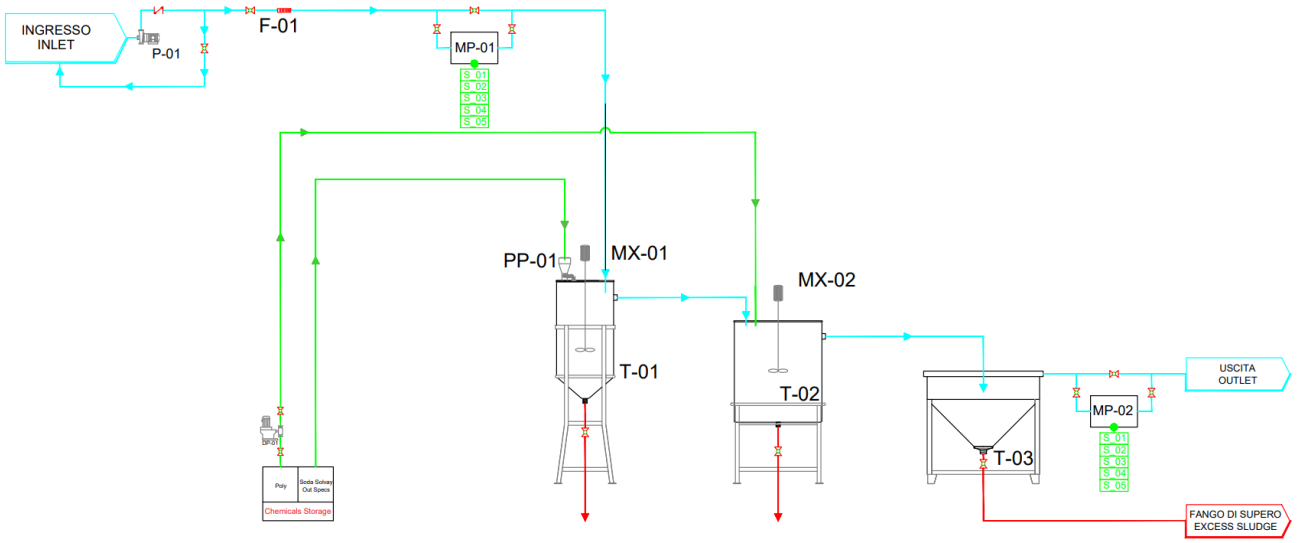
ULTIMATE Project

- Pilot plant design based on laboratory data
- Planned experimental campaign to evaluate cost and saving by treating wastewater with by-products



The pilot has been installed at ARETUSA facility in April 2024



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ULTIMATE Project

WATER SCARCITY and RESOURCE DEPLETION – WATER REUSE – INDUSTRIAL SYMBIOSIS

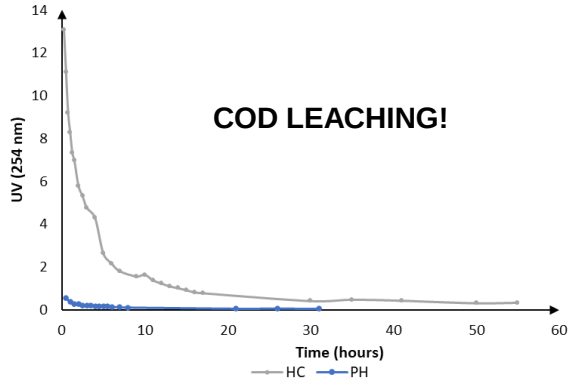
BY-PRODUCTS reuse in ADVANCED TREATMENT PROCESSES for water reuse in industries

Hydrochar for Adsorbption process



Hydrochar (HC) produced from sewadge sludge

Activation procedure needed!



Chemical activation conducted at laboratory scale!

Characterization of Hydrochar – Chemical activation

- Mixing of char pellets with KOH in flakes (KOH to char ratio: 1:1).
- Heating up to 600°C (5°C/min), isotherm for 1 hr and cooling (5°C/min) with N2 purging.
- Washing with 5M HCl and demi water (up to pH 7).
- Drying at 105°C until constant weight.

Pyrolysed Hydrochar produced at Pilot Scale



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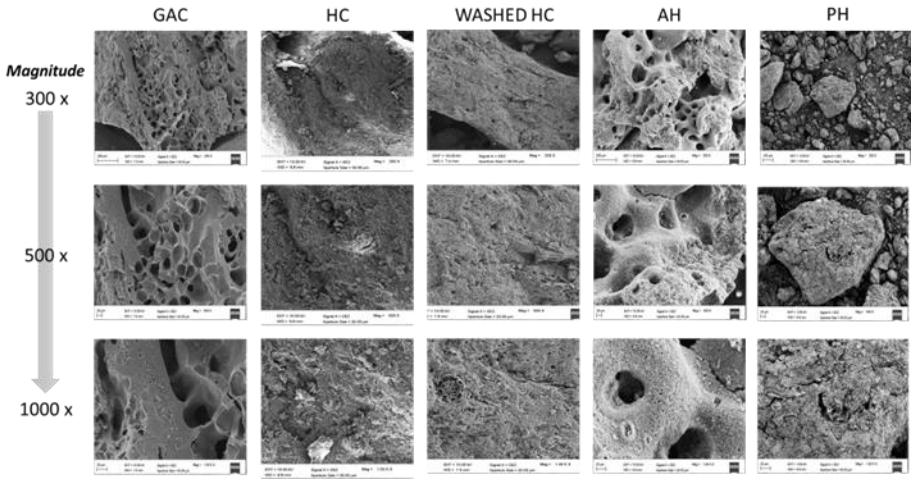

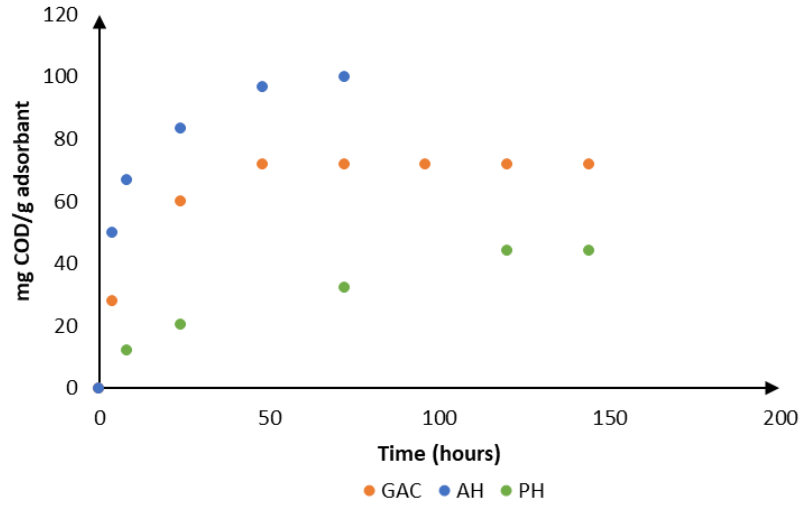

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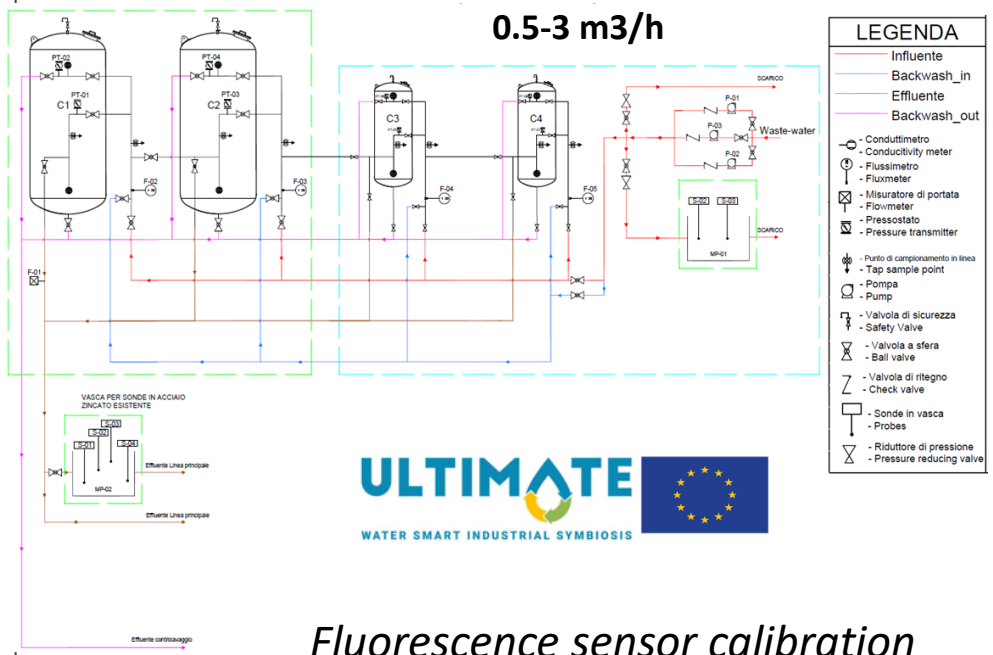
ULTIMATE Project

WATER SCARCITY and RESOURCE DEPLETION – WATER REUSE – INDUSTRIAL SYMBIOSIS

BY-PRODUCTS reuse in ADVANCED TREATMENT PROCESSES for water reuse in industries

Hydrochar for Adsorbption process

Adsorption process scale-up



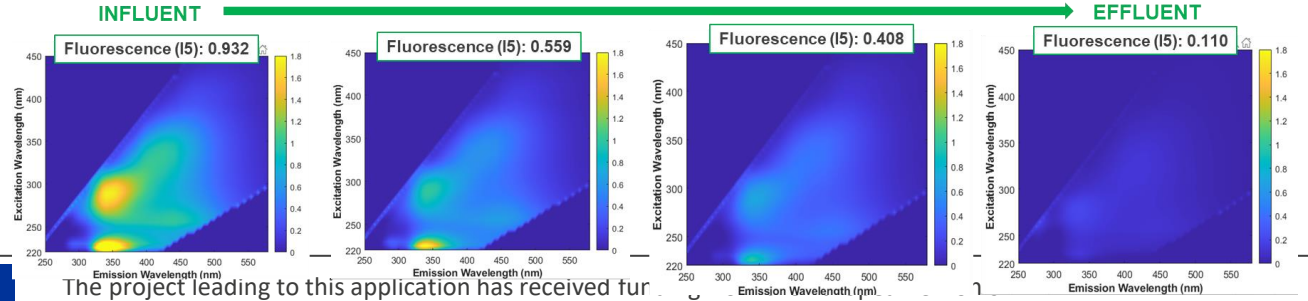


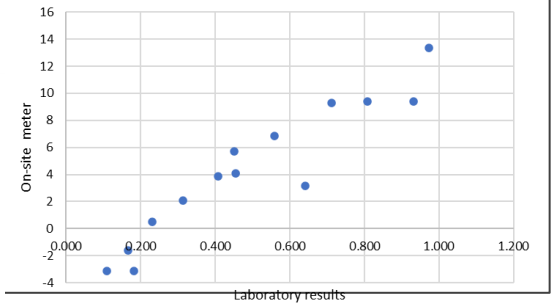






Fluorescence sensor calibration





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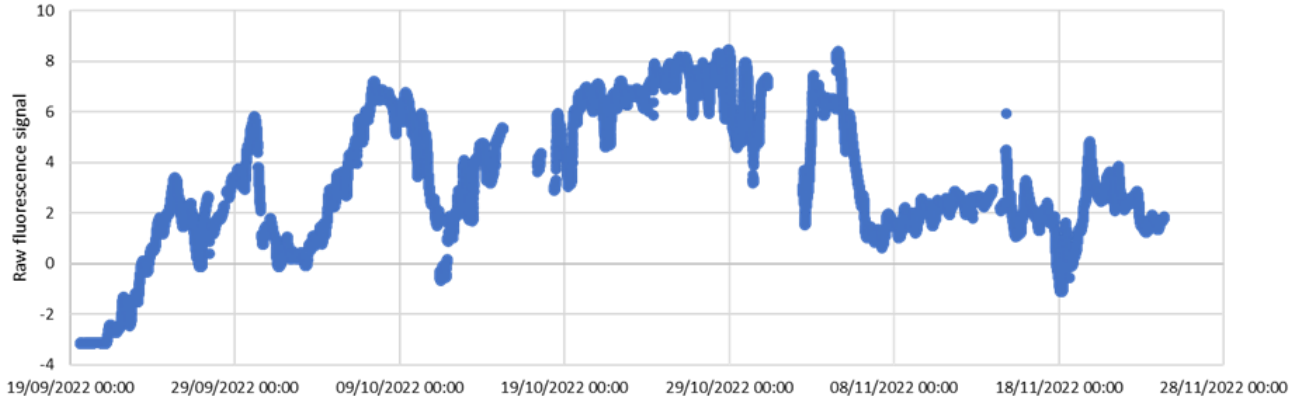
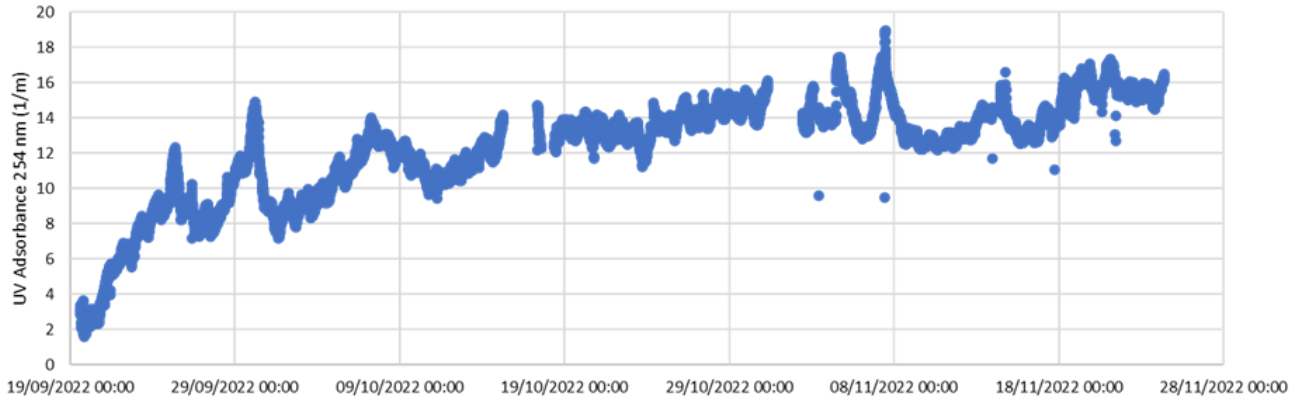
Fluorescence 275/354 nm



UV abs 254 nm



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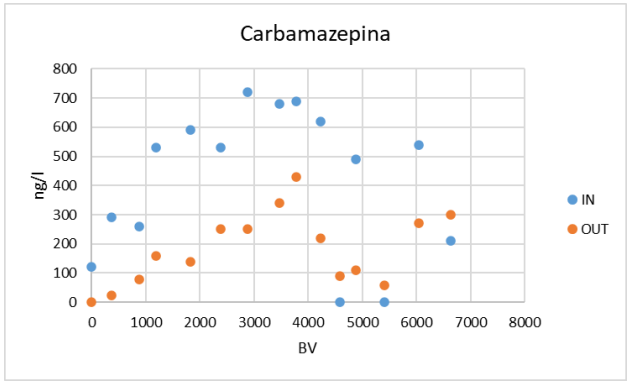
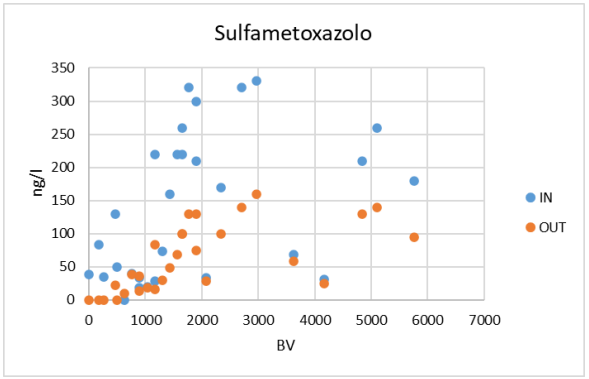
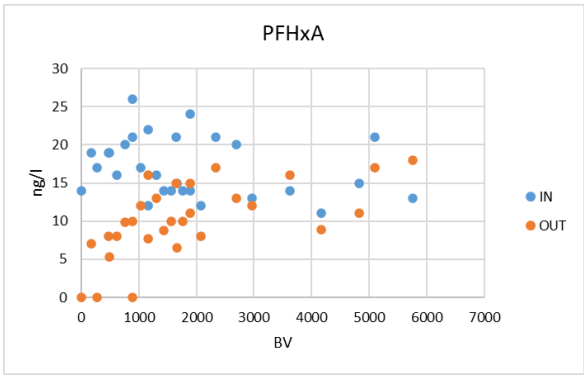
ULTIMATE Project

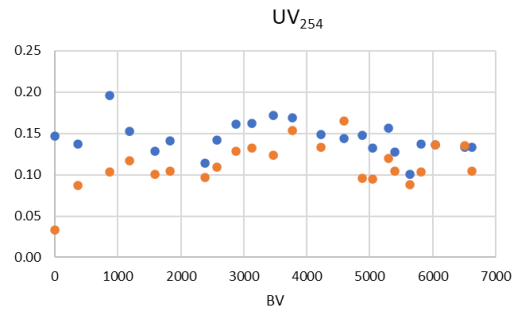
Lab analysis of emerging contaminants

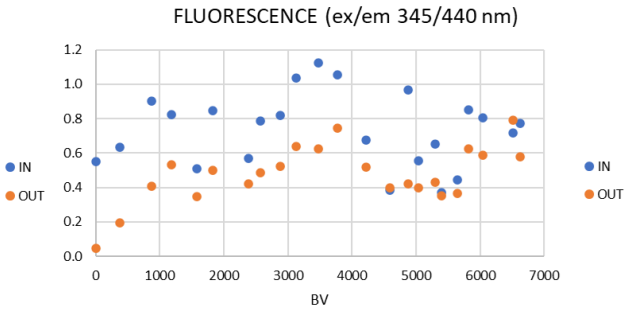


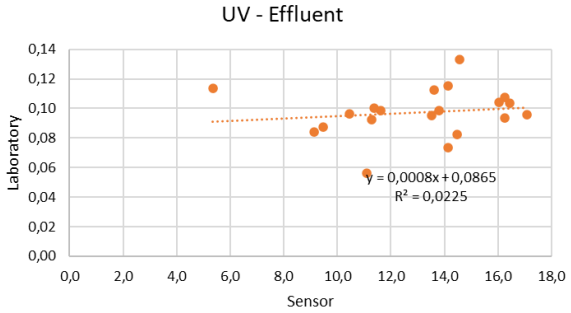


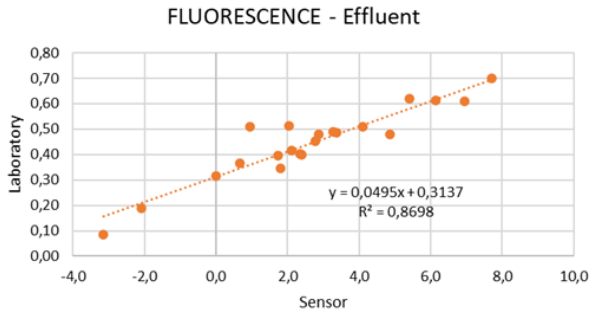


Real-time sensors measurement

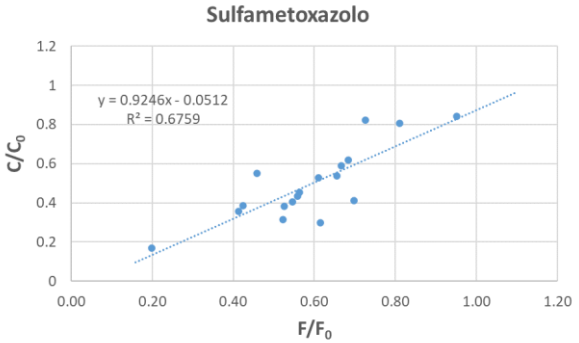


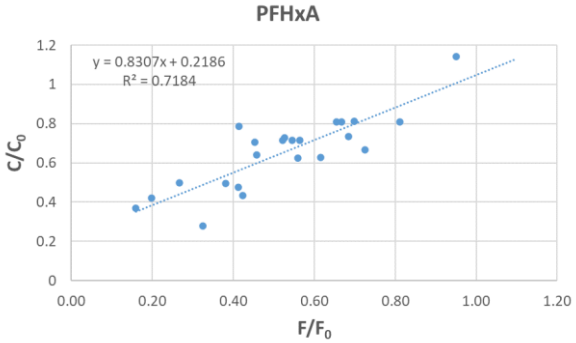






Monitoring of emerging contaminants





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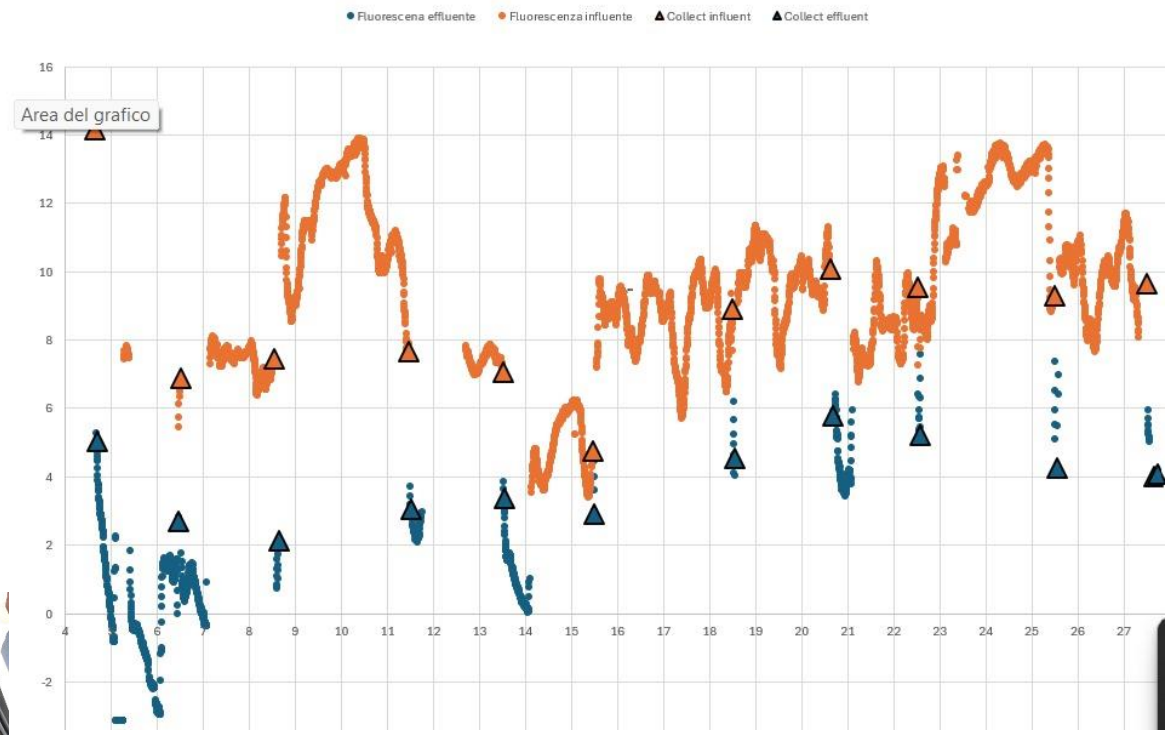
ULTIMATE Project

WATER SCARCITY and RESOURCE DEPLETION – WATER REUSE – INDUSTRIAL SYMBIOSIS

BY-PRODUCTS reuse in ADVANCED TREATMENT PROCESSES for water reuse in industries

UV/H2O2 process – upgrade of treatment process





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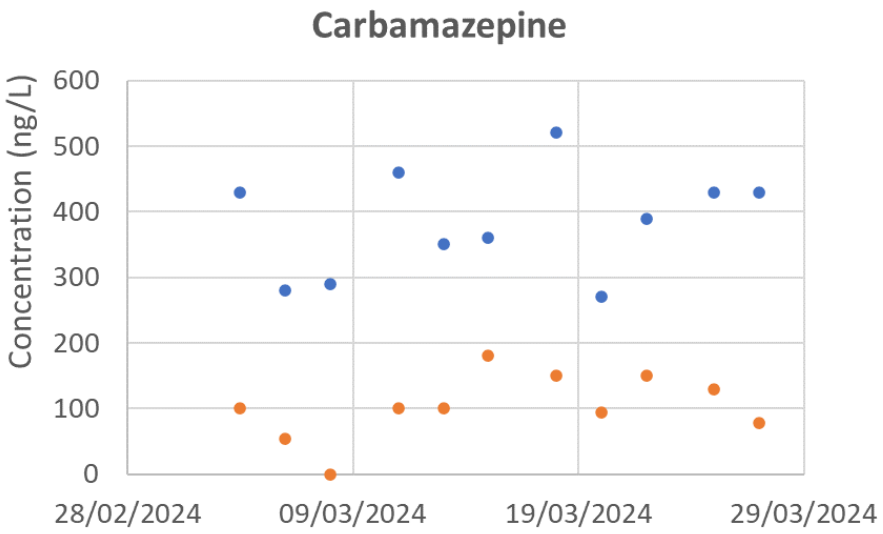
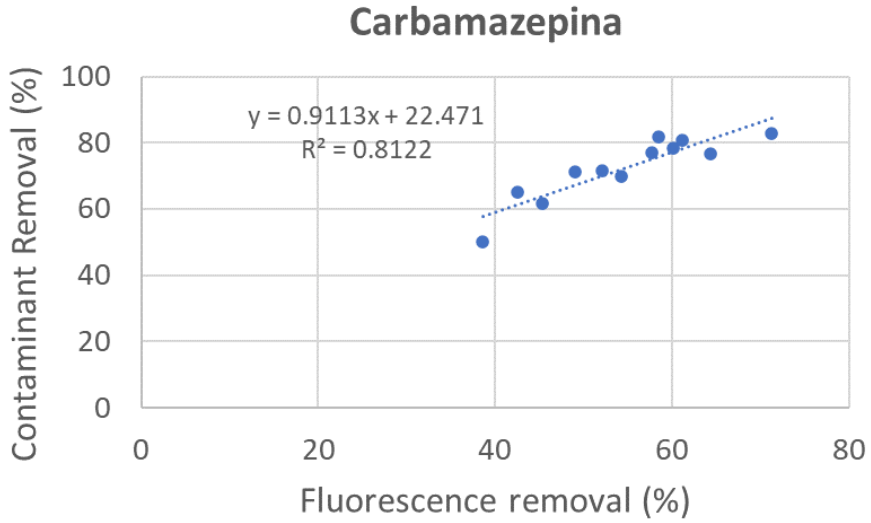
ULTIMATE Project

UV/H_2O_2 AOP PROCESS

Lab measurements of emerging contaminants



Real-time Monitoring of emerging contaminants



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ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

Thank You!

m.sgroi@univpm.it

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ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

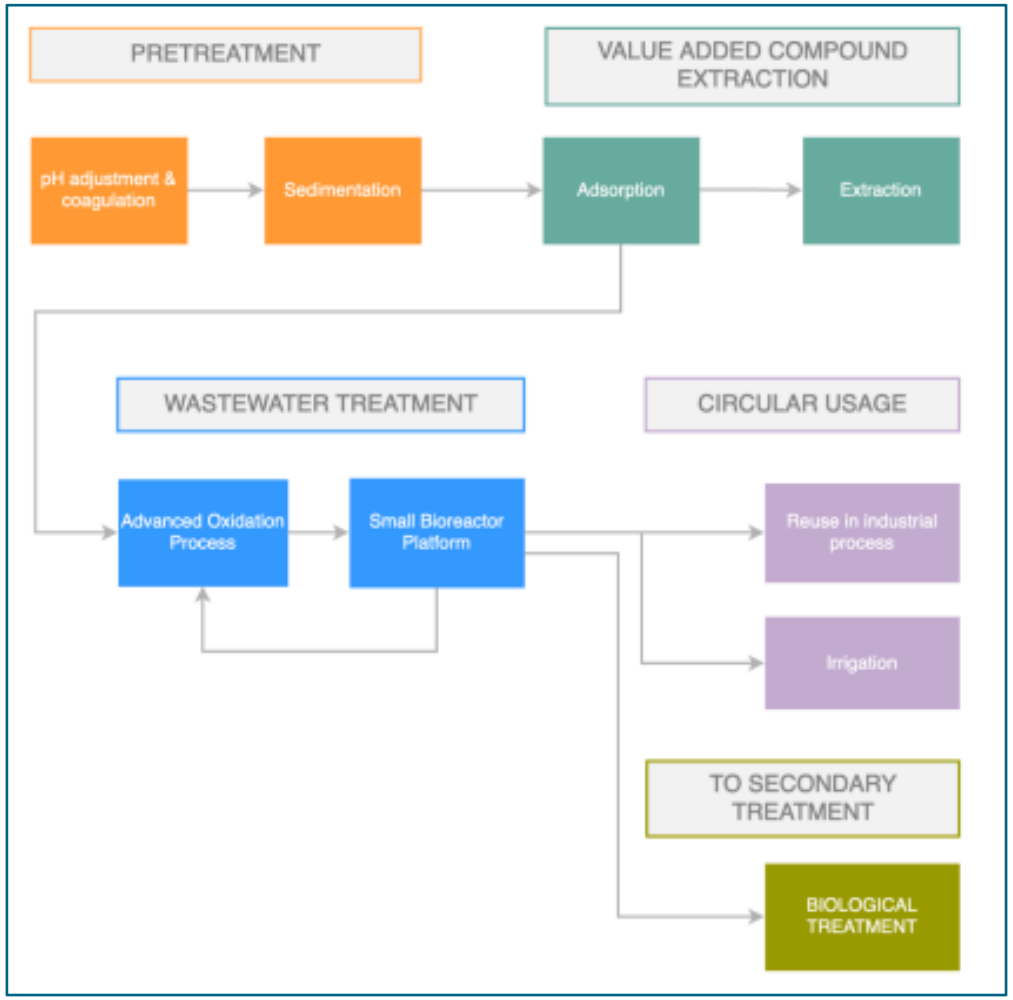
Recovery of antioxidants from fruit processing wastewater

Myrto Touloupi

Greener than Green Technologies



Overview





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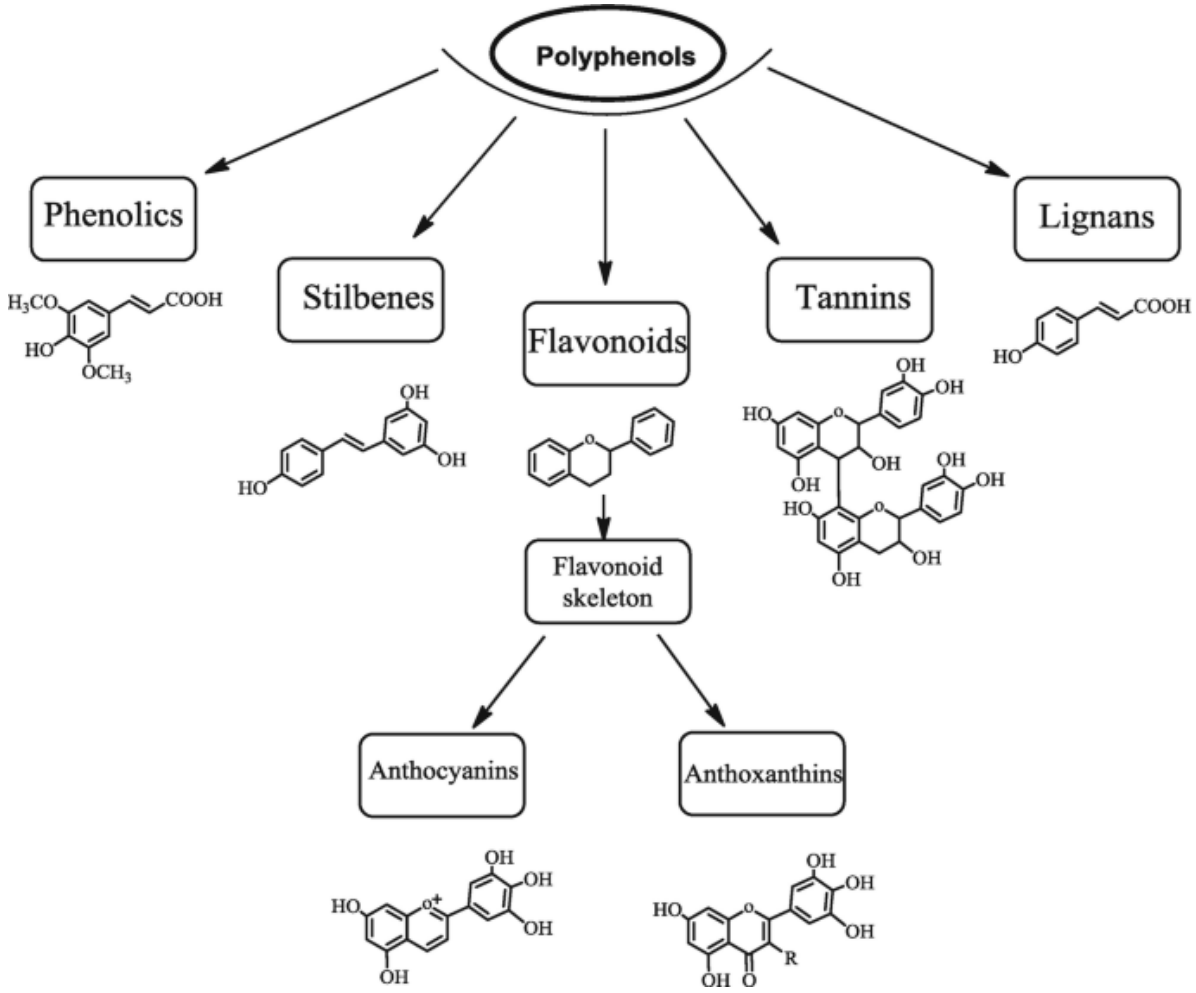
Value Added Compounds - Polyphenols

- Naturally occurring compounds
- Complex structures with multiple phenolic rings
- Flavonoids, Phenolic Acids, Lignans, Tannins, and Stilbenes
- Important Biological Activity



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Value Added Compounds

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
Carrot	3,4-Dicaffeoylquinic acid	Phenolic acid	Antioxidant, anti-inflammatory, anti-cancer, DNA protective, Neuroprotective, Hepatoprotective, Anti-influenza viral activity	€ 374.000
Olive	Oleocanthal	Phenylethanoid	Antioxidant, Anti-inflammatory, Anti-cancer, Reduce risk of AD, Reduce risk of heart disease	€ 5.780
	3-Hydroxytyrosol	Phenylethanoid	Antioxidant, Anti-inflammatory, Anti-cancer, Protects skin & eyes, Protection from pathogens	€ 1.620
	Oleuropein	Glycosylated seco-iridoid	Antioxidant, Anti-inflammatory, Anti-cancer, Antinociceptive, Antimicrobial, Gastrorotective, Neuroprotective	€ 7.240
Tomato	Lycopene	Carotenoid	Reduced blood lipids and blood pressure, potential effects on cardiovascular diseases and prostate cancer	€ 81.100
Grapes	Resveratrol	Stilbene	Antioxidant, Anti-inflammatory, Anti-cancer, protects from diabetes and Alzheimer	€ 2.160
	Quercetine	Flavonoid	Anticancer activity	€ 9.600

*Price of analytical standards normalised to 1g

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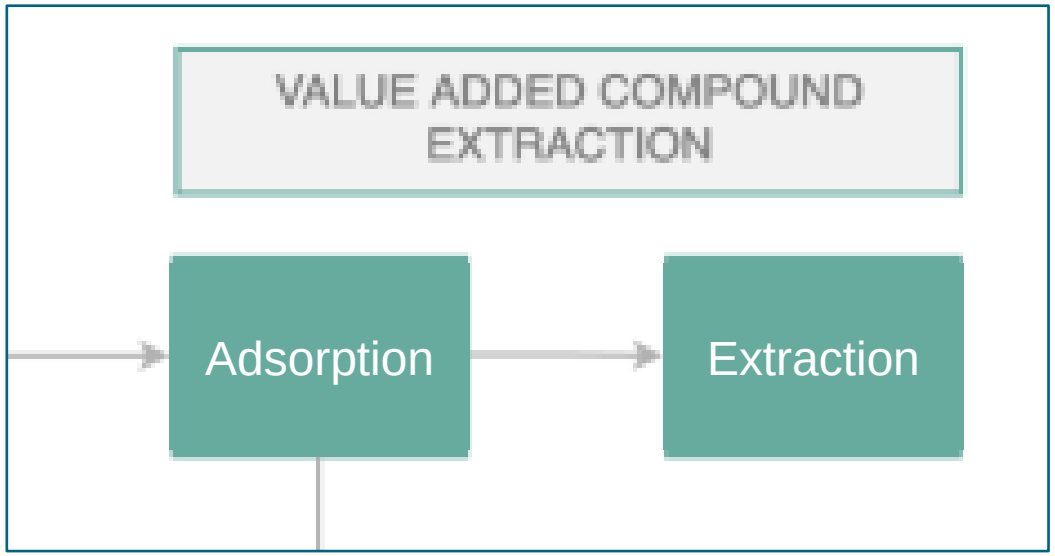
Adsorption





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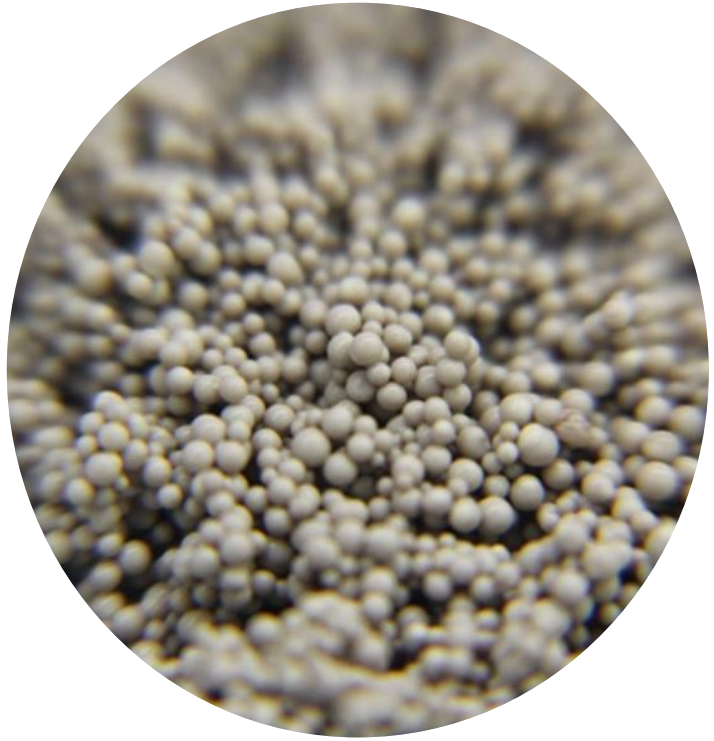
Sorbents

Adsorbent	Material	Structure	Particle size (µm)	Surface Area (m2/g)	Pore Size
Amberlite TM FPX66	Resin	Aromatic	700	800	150
Amberlite ™ XAD-4	Resin	Aromatic	640	750	100



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Extraction

A. Conventional extraction using Solvents



- **H_2O :** Cheap, Non-toxic, Inefficient
- **Methanol :** High cost, Increased toxicity
- **Ethanol :** High cost, Lower toxicity

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Extraction

B. Subcritical Water Extraction

- **Subcritical water is liquid water under pressure at temperatures above usual boiling point, 100 °C (212 °F).**
- Pressure **10 to 20 bar**
- Efficiency
- Low-cost
- Non-hazard / Green



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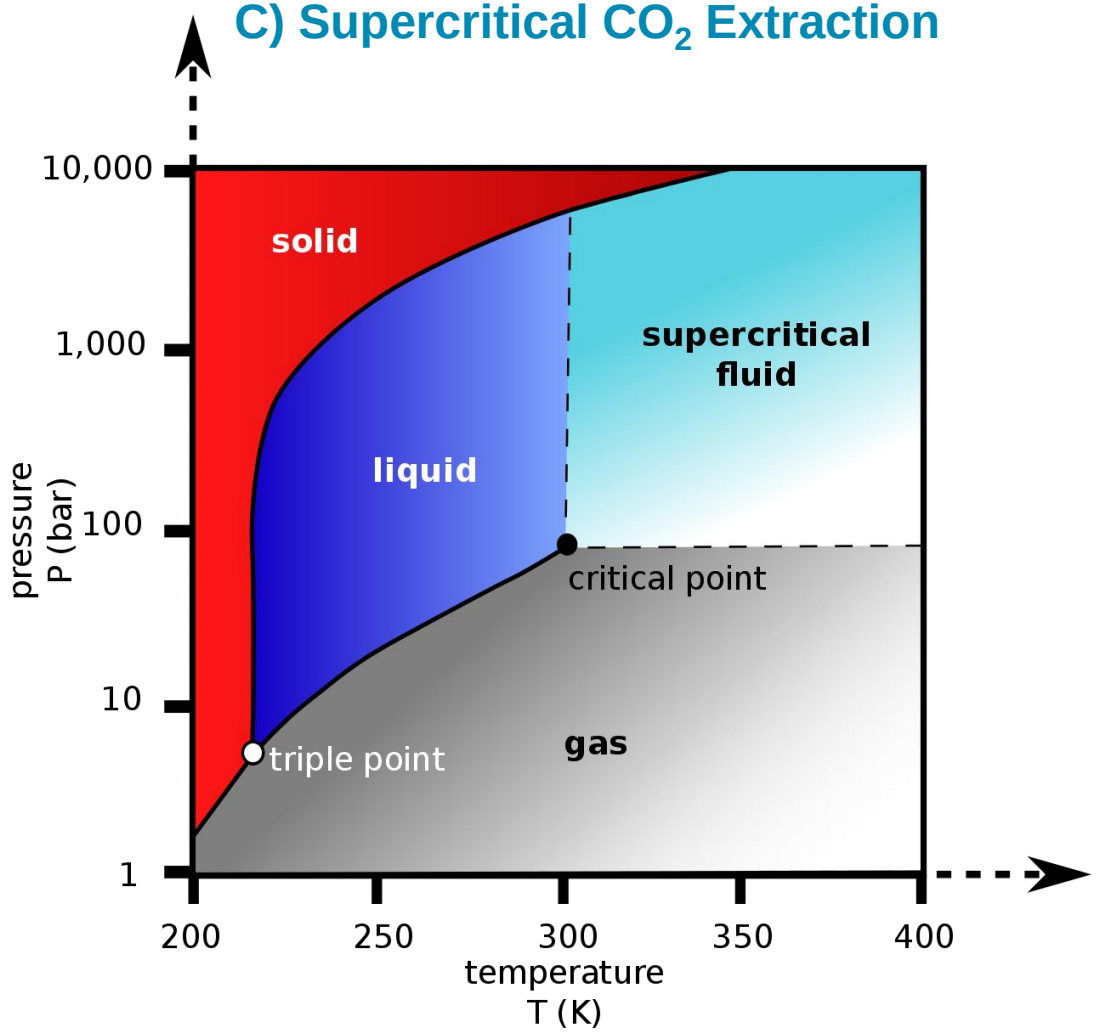
Extraction

C) Supercritical CO_2 Extraction



- **CO_2 Critical point: 31 °C & 73.7 bar**
- Acts like a **solvent**
- **Low toxicity**
- When the **pressure decreases, CO_2 escapes** as gas.

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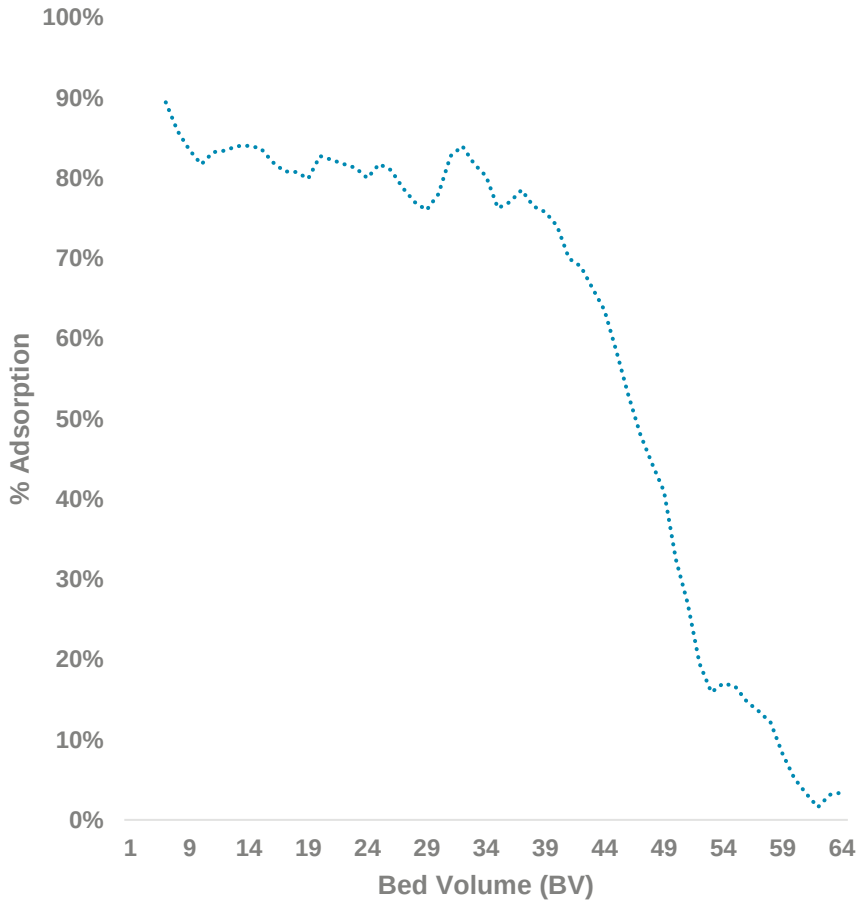
Results - Adsorption

- On average **85% of the polyphenols** present in wastewater are **adsorbed** on the resin

- **Orange byproduct:** each kg of resin can adsorb **4,7 g of polyphenols**
- **Olive byproduct:** each kg of resin can adsorb **23,7 g of polyphenols**



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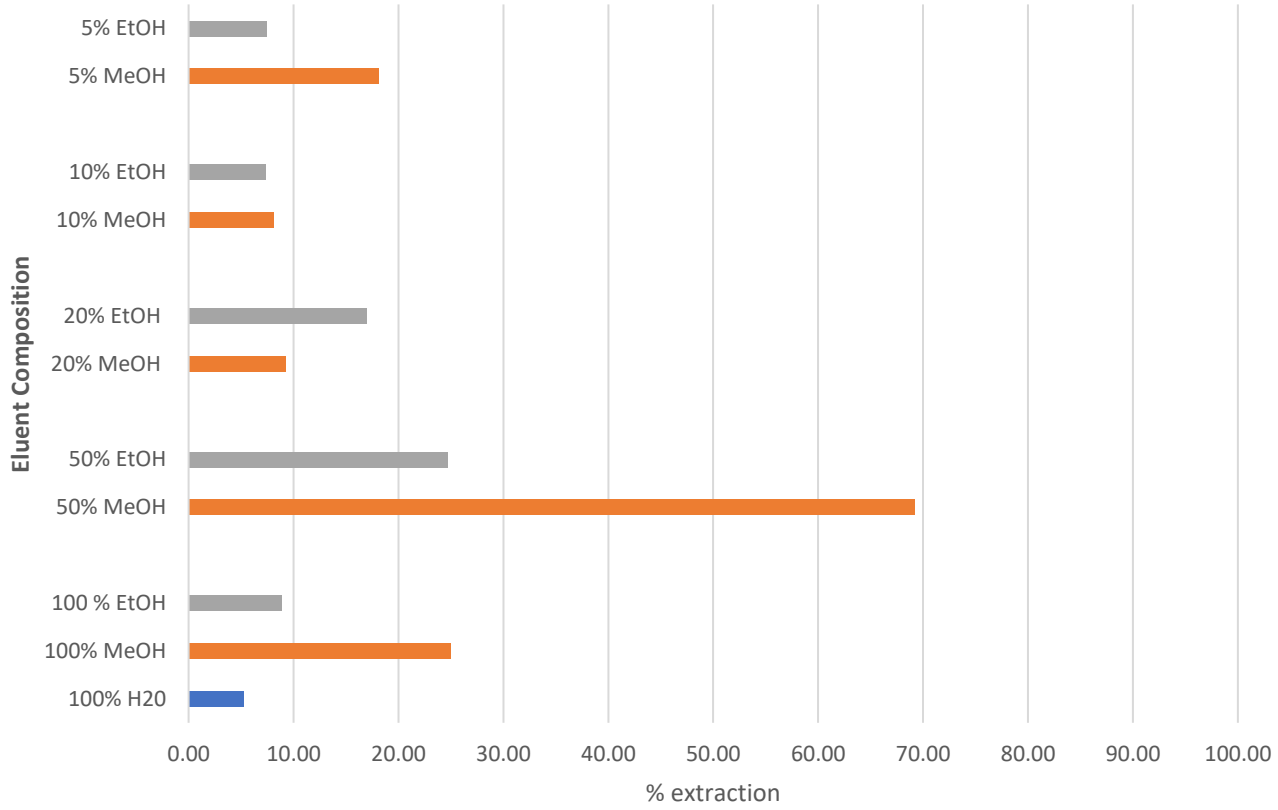
Results - Extraction

A. Conventional extraction using Solvents - Overview

- Extraction conditions **60°C** using **Ultrasound – 5L of solvent per kg of resin**
- Polyphenols determination method**: Folin- Ciocalteu**
- Total phenolic content (TPC) expressed as **Gallic Acid equivalents**



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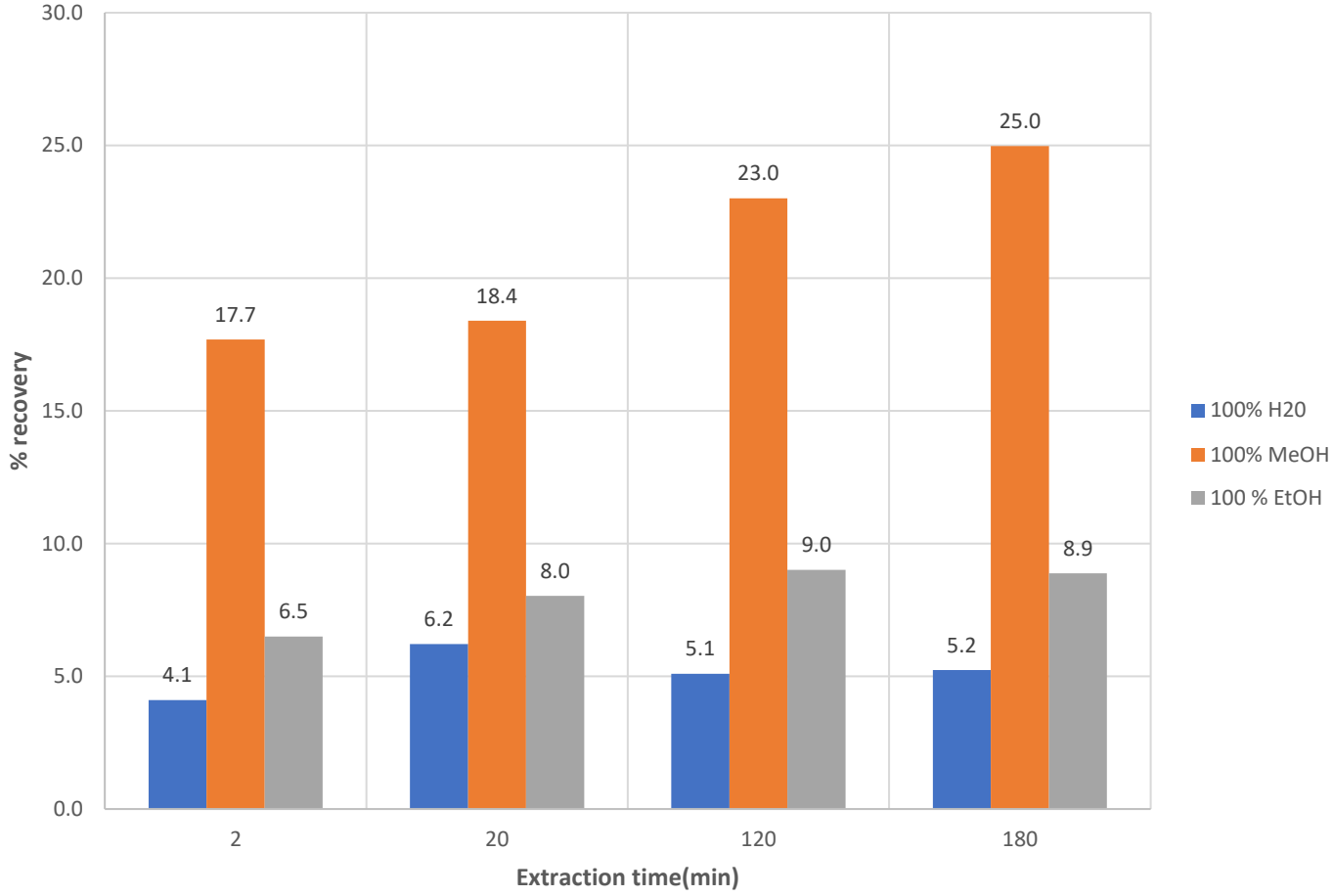
Results - Extraction

A. Conventional extraction using Solvents

Pure water extraction with 5 L of water per kg of resin yield **5 % recovery.**

While **using 100% methanol results in better yields**, it is toxic, and the required 5 L per kg of resin costs approximately 200 € (HPLC grade).

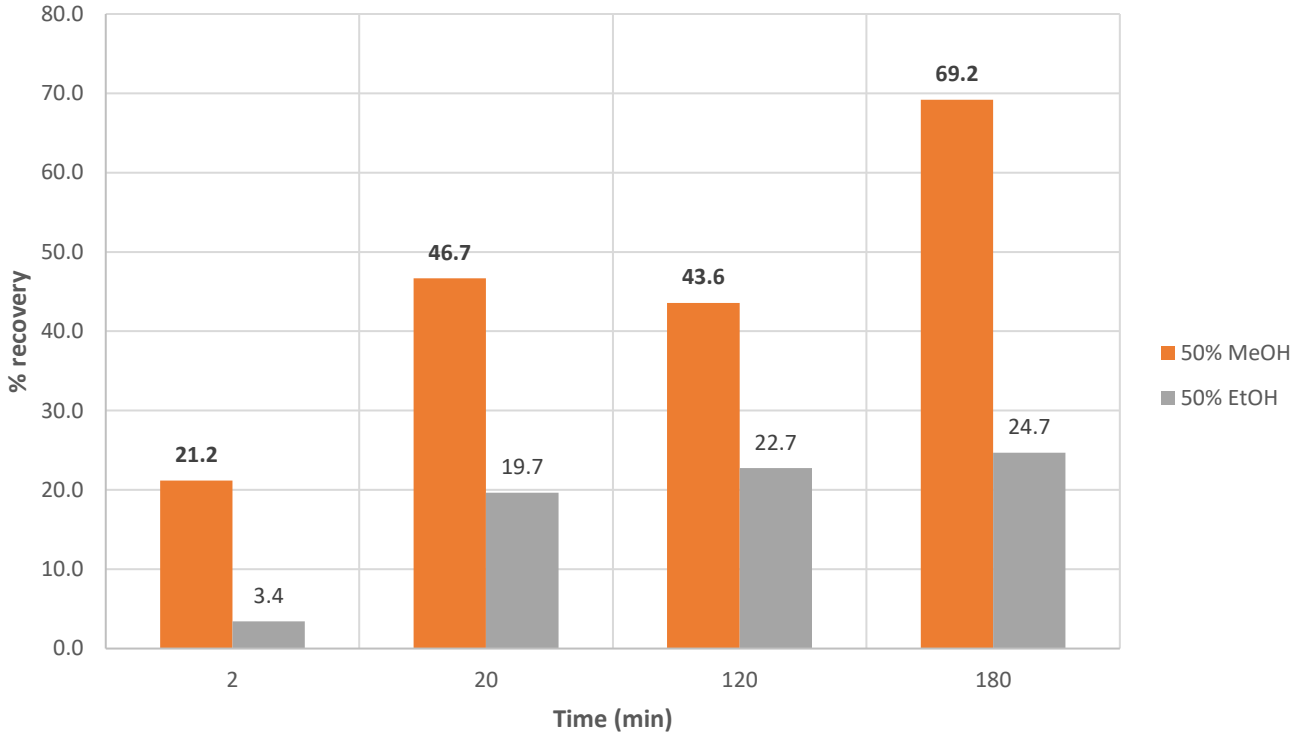


The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

Results - Extraction

A. Conventional extraction using Solvents

69% recovery of polyphenols was achieved using a **50% water-methanol mixture**; however, the method remains costly and has significant toxicity concerns



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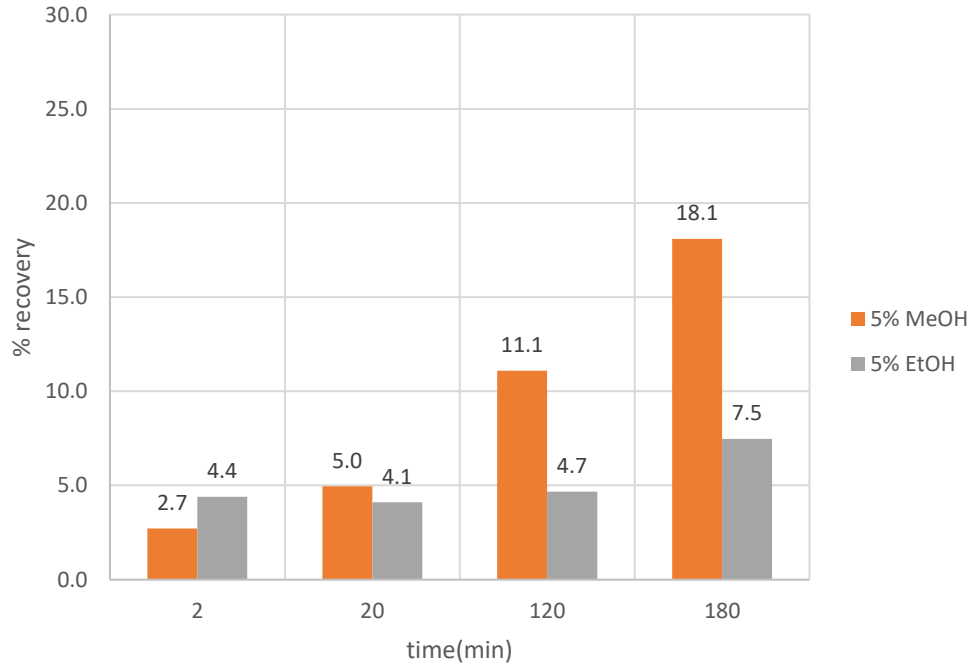
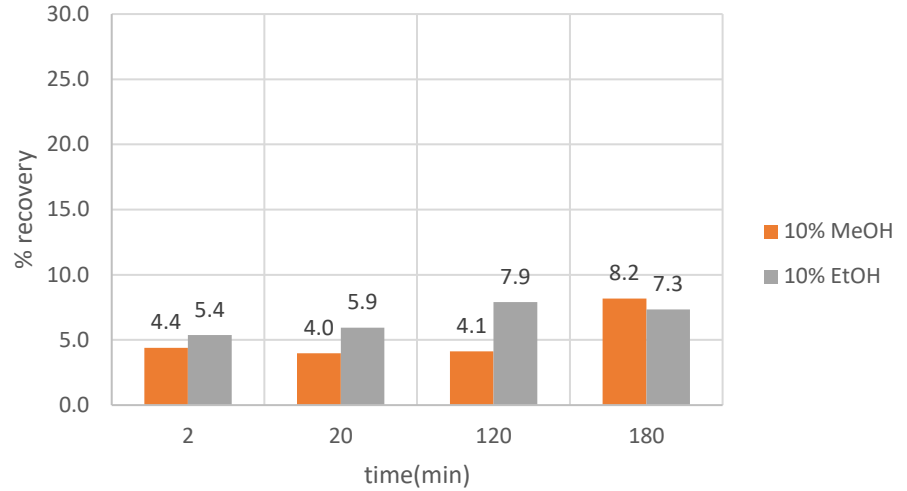
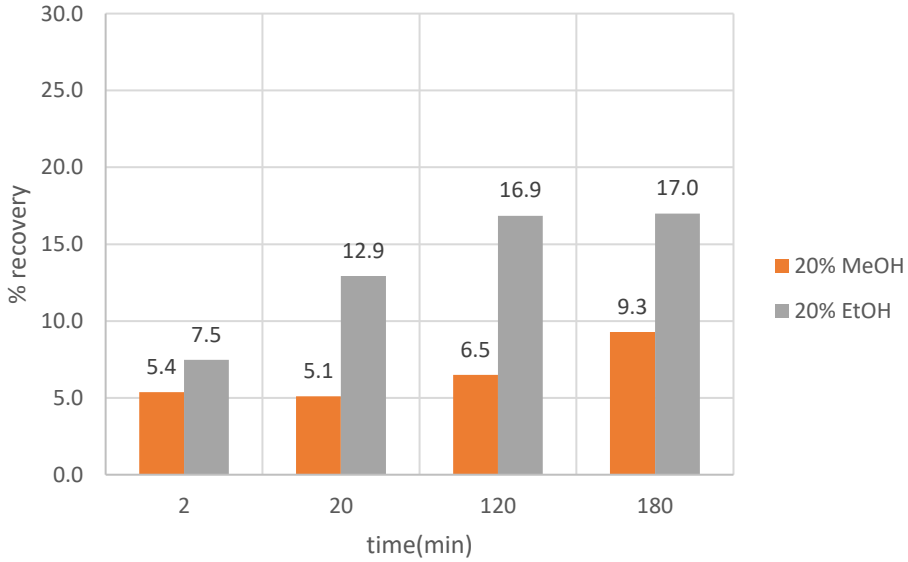
Results - Extraction

A. Conventional extraction using Solvents







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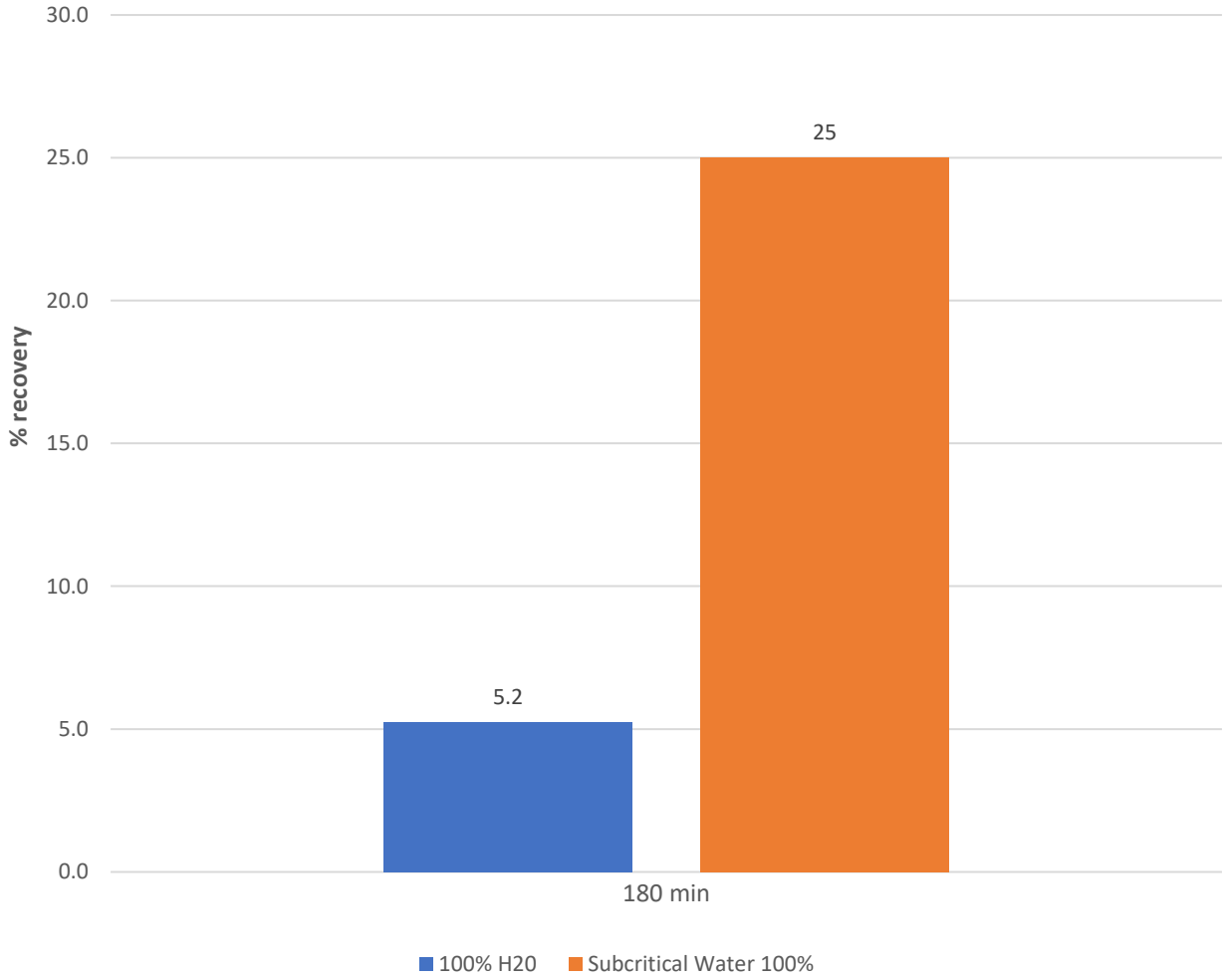
Results - Extraction

B. Subcritical Water Extraction

Subcritical Water extraction: 1 L of water per kg of resin **120 ° C – 12 bar**

Subcritical water extraction achieved a **yield that was five times higher** and required **five times less solvent volume.**



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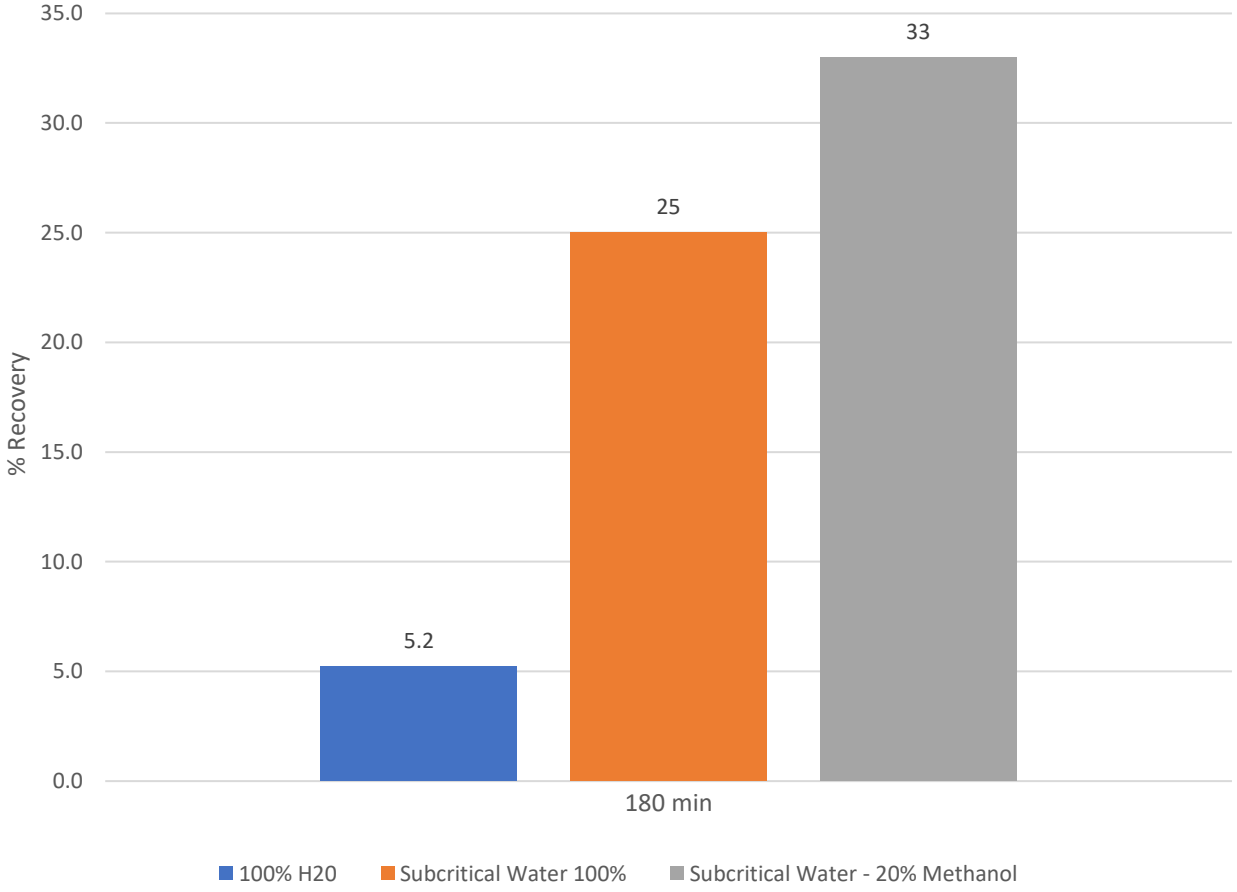
Results - Extraction

B. Subcritical Water Extraction

Subcritical Water extraction – 20% Methanol: 1 L of water- 20% Methanol per kg of resin **120 ° C – 12 bar**

20% Methanol enhanced the process **by 10%**



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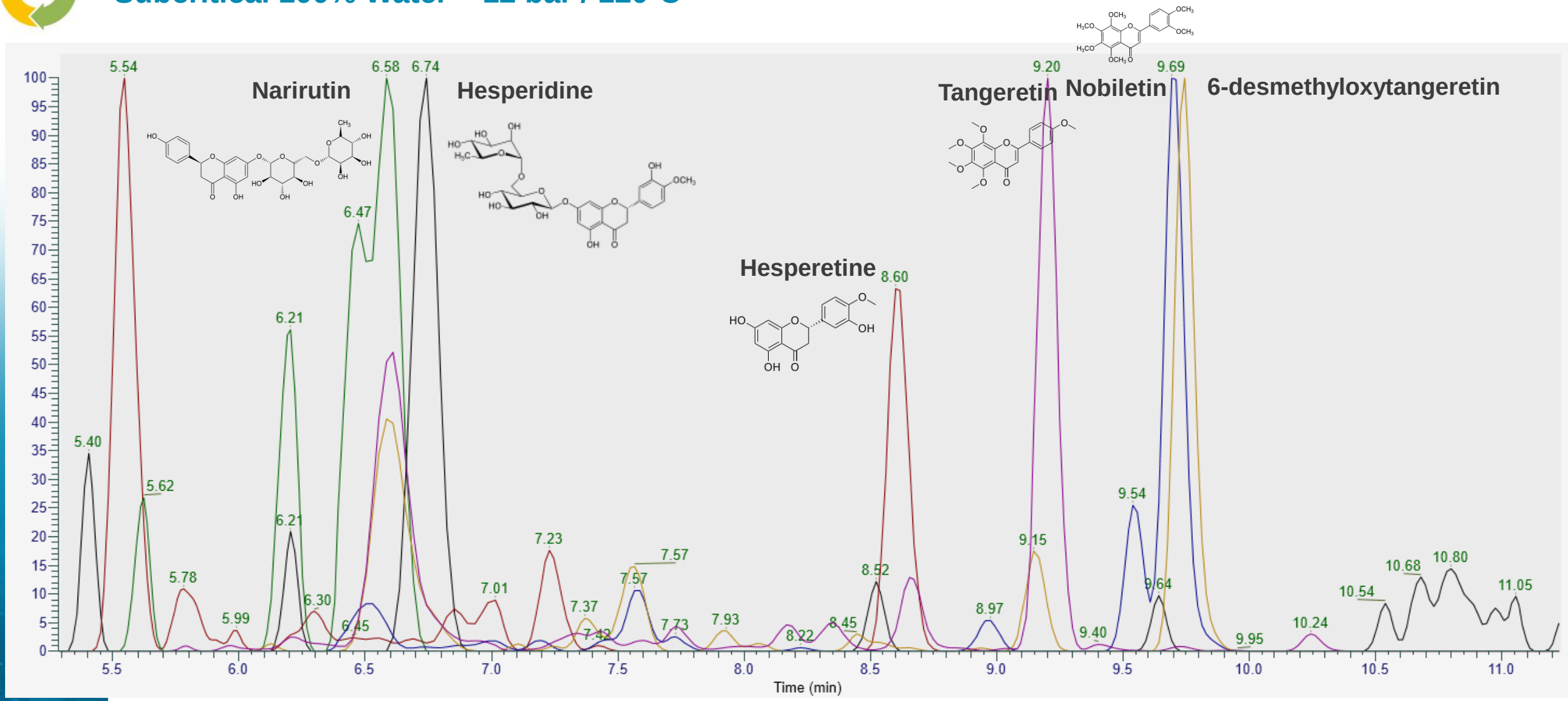
Flavanones
Subcritical 100% Water 12 bar / 120°C



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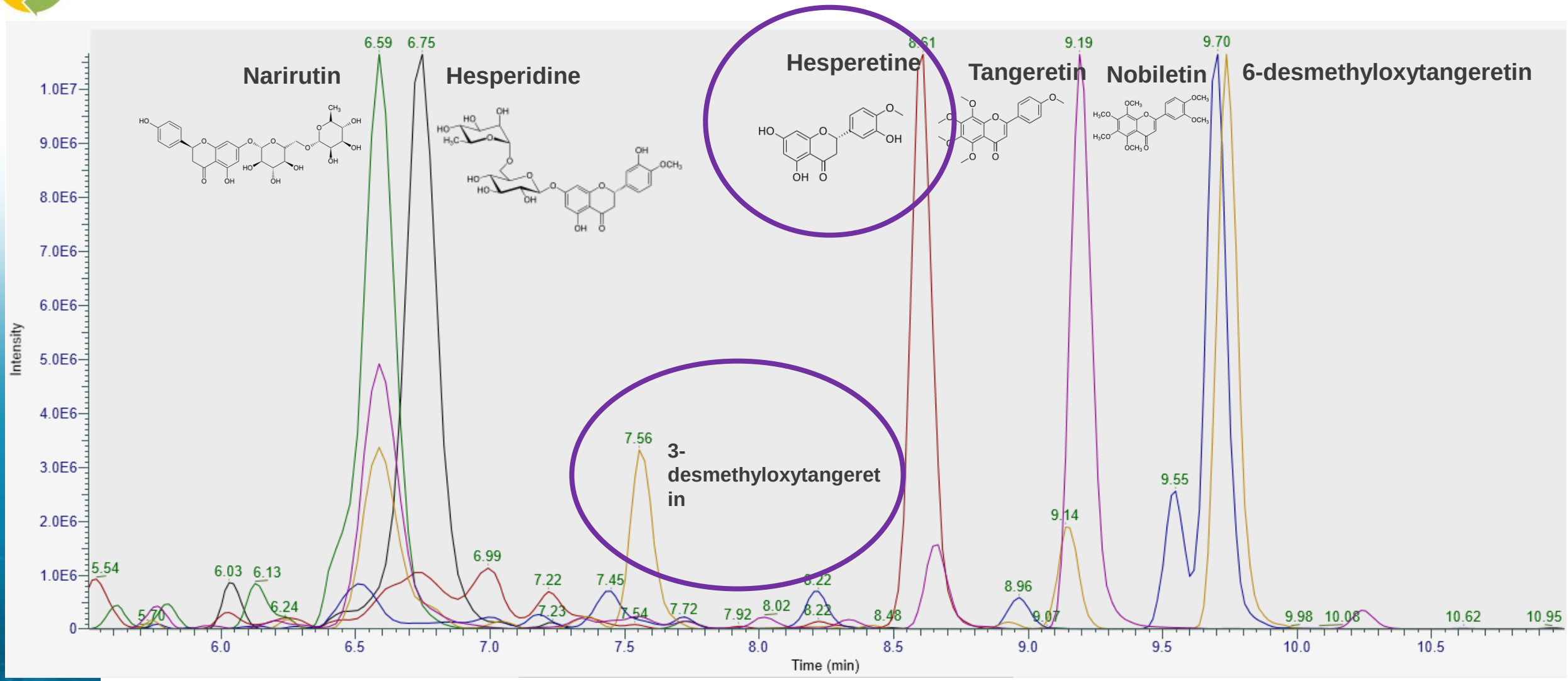
Flavanones
Subcritical Water 80% / MeOH 20%



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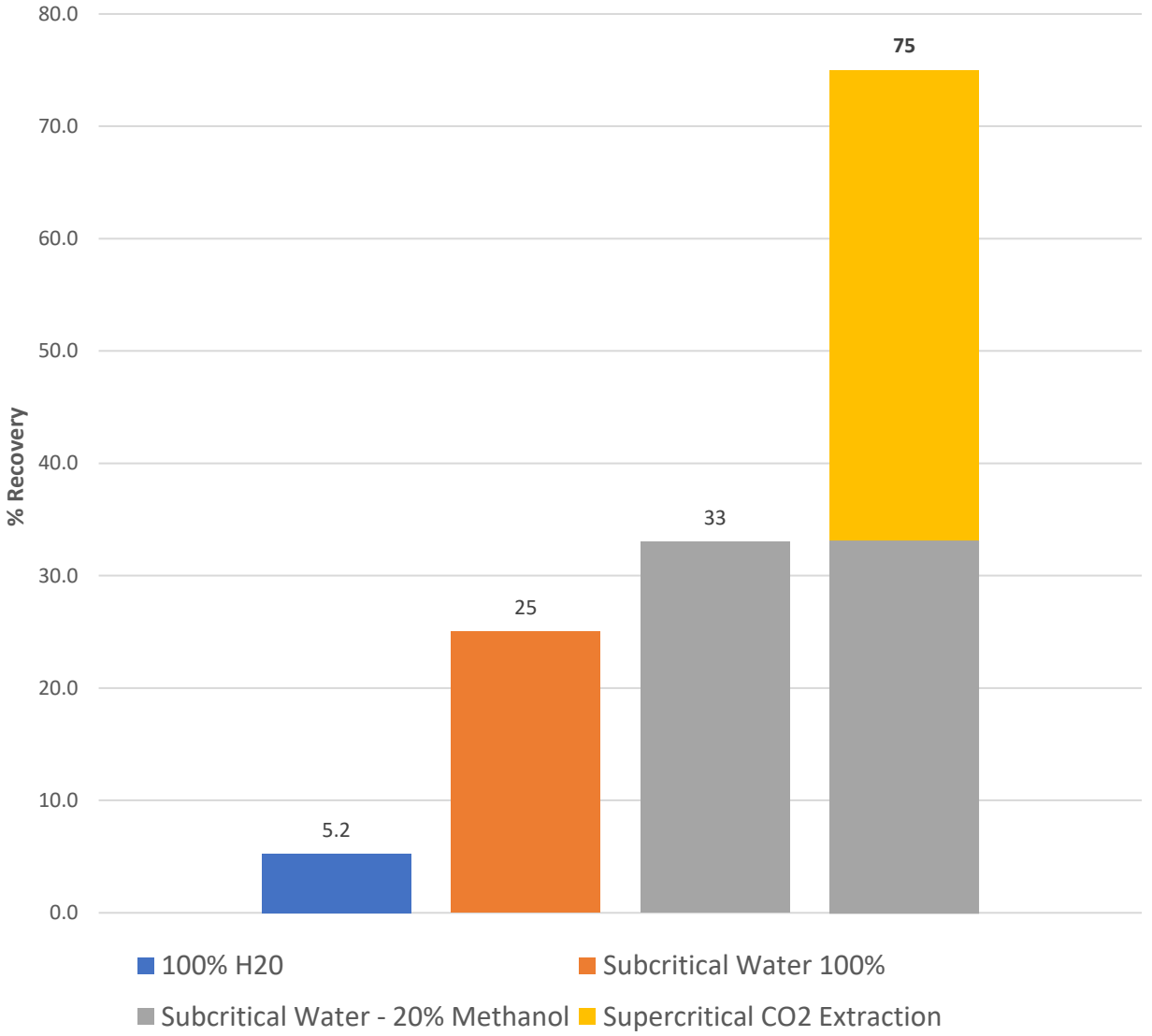
Results - Extraction

C. Supercritical CO_2 Extraction

Supercritical CO_2 Extraction

70 ° C – 150 bar - CO_2 flow 50 g/min

Double yield (75%) without using any additional solvents



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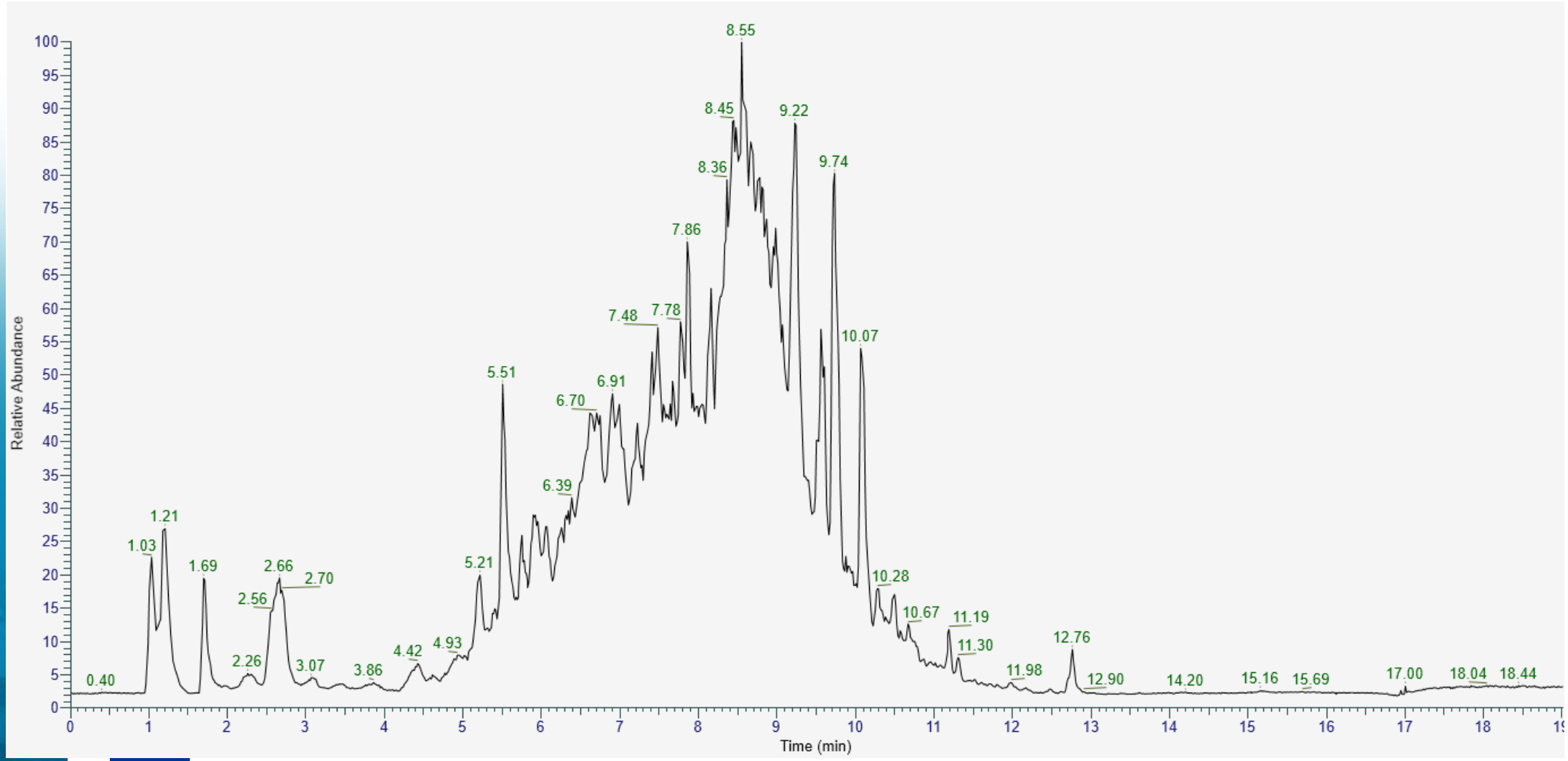
B24 TIC
Supercritical CO_2 Extraction-2h 150bar / 70oC



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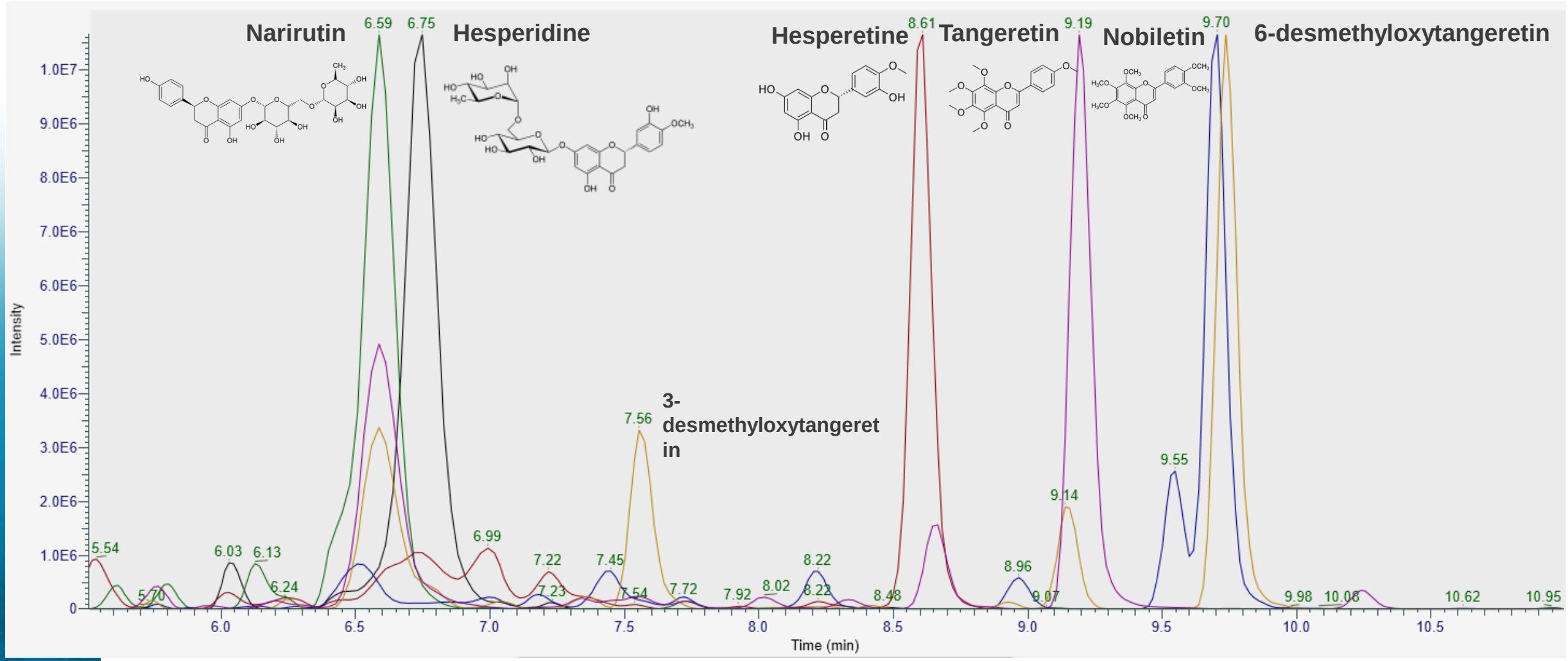
Flavanones A24
Supercritical CO_2 Extraction-2h 150bar / 70°C



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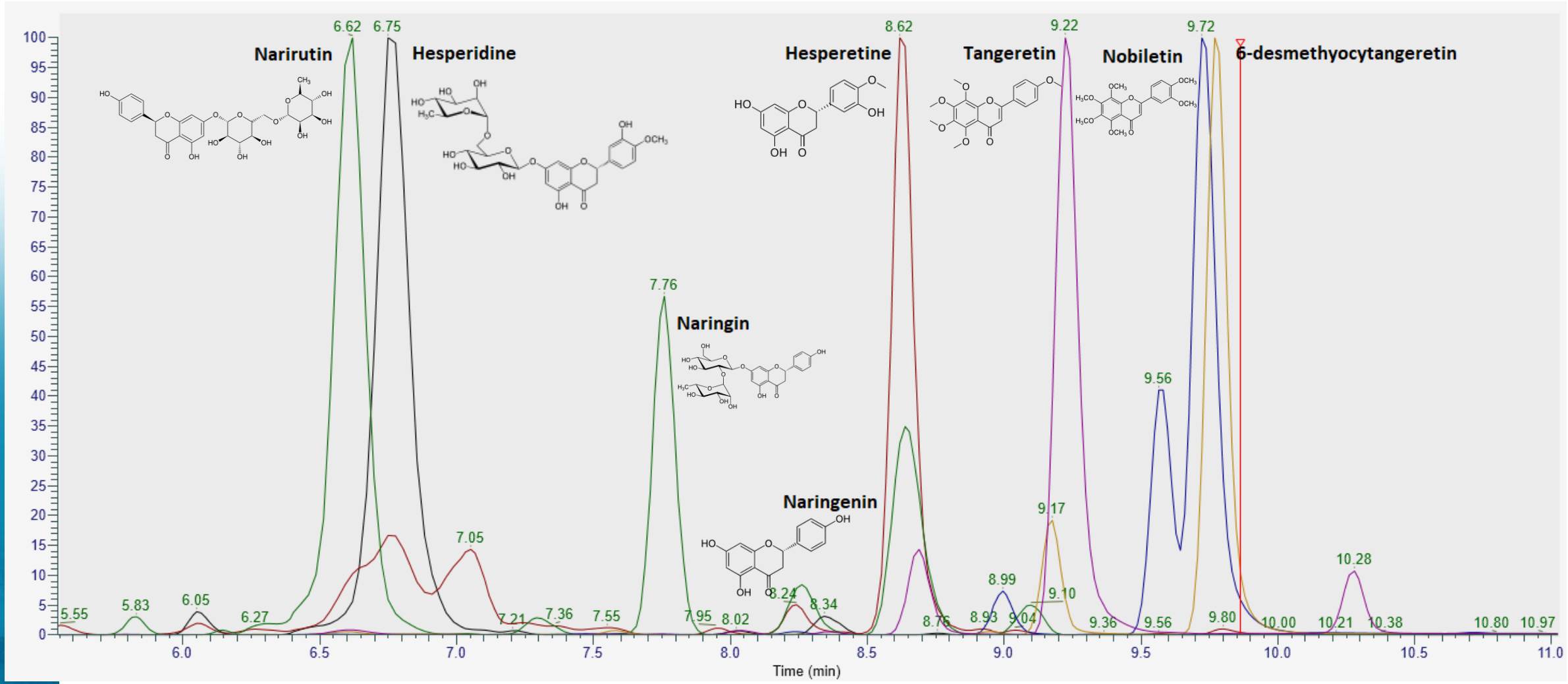
Flavanones B24
Supercritical CO_2 Extraction-2h 150bar / 70°C



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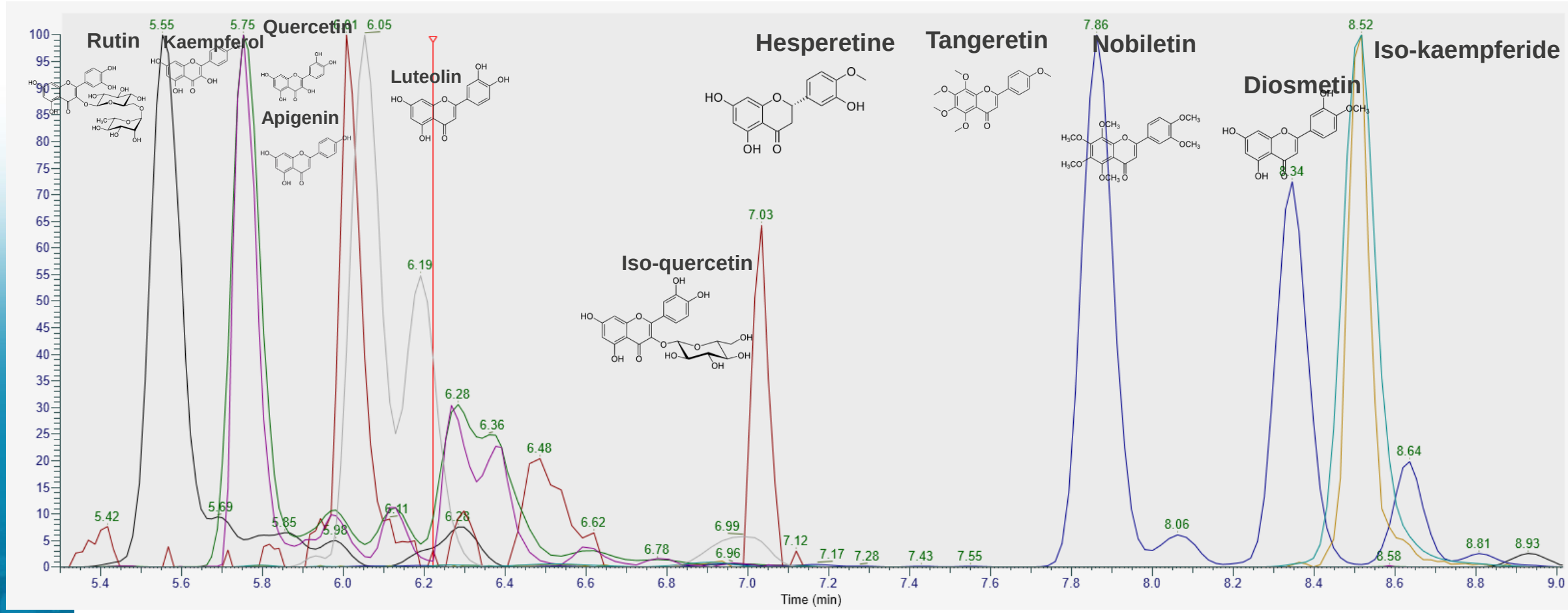
Flavonols B24
Supercritical CO_2 Extraction-2h 150bar / 70°C



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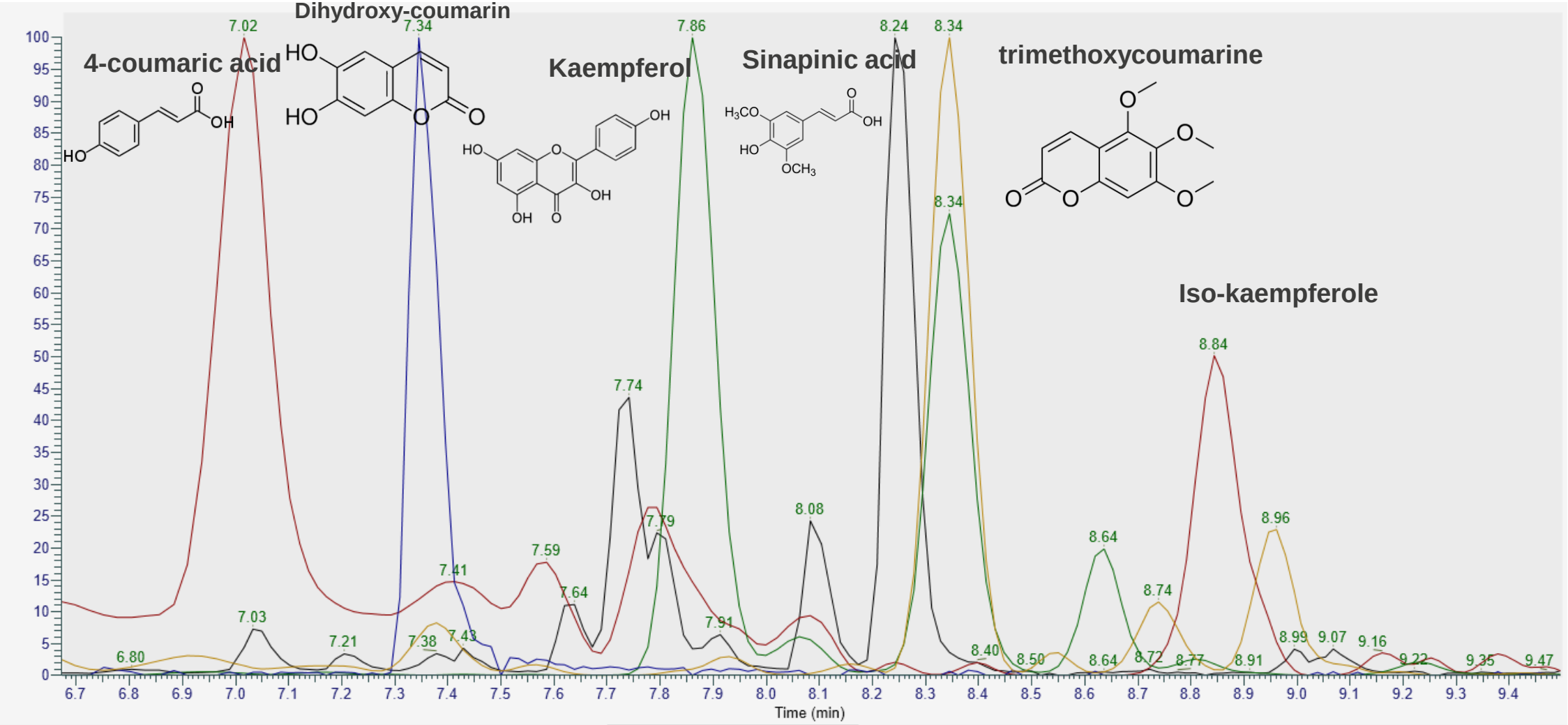
Coumarins B24
Supercritical CO_2 Extraction- 2h 150bar / 70°C



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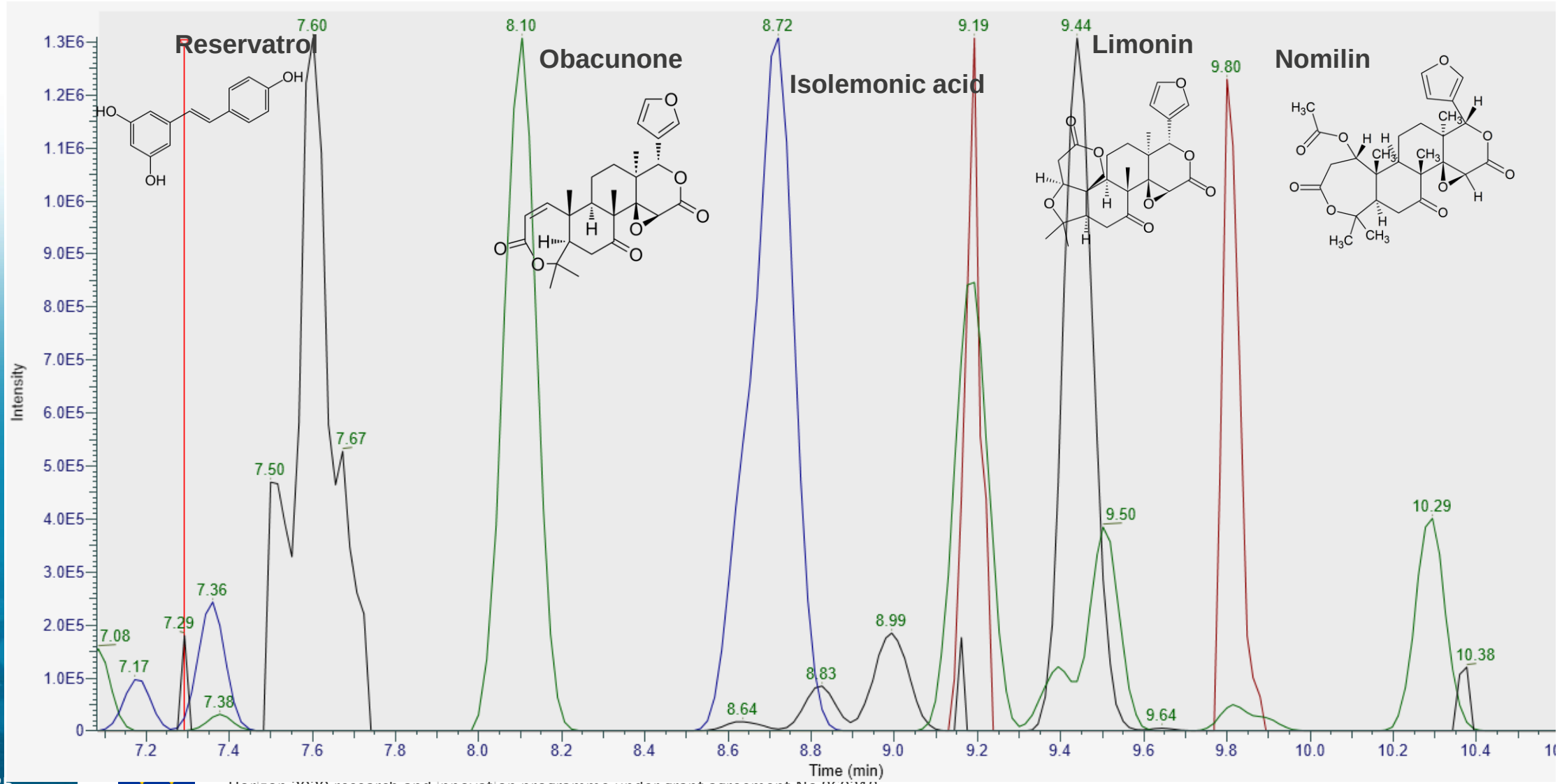
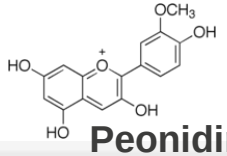
Terpenes B24

Supercritical 2h 150bar / 70°C

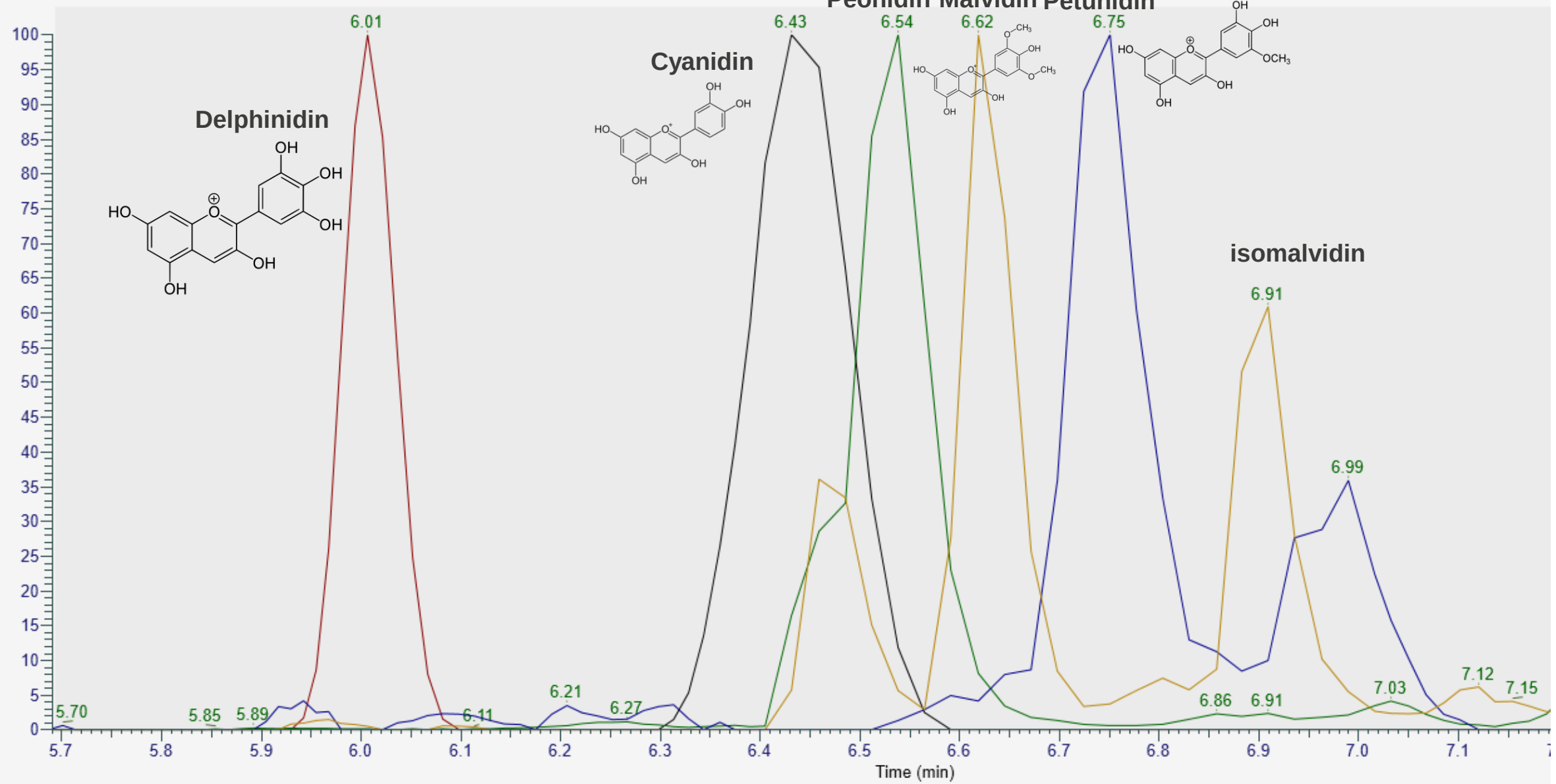


Horizon 2020 research and innovation programme under grant agreement No 869318

Anthocyanins B24
Supercritical CO_2 Extraction- 2h 150bar / 70°C



Peonidin Malvidin Petunidin



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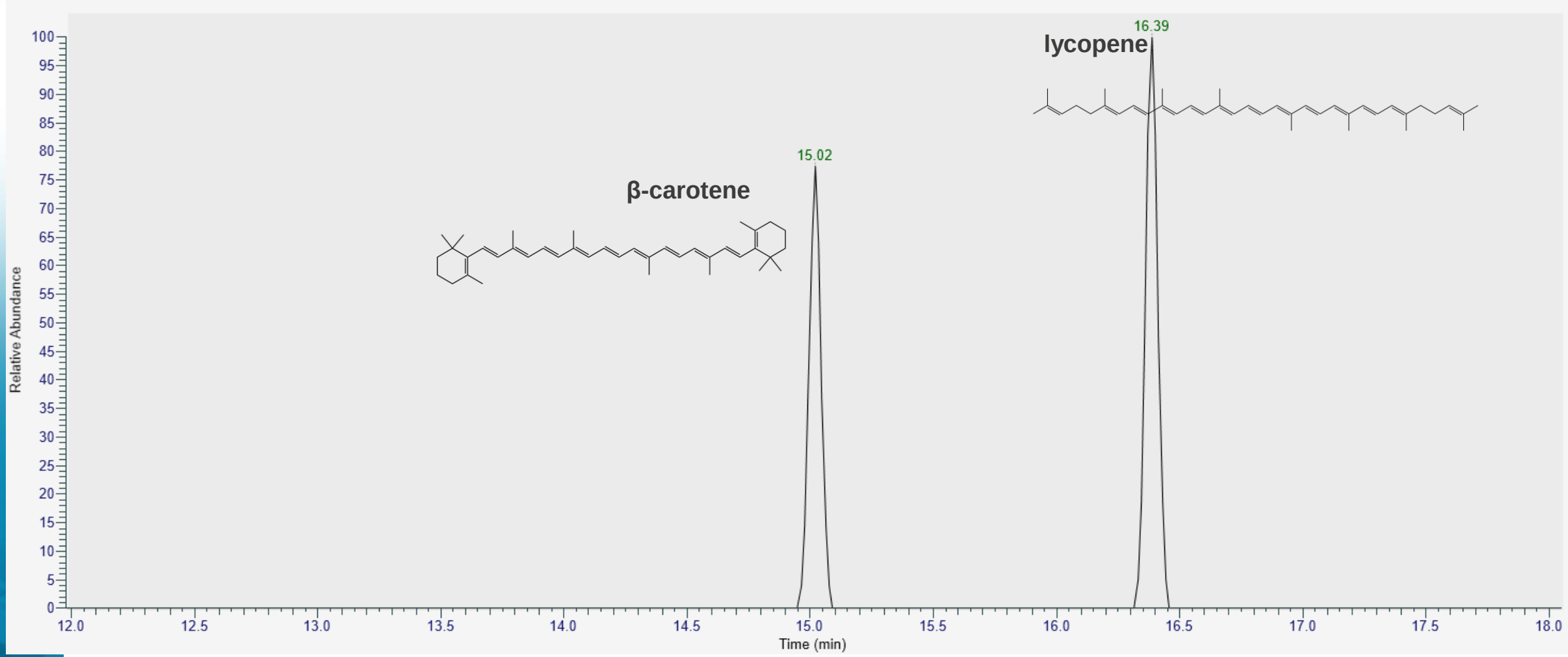
Carotenoids B24
Supercritical CO_2 Extraction-2h 150bar / 70°C



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Beyond Ultimate

A. Polyphenols quantification, isolation & purification

Reference materials are hard to find and have high cost

B. Use of solid industrial by-products to replace resin

Expected to reduce cost by 90% (FPX cost € 2500 /20 kg)

Eliminates the use of resin, which will end up as waste.

Makes use of materials that would otherwise be discarded.



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ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

Contact

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WATER SMART INDUSTRIAL SYMBIOSIS

CS7 – Tain (Glenmorangie distillery)

Nutrients recovery

Cranfield University

Aquabio

Meeting: 3rd June 2024



CS7 - Glenmorangie distillery in Tain, Scotland

Partners:

Aquabio

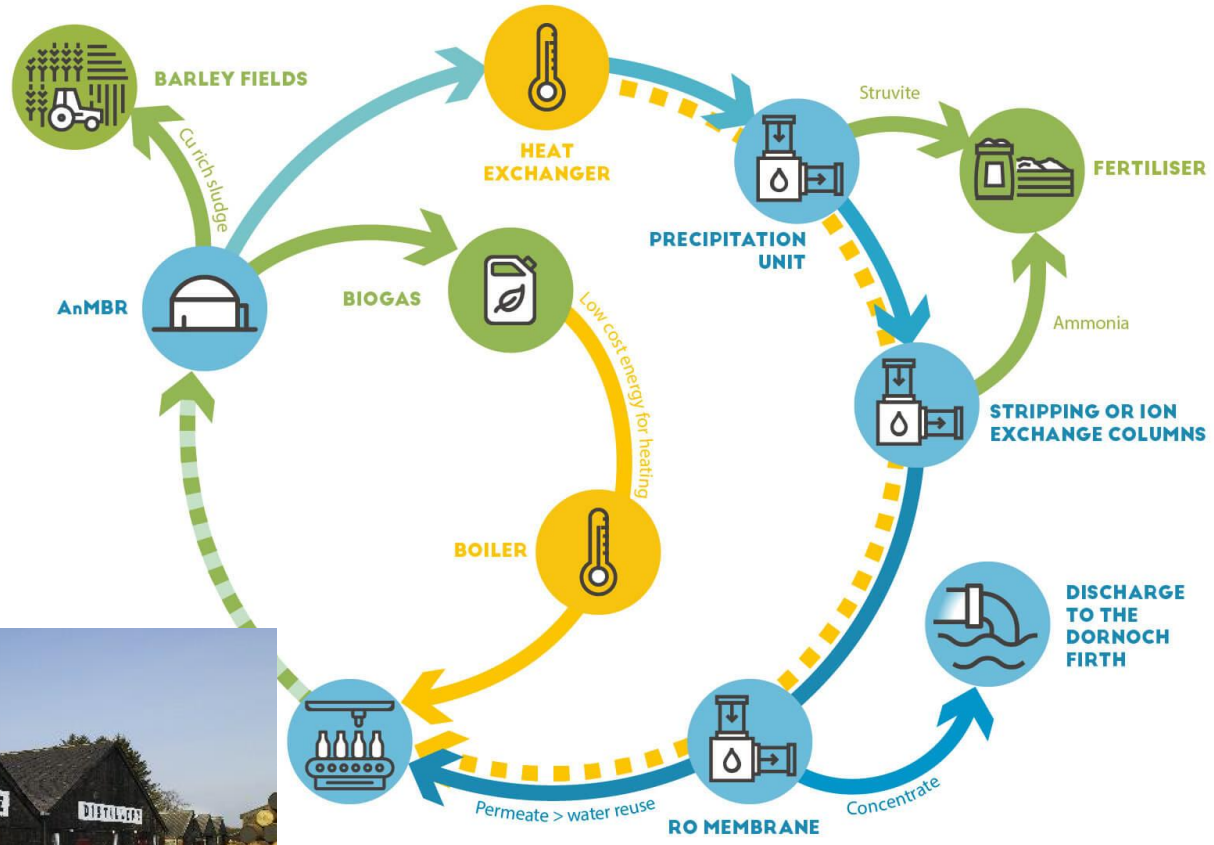
Cranfield University

With the support of:

The GLENMORANGIE COMPANY

Alpheus
part of the Anglian Water Group





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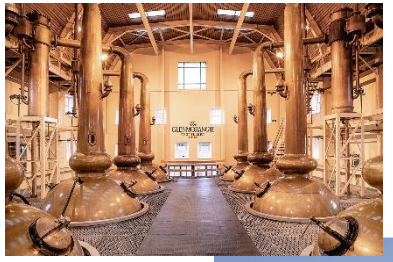
Current system











Low-cost energy for heating

Boiler

Biogas

Ww

Effluent

Dornoch Firth

AnMBR

Barley fields

Cu rich sludge

Parameter	Unit	Raw waste	AnMBR effluent
Chemical oxygen demand (COD)	mg/l	33247	673
Total suspended solid (TSS)	mg/l	8380	3
pH		4.44	7.03
Ammonia (N-NH4)	mg/l	39	789
Nitrates (N-NO3)	mg/l	41	5.6
Phosphate (P-PO4)	mg/l	289	236
Magnesium (Mg)	mg/l	107	43

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Ultimate interventions



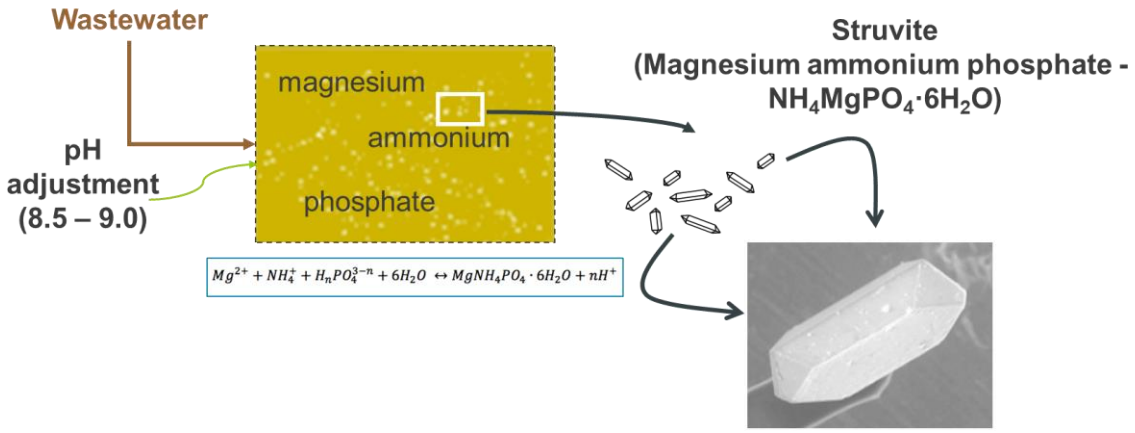




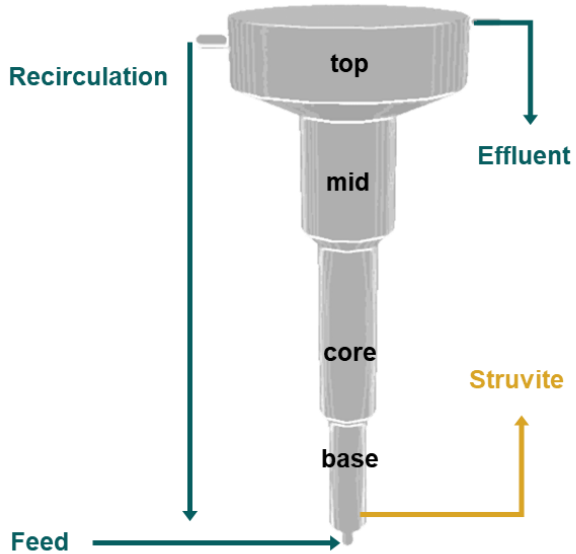


Low-cost energy for heating
Boiler
Biogas
Ww
Effluent
Pre-precipitation
Fertiliser
Ammonia
Concentrate
Discharge to the Dornoch Firth
Heat utilisation
RO membranes
Permeate
Heat utilisation
Stripping column and scrubber
AnMBR
Struvite
Barley fields
Cu rich sludge
Water reuse

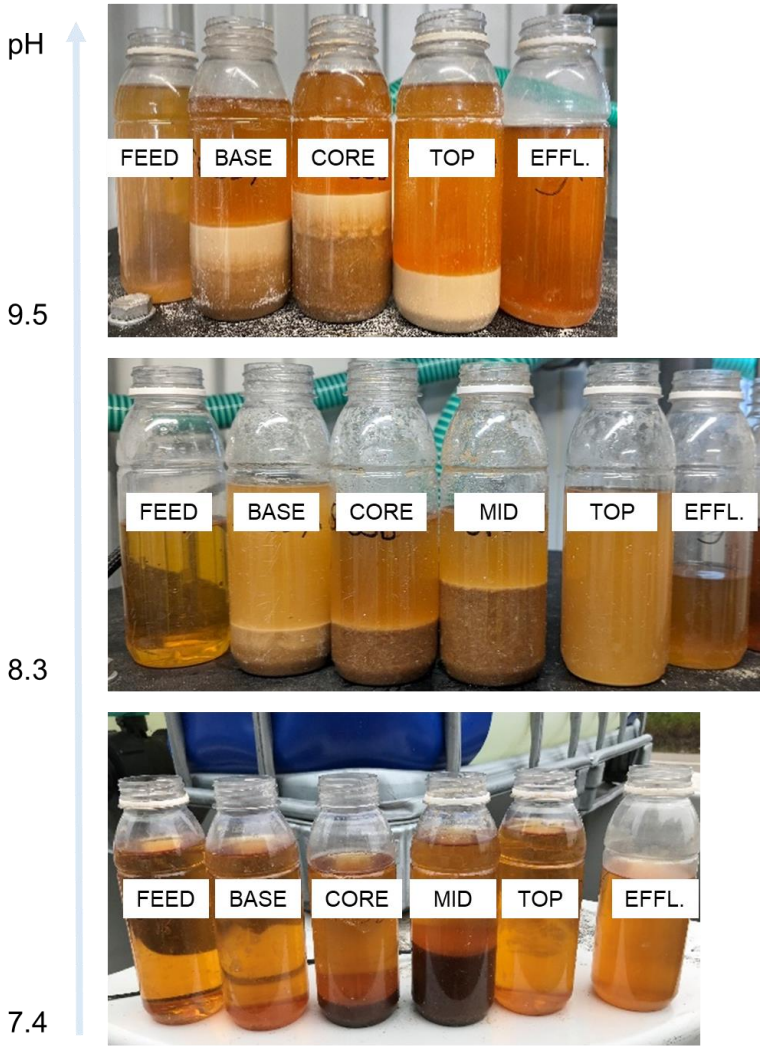
Struvite precipitation



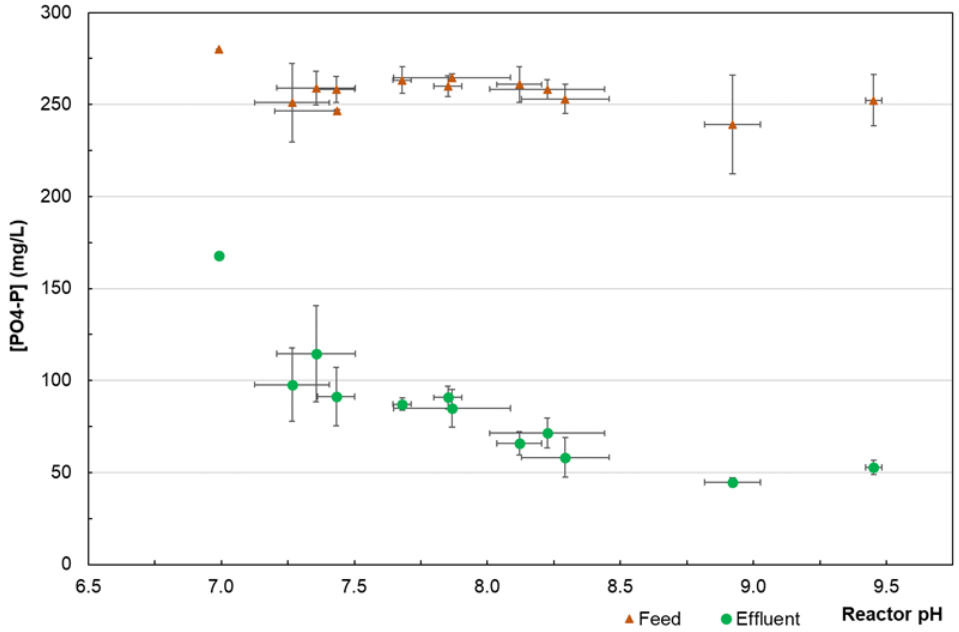


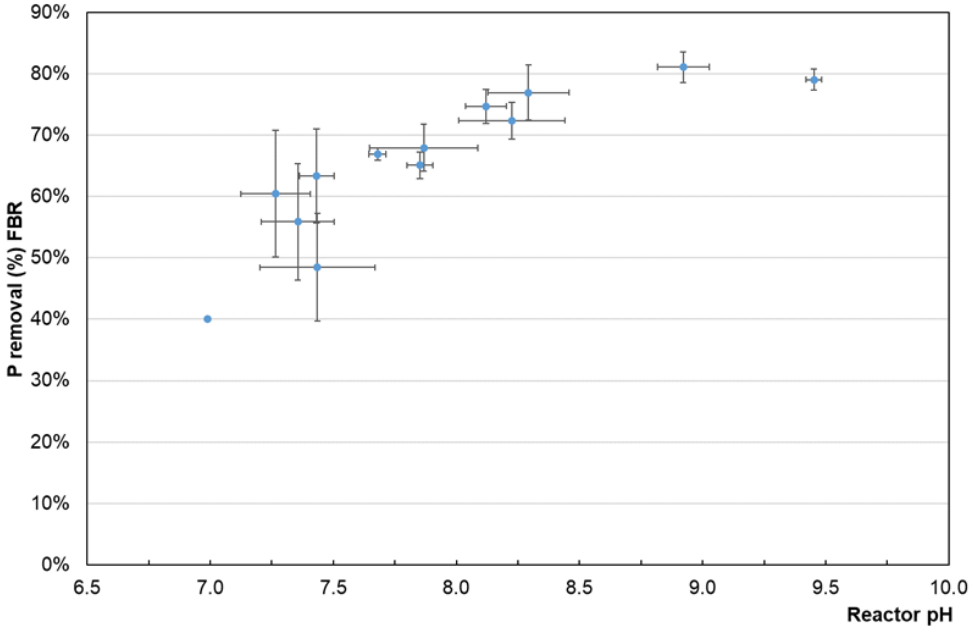






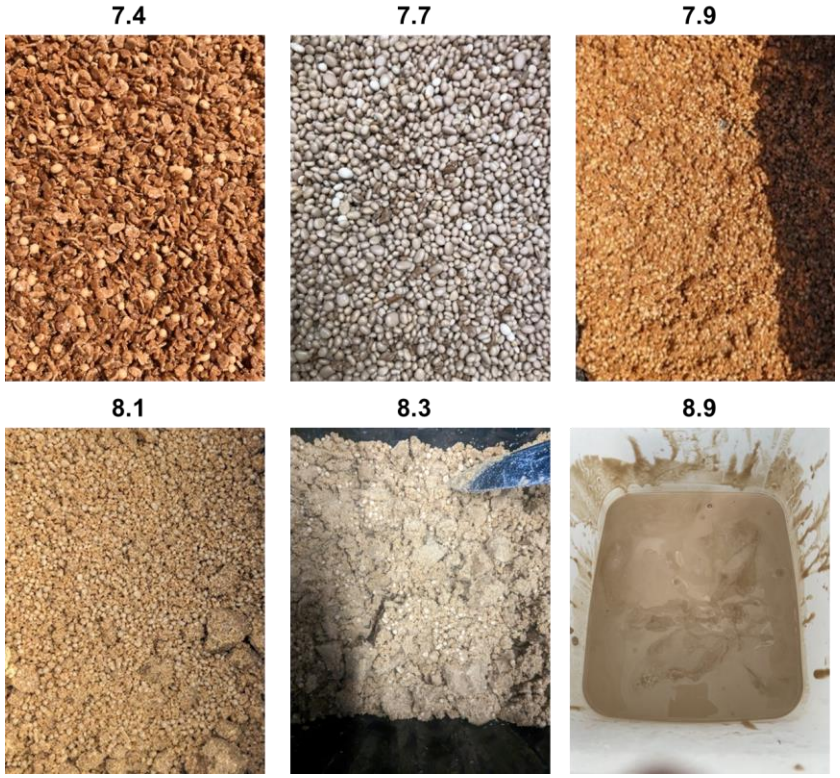
Struvite precipitation



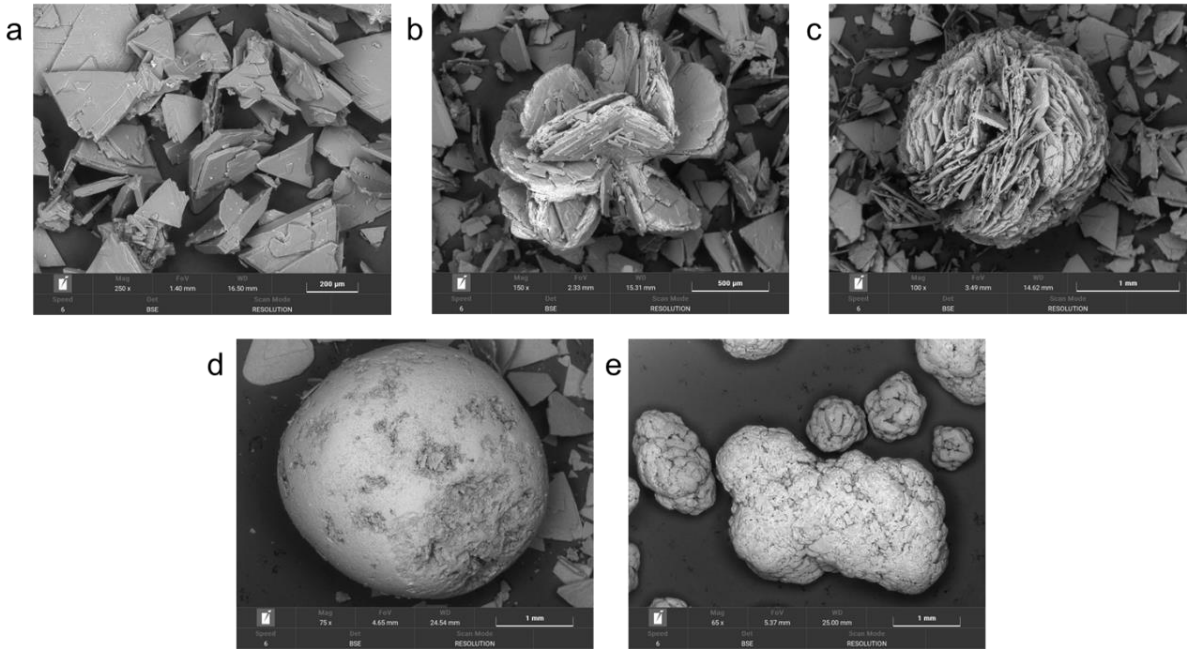


- P removal increased with ↑ reactor pH
- Highest P removal (79%-81%) at pH ≥ **8.9** (SSR = ca. 16)
- At highest P removal, $[PO_4\text{-}P]_{eff}$ was 45-53 mg P/L
- Higher P removal likely achievable with higher Mg/P: 0.5-1.1 (pH 9.45)

Struvite product

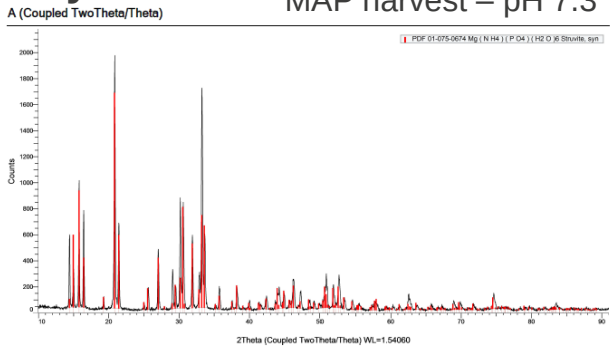


SEM imaging

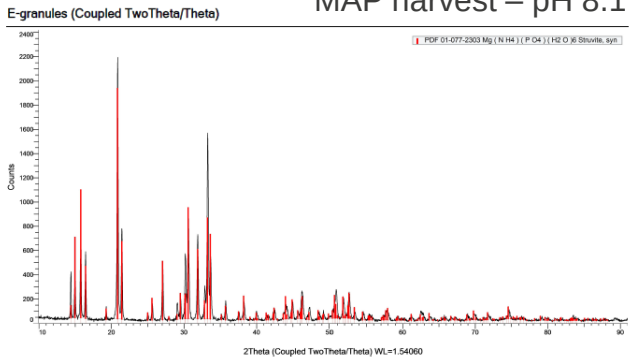


XRD analysis

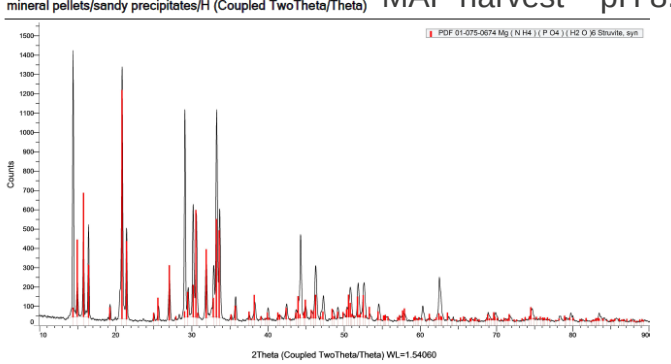
MAP harvest – pH 7.3



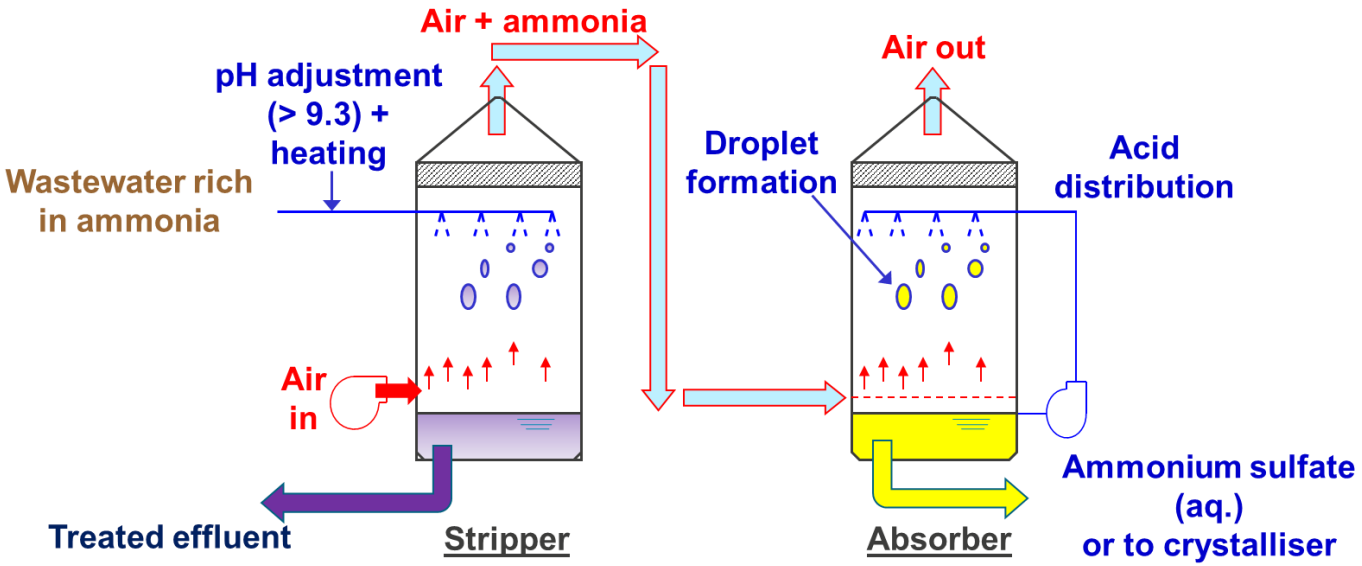
MAP harvest – pH 8.1



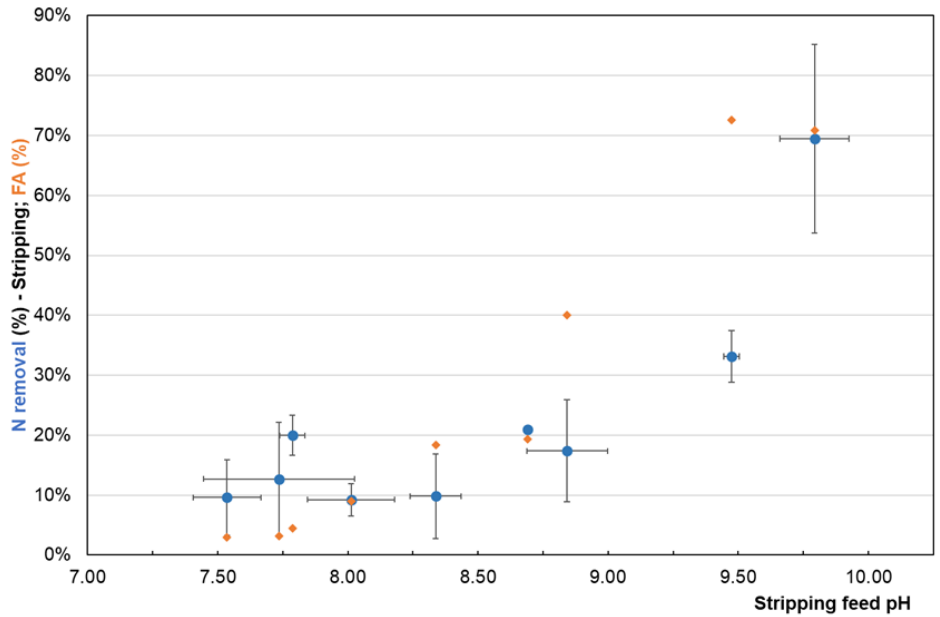
MAP harvest – pH 8.9



Ammonia stripping



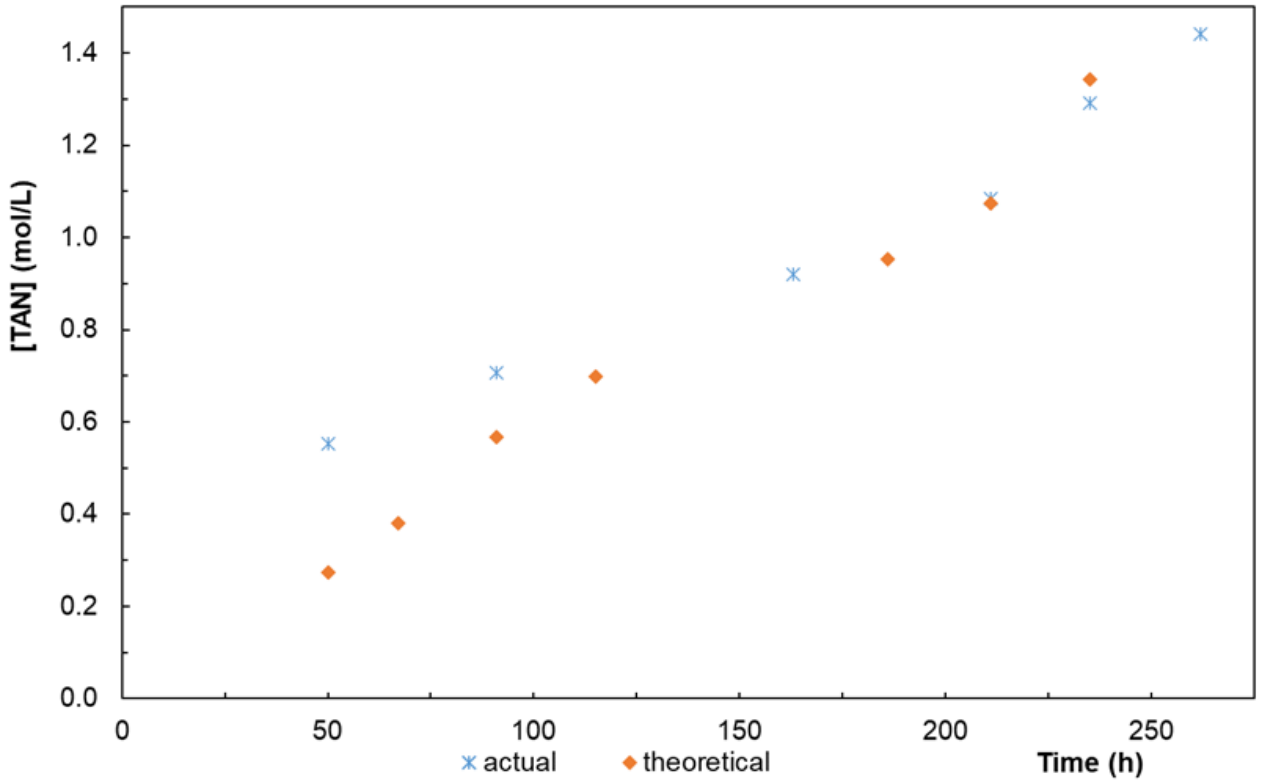




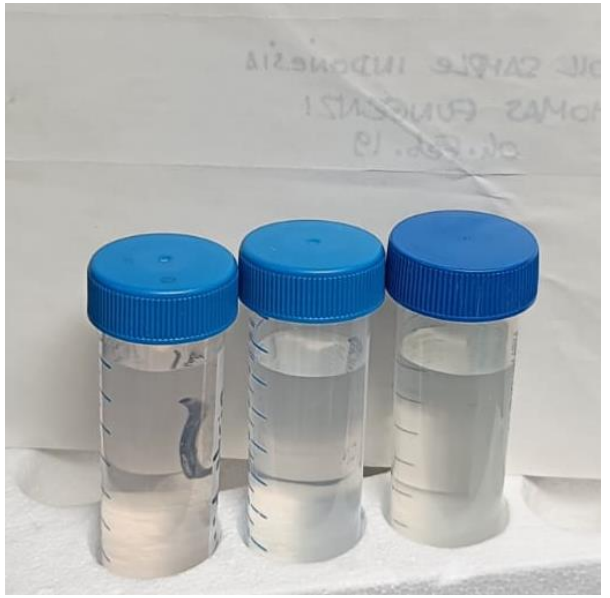
- N removal increases with ↑ pH
- Highest N removal at pH 9.8 ± 0.1 = 69 ± 16%

Ammonia recovery

Example for 1 batch of sulfuric acid in the scrubber



Ammonium sulphate solution recovered



pH	EC	[TAN]	[SO4]	[COD]	[TOC]	[Mg]	[Ca]	[Na]
-	mS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1.93	57.3	10,230	21,652	**681**	30.81	0.0	3.89	0.0

Key findings

- Up to 80% of P and N removal were achieved with tested technologies with distillery wastewater, proving their feasibility but also highlighting related challenges

- Products quality was high, with limited organics and metals contamination

- Operation pH directly impacted removal in both units:
  - **FBR**: affecting solubility and SSR. At optimised pH, removal was limited by Mg supply
  - **Stripping**: affecting ammonia speciation and N removal rate, which can be further help with increased temperature

- Operation pH impacted products quality/management:
  - At increasing pH, the size of pellets/agglomerated decreased → tuneable product
  - At increasing pH, concentration rate of TAN in scrubber liquor increased → shorter liquor age, but greater concentration by limiting dilution by water carryover

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ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

Thank you!

ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

CS7 Tain

Quantitative chemical risk assessment (QCRA)

Johannes Koslowski, Malte Zamzow, Anne Kleyböcker

KWB

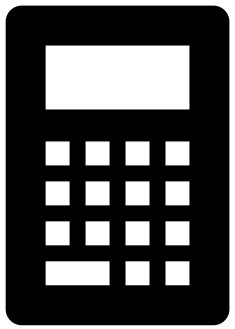
Kompetenzzentrum Wasser Berlin gGmbH

Environmental risk assessment

> A bend in the road is not the end of the road… Unless you fail to make the turn.
>
> **- Helen Keller -**

Find the bend in the road before you accelerate:

1. Quantification
2. Classification





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Methodology – Risk

The **Risk Quotient RQ** is expressed as the quotient of **PEC** and **PNEC:**

$$\mathbf{RQ} = \frac{\mathbf{PEC}}{\mathbf{PNEC}}$$

*PEC: **p**redicted **e**nvironmental **c**oncentration (expected stable concentration 30 days after fertilisation)*

*PNEC: **p**redicted **n**o **e**ffect **c**oncentration*

*Methodology described in detail in: IHCP (2003). **Technical Guidance Document on Risk Assessment**, JRC of the European Commission. Part II.*

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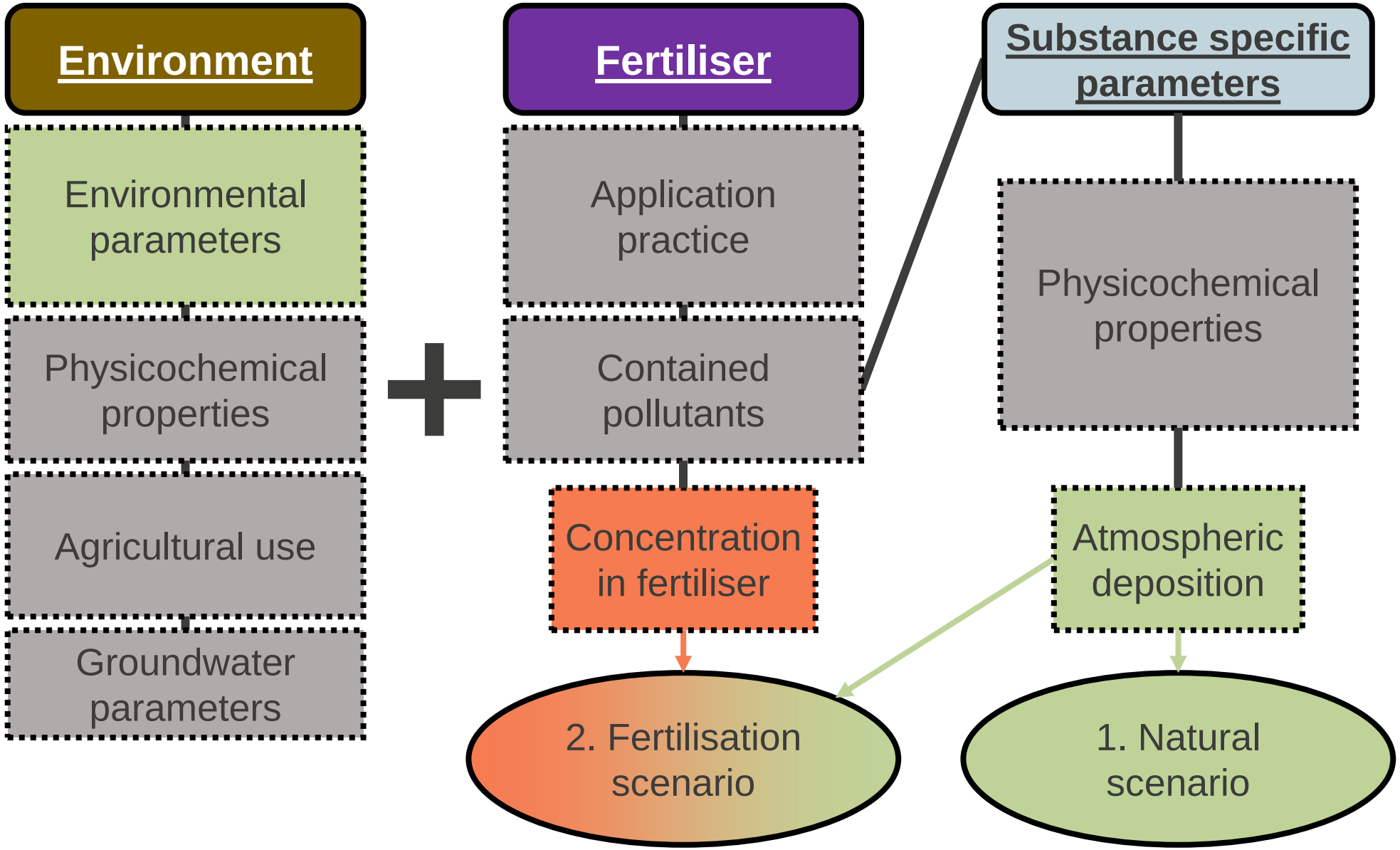
Methodology – Input parameters



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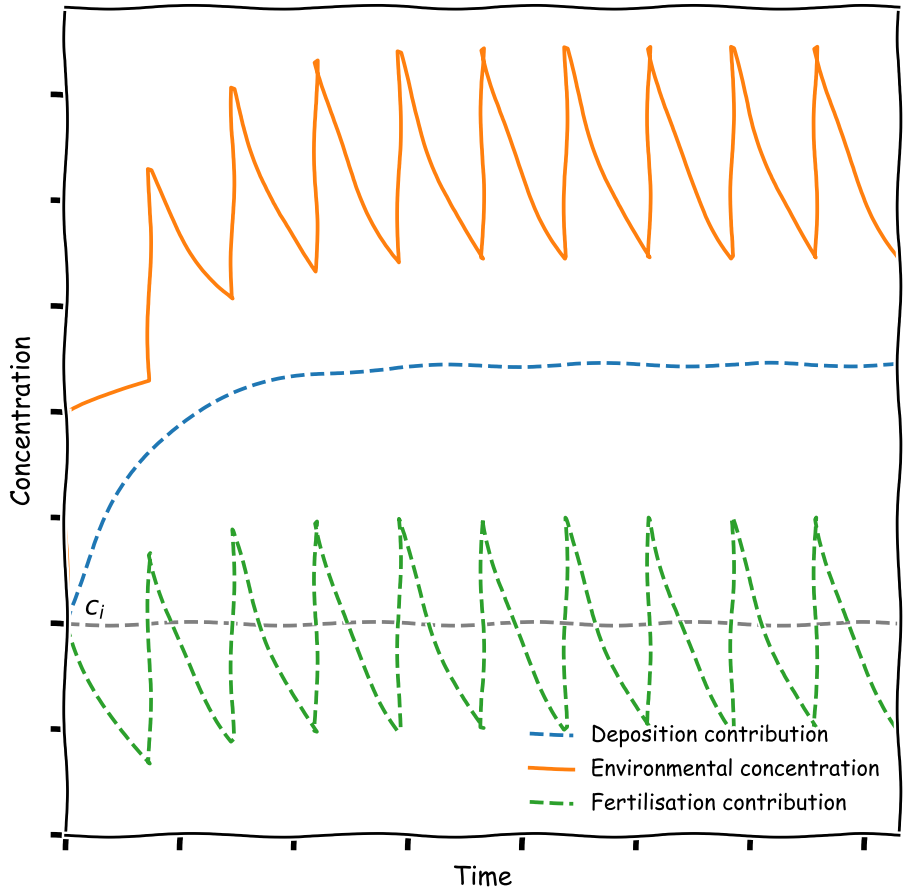
Simplified example

Starting point: initial concentration $\mathbf{c_i}$

Concentration changes in environment:

1. **Deposition**
2. **Fertilisation**
3. **Decay** (leaching, plant uptake, volatilisation)

In the simulation, c_i will be set to PNEC



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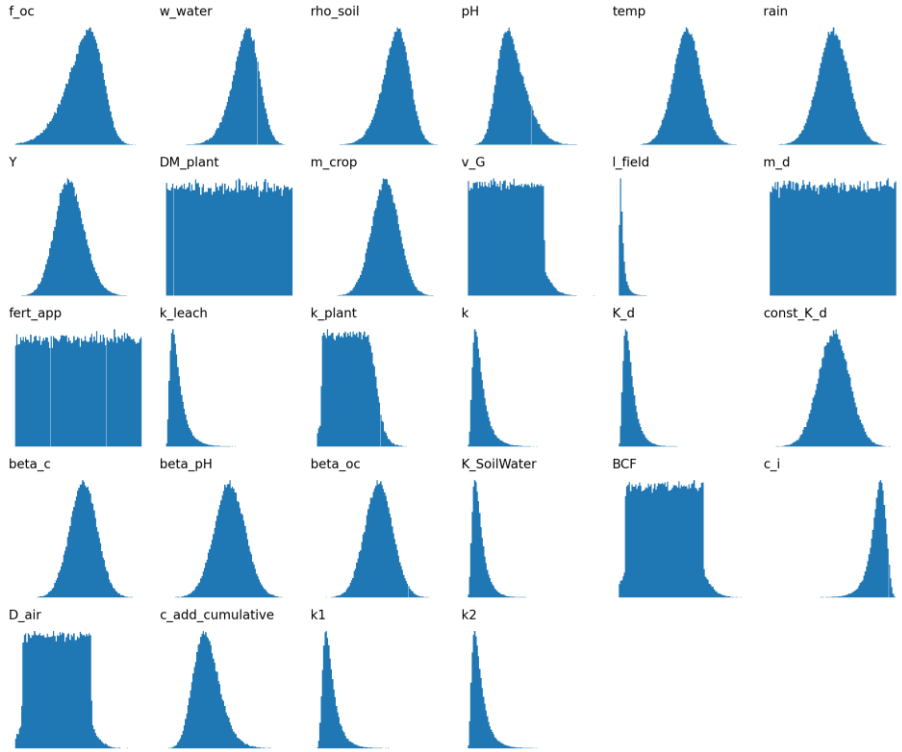
Methodology – Monte Carlo Simulation 1

- Dynamic of pollutants is massively impacted by variation in environmental and substance specific parameters

→ **Research & utilisation of representative distributions for parameters**



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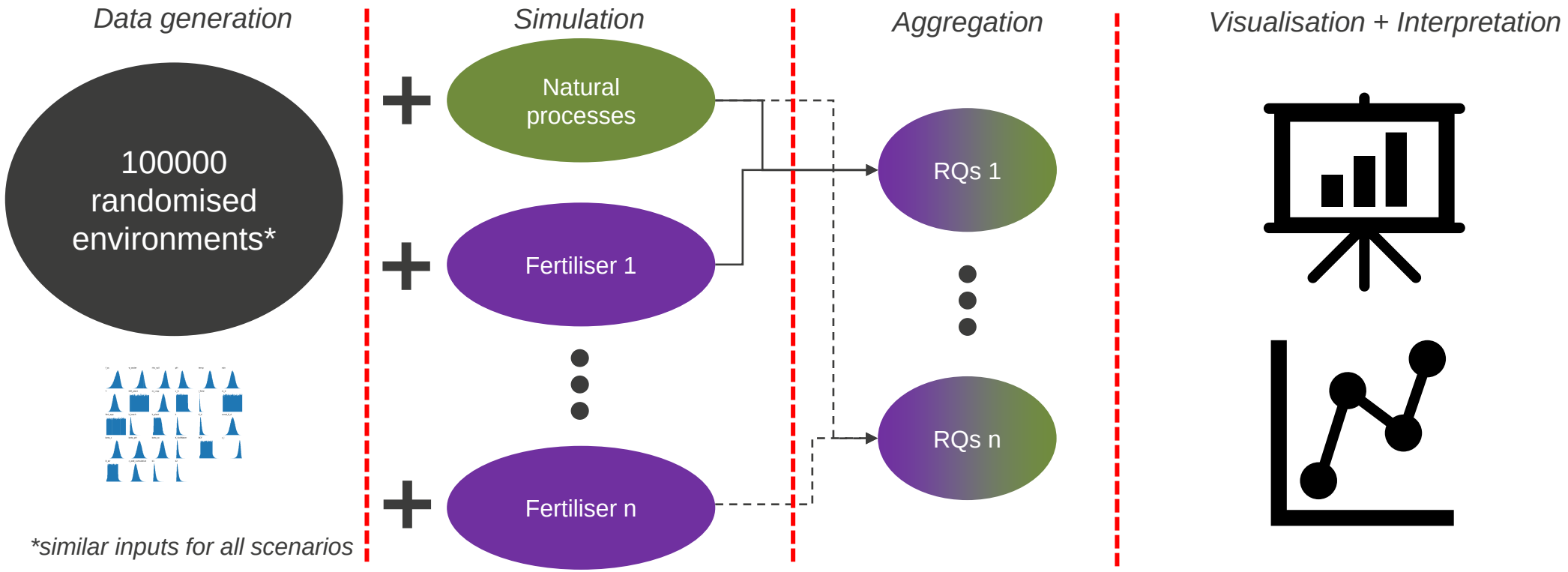
Methodology – Monte Carlo Simulation 2



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Methodology – Interpretation

$$\mathbf{RQ} = \frac{\mathrm{PEC}}{\mathrm{PNEC}}$$

ΔRQ: Difference between RQs of both simulated scenarios

R_{max}: Average of the highest 5% of the relevant RQs > 1 to compensate outliers

		RQ_{max}		
		< 2	< 5	≥ 5
ΔRQ_{mean}	< 0.01	Negligible	Negligible	Acceptable
	< 0.1	Negligible	Acceptable	Increasing concern
	< 1	Acceptable	Increasing concern	Unacceptable
	≥ 1	Increasing concern	Unacceptable	Unacceptable

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CS7: Questions asked

- Earlier risk assessments show: struvite in general has comparably low concentrations of heavy metals and does not lead to significant risk increases

- Distilleries utilize **construction materials like zinc and copper**

→ **Can this lead to additional risk from Tain struvite?**

- **Local** fertilisation of winter barley fields

→ Soil and climate in differ from „mean european“

→ **Can this lead to additional risk from Tain struvite?**

redacted

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Model parameters - Fertiliser concentrations

- Three relevant heavy metals (relevant=negative environmental effects) identified in acidic analysis
- Cu, Ni, Zn
- Measurements in acid digestion analysis show **significant spread**
- Solution: **definition of multiple scenarios** (**low** concentrations, **high** concentrations; arbitrary boundaries)

redacted

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Tain struvite application

- 30 - 60 kg P_2O_5 ha^{-1} a^{-1} fertilisation target
- Mean purity of Tain struvite: 82 %

➢ 126 – 253 kg Tain struvite ha^{-1} a^{-1}

- Approximate annual pollutant application through fertilisation (high concentration range):

- Cu: 58 – 167 mg ha^{-1} a^{-1}
- Ni: 68 – 435 mg ha^{-1} a^{-1}
- Zn: 87 – 394 mg ha^{-1} a^{-1}

redacted

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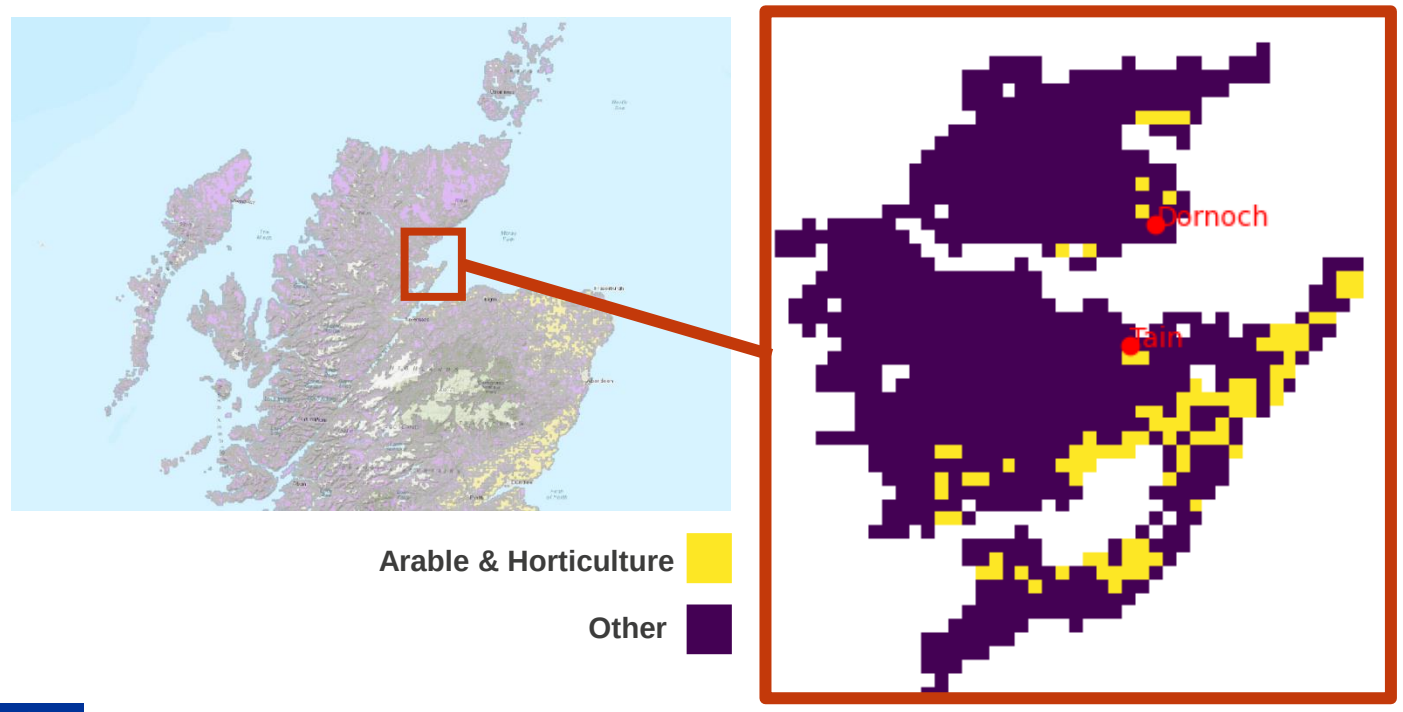
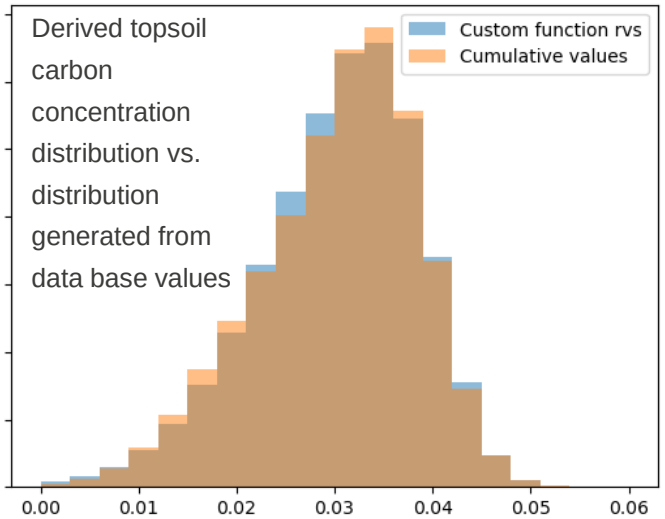
Environmental parameters

- Efforts were made to **use local information** for using openly available data sets (UK Soil Obervatory and others)
- Where no information could be obtained: IHCP TGD standard parameters for european soil





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Results

Comparison of three fertilisers:

1. **Municipal sewage sludge** (*reference scenario)*
2. **Tain Struvite** (**low** concentration range)
3. **Tain Struvite** (**high** concentration range)

- Assessment of **soil (microbial risk) and groundwater** (it is assumed, that groundwater concentration equals soil porewater concentration)

redacted

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Summary Risk

- **Tain struvite** risk increase is **negligible**
- **reference** scenario risk increase magnitudes higher
- Atmospheric deposition massively outweights contribution from Tain struvite

Compartment	Substance	Fertiliser	ΔRQ	R_{max}	Risk classification
Soil	Cu	Sewage sludge	redacted		acceptable
		Struvite (low)			negligible
		Struvite (high)			negligible
	Ni	Sewage sludge			negligible
		Struvite (low)			negligible
		Struvite (high)			negligible
	Zn	Sewage sludge			acceptable
		Struvite (low)			negligible
		Struvite (high)			negligible
GW	Cu	Sewage sludge			acceptable
		Struvite (low)			negligible
		Struvite (high)			negligible
	Ni	Sewage sludge			acceptable
		Struvite (low)			negligible
		Struvite (high)			negligible
	Zn	Sewage sludge			increasing concern
		Struvite (low)			negligible
		Struvite (high)			negligible

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Takeaway

The product from CS7 Tain is **not expected to lead to any significant environmental risk increase** through the substances Cu, Ni and Zn when applied as an equivalent to 30 - 60 kg P_2O_5/ha P-fertiliser on arable soils near Tain/Dornoch.



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ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

Ultimate Webinar / Workshop

Material recovery and reuse



CS8 - SUEZ RR IWS CHEMICALS

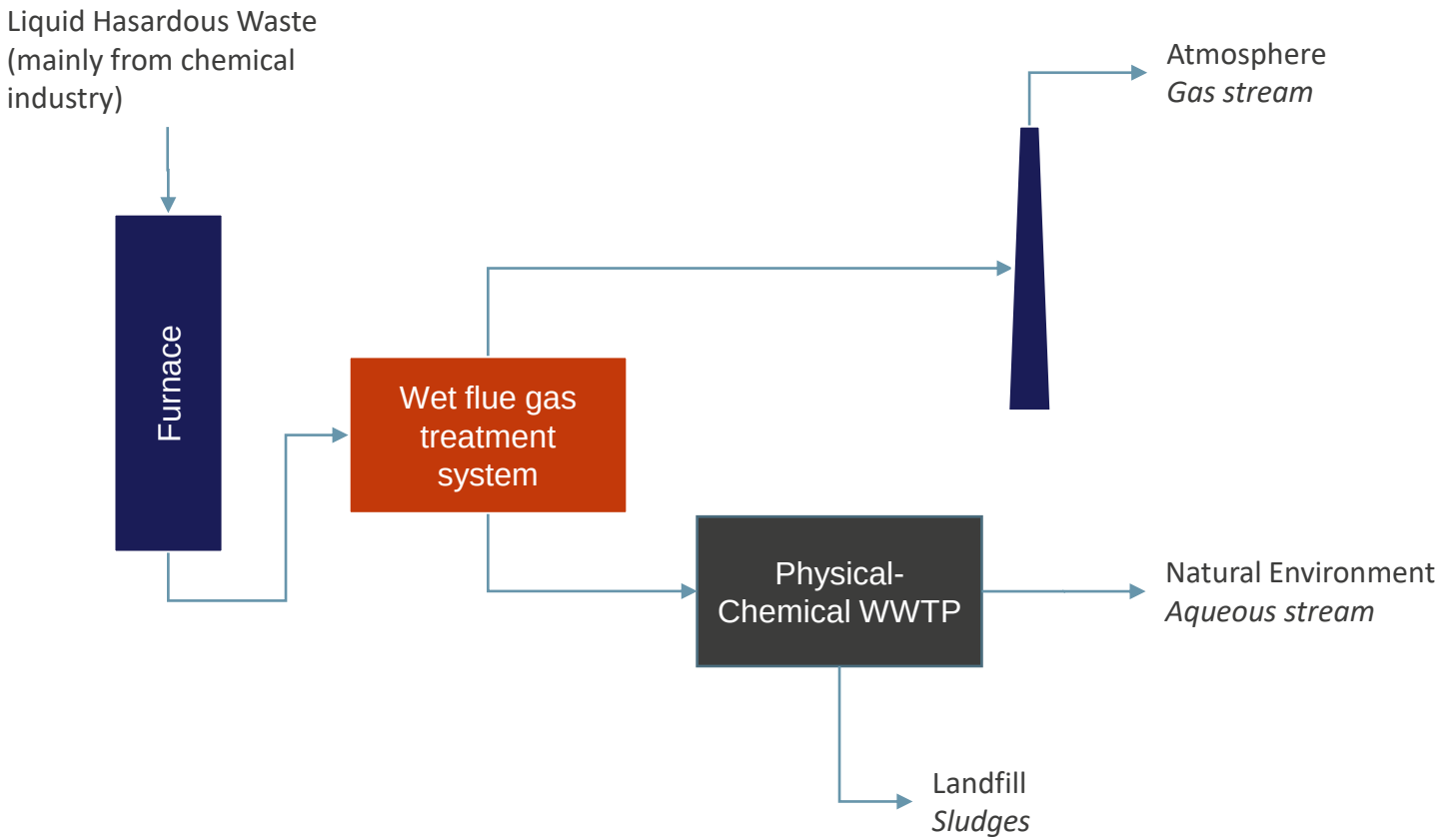
CS8: Sulphur recovery - Context

Subtask: **1.4.7 Recovery of Sulphur and metals at the chemical platform of Roussillon**

→ Hazardous waste incineration unit on the chemical platform of Roussillon

→ Specialized in aqueous waste with high salt and sulfur content.

→ Today, flue gases are efficiently desulfurized, but the sulfur is not recovered.



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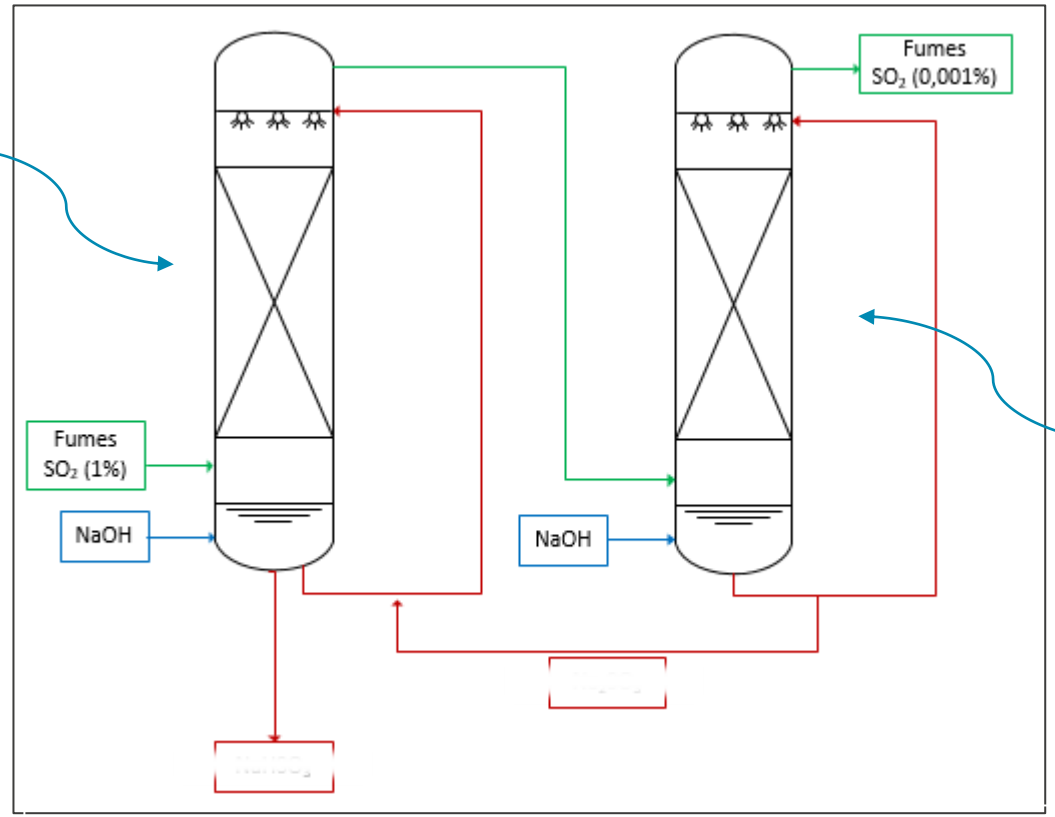
General

CS8: Sulphur recovery - Principle

Subtask: 1.4.7 Recovery of Sulphur and metals at the chemical platform of Roussillon

Objective: Recover SO_2 in the form of a marketable sodium bisulfite solution $NaHSO_3$

Concentrate the solution



Absorb the remaining SO_2

Principle of the process

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General

CS8: Sulphur recovery – The industrial pilot





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CS8: Sulphur recovery

Subtask: **1.4.7 Recovery of Sulphur and metals at the chemical platform of Roussillon**

Challenges linked to real operating conditions

Theme	Problem	Action planned
Customer	Many **deliveries cancelled**. Commercial contract not respected.	We suggested to the sales representative that we present the initial results to customers and explain the benefits for them.
Logistic	The chemical industry is facing difficulties, which is reducing waste deliveries. Some waste relevant to our project has then to be treated at **weekends**, but people working on the project can't carry out tests during the weekends.	
Annual shutdown	**4 weeks** annual shutdown per incineration line.	
Damage shutdown	**10-day** shutdown following a general power failure of the incineration unit	
Human behaviour	Acceptance of process modifications : incineration operating instructions to optimize SO2 levels arriving at the pilot may contradict certain habits and beliefs, and thus lead to operating errors.	The plant's process engineer analyzes the operating data after each test to explain the origin of the over-consumption of reagents.

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General

CS8: Sulphur recovery

Subtask: **1.4.7 Recovery of Sulphur and metals at the chemical platform of Roussillon**

Description of pilot tests and improvements on the last 6 months

Customer	Sulfur concentration range	Number of pilot tests	Number of relevant pilot tests
A	12 - 25%	5	0
B	33 - 44%	5	4
C	47 - 49%	3	3
D	13 - 19%	1	1

Duration of one pilot test: **between 1 and 3 consecutive days (total duration: about 550 h)**

Improvements made:

- Reduction of washing water **volume** in scrubbers (November)
- **Temperature** maintained in scrubbers to avoid condensation (January)
- **Continuous** operation during sulfur waste incineration (February)
- **Connections** between pilot and incinerator modified to reduce turbulence and improve flow gas measurement (April)
- Regular **bleeding** of bottom points to avoid water accumulation (April)

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General

CS8: Sulphur recovery

Subtask: 1.4.7 Recovery of Sulphur and metals at the chemical platform of Roussillon

Results (pilot tests still in progress)

- **Sodium bisulfite concentration obtained**

Test number	pH	[$NaHSO_3$] ($g.L^{-1}$)	[Na_2SO_3] (g.L-1)	[Na_2SO_4] ($g.L^{-1}$)	Oxidized sulfur rate (%)
7	5,1	106	1,0	0,4	0,3 %
8	5,7	216	8,3	0,9	0,3 %
10	3,4	83	0,1	2,4	2,1 %
13	5,8	154	7,4	3,3	1,5 %
Target	**3,5 - 4,5**	**510** ✗	**< 10** ✓	**< 30** ✓	**~ 4%** ✓

→ Pilot tests have to be carried out to **increase the concentration**.

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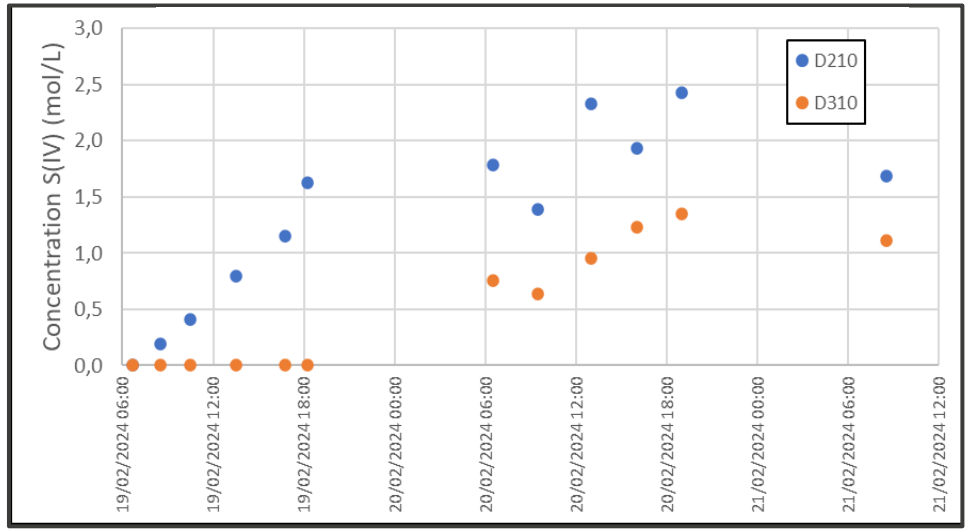
General

CS8: Sulphur recovery

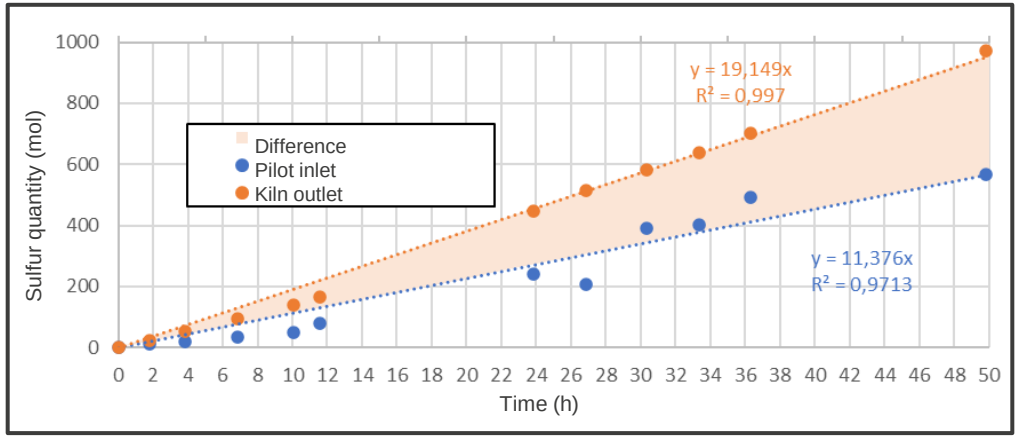
Subtask: 1.4.7 Recovery of Sulphur and metals at the chemical platform of Roussillon

Results (pilot tests still in progress)

- **Sodium bisulfite concentration obtained: first results**



Typical evolution of sulfite concentration in the 2nd column (blue) and bisulfite concentration in the 1st column (orange).



A significant proportion (about 40%) of the sulfur dioxide is captured by the flue gas washing process before entering the pilot plant.

To improve this yield, it is necessary to:

- **remove basic waste** from the furnace inlet
- **reduce the pH of the first washing steps** (quench and acid column)

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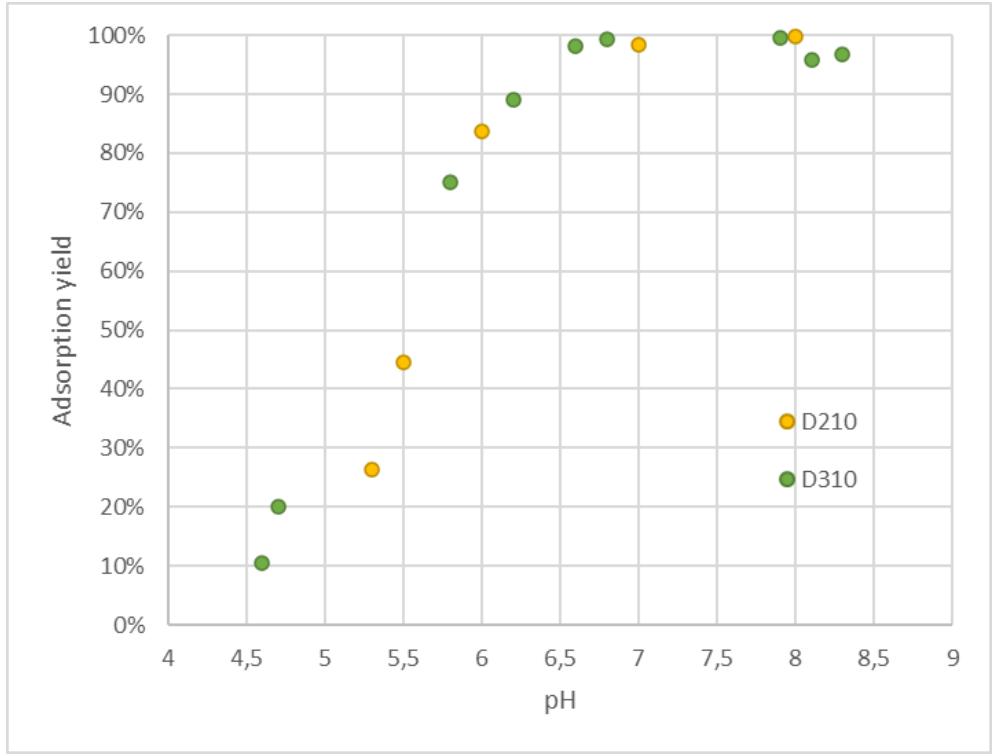
General

CS8: Sulphur recovery

Subtask: 1.4.7 Recovery of Sulphur and metals at the chemical platform of Roussillon

Results (pilot tests still in progress)

- **Adsorption yield (results)**

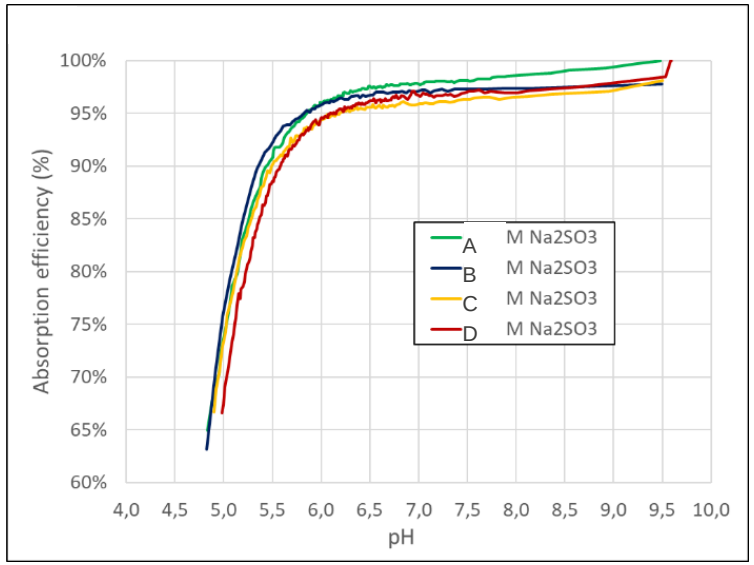


Overall adsorption yield on the industrial pilot: **~ 99%**

2nd step (sulfite production): > 99%

1st step (bisulfite production): < 10%

Adsorption yield of SO2 decreases significantly with pH, at a **higher level than observed in laboratory tests**



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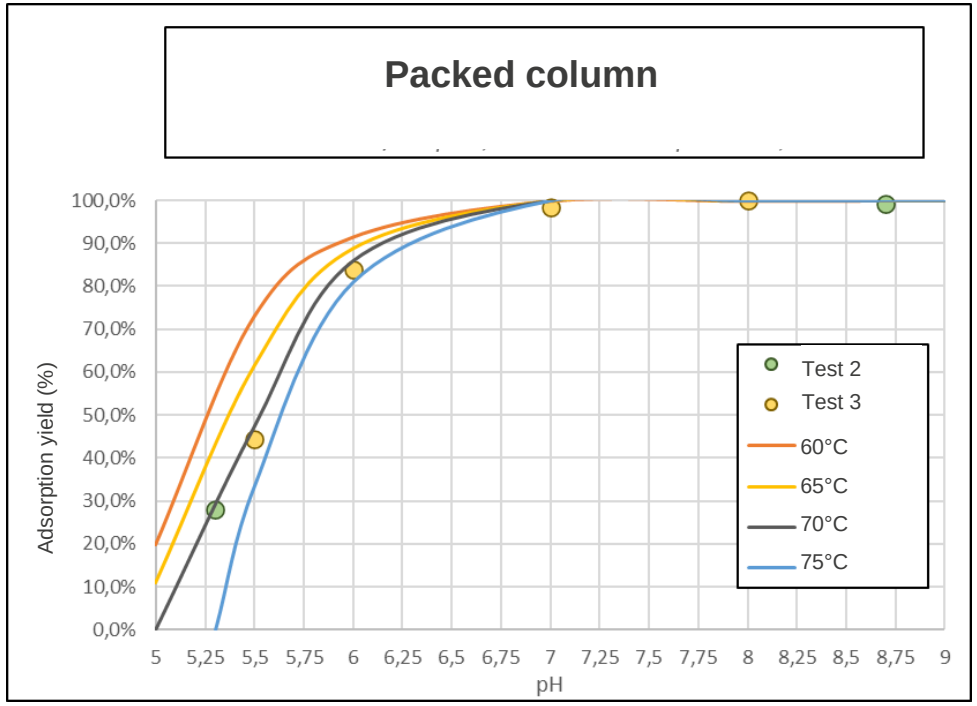
General

CS8: Sulphur recovery

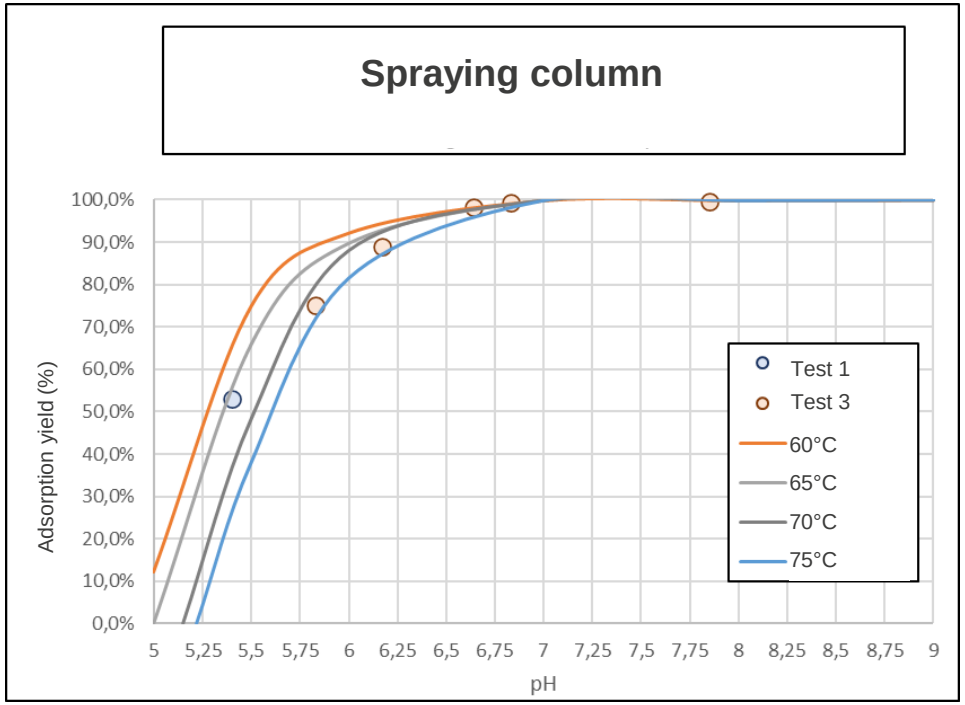
Subtask: 1.4.7 Recovery of Sulphur and metals at the chemical platform of Roussillon

Results (pilot tests still in progress)

- **Adsorption yield (improvement)**



According to scrubber modelling, adsorption yield on the second column can be improved by **reducing the flue gas temperature.**



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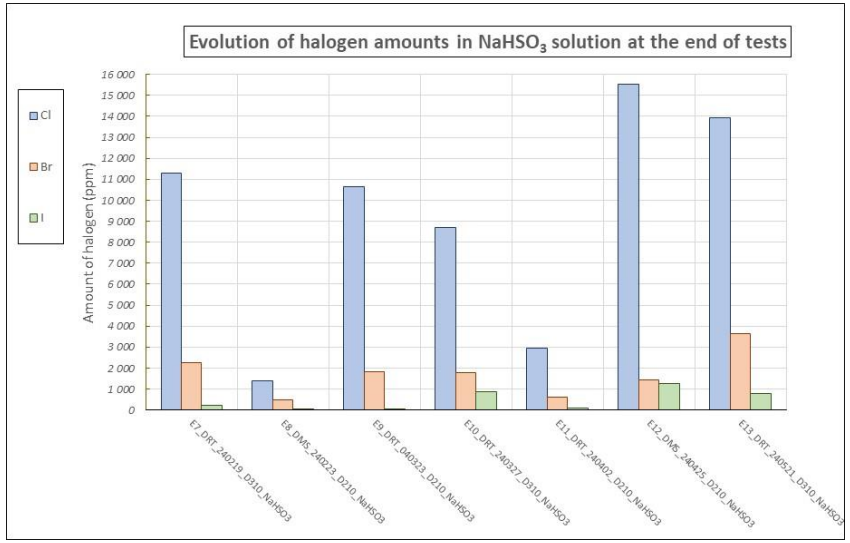
→ To reach the pH target, a **third scrubber** is required.

CS8: Sulphur recovery

Subtask: 1.4.7 Recovery of Sulphur and metals at the chemical platform of Roussillon

Results (pilot tests still in progress)

- **Sodium bisulfite quality obtained**

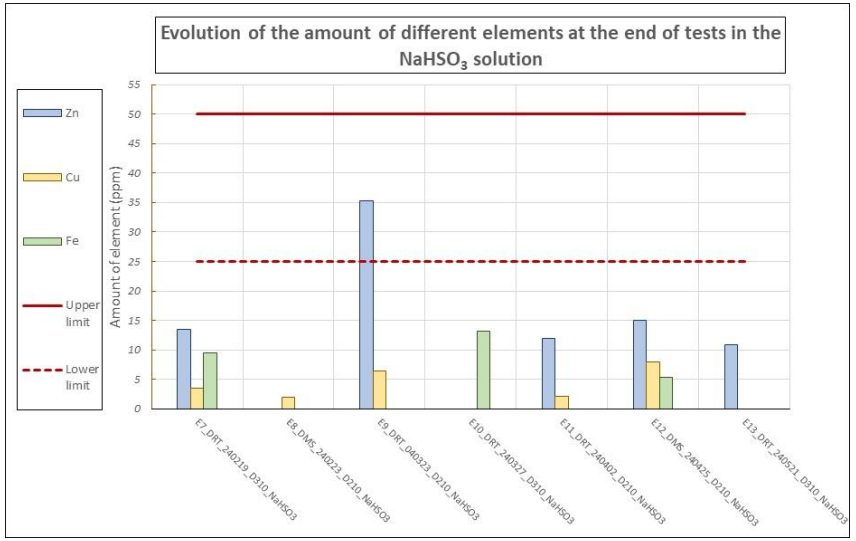


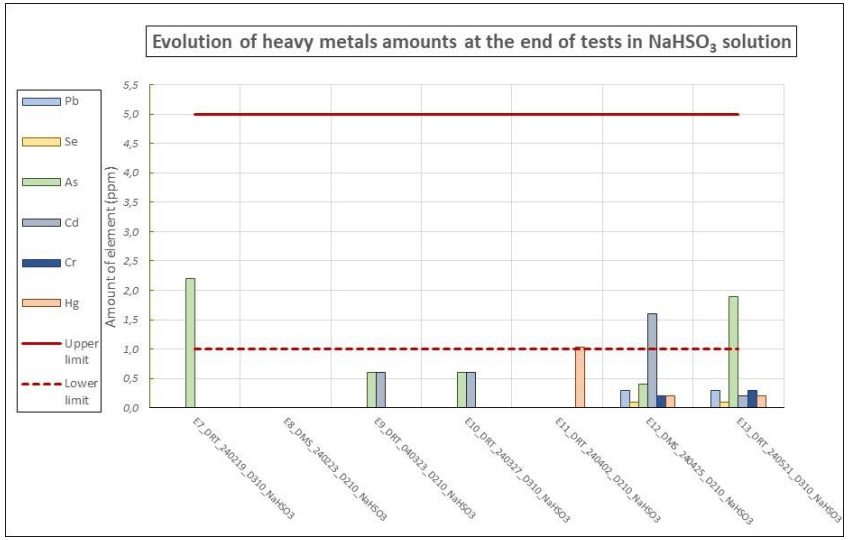
Chlorine concentration must be reduced.

Salt treatment process must be improved upstream of the recovering process.

Promising results for **metals** composition.

Strict monitoring of metals content of incoming waste must be carried out.





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General

CS8: Sulphur recovery

Subtask: **1.4.7 Recovery of Sulphur and metals at the chemical platform of Roussillon**

Conclusion on the task of Sulphur recovery

- **A sodium bisulfite solution has been produced on the industrial pilot**, but pilot tests have to be carried out to **increase the concentration**.
- **Yields are lower than expected**, but optimization solutions have been identified.
- To improve overall recovery efficiency:
  - The flue gas treatment process upstream of the recovery unit needs to **operate at a lower pH**.
  - The recovery process must operate at **the lowest possible temperatur**e (which will increase the plant's overall energy consumption).
- To improve the quality of the solution obtained:
  - The efficiency of the **salt treatment steps needs to be increased**.
  - A **third column** would probably need to be added to the recovery process.

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General

CS8: Sulphur recovery

Subtask: 1.4.7 Recovery of Sulphur and metals at the chemical platform of Roussillon

IT issues

Context:

- 3S (SUEZ Smart Solutions), subsidiary of SUEZ, partner with IWS on CS08
- 3S is a software developer for the water and waste sectors

Objectives:

- Configure a single IT application to enable IWS to carry out its technical and economic studies for CS08:
  - Material recovery
  - Energy recovery
- … based on the software product WasteAdvanced®, developed by 3S for the waste sector (EFW = Energy From Waste)

Stakes:

1. Assess whether WasteAdvanced® is technically suitable for the IWS sector (incineration of hazardous liquid waste)
2. Develop a technical-commercial offer (beyond the ULTIMATE project)

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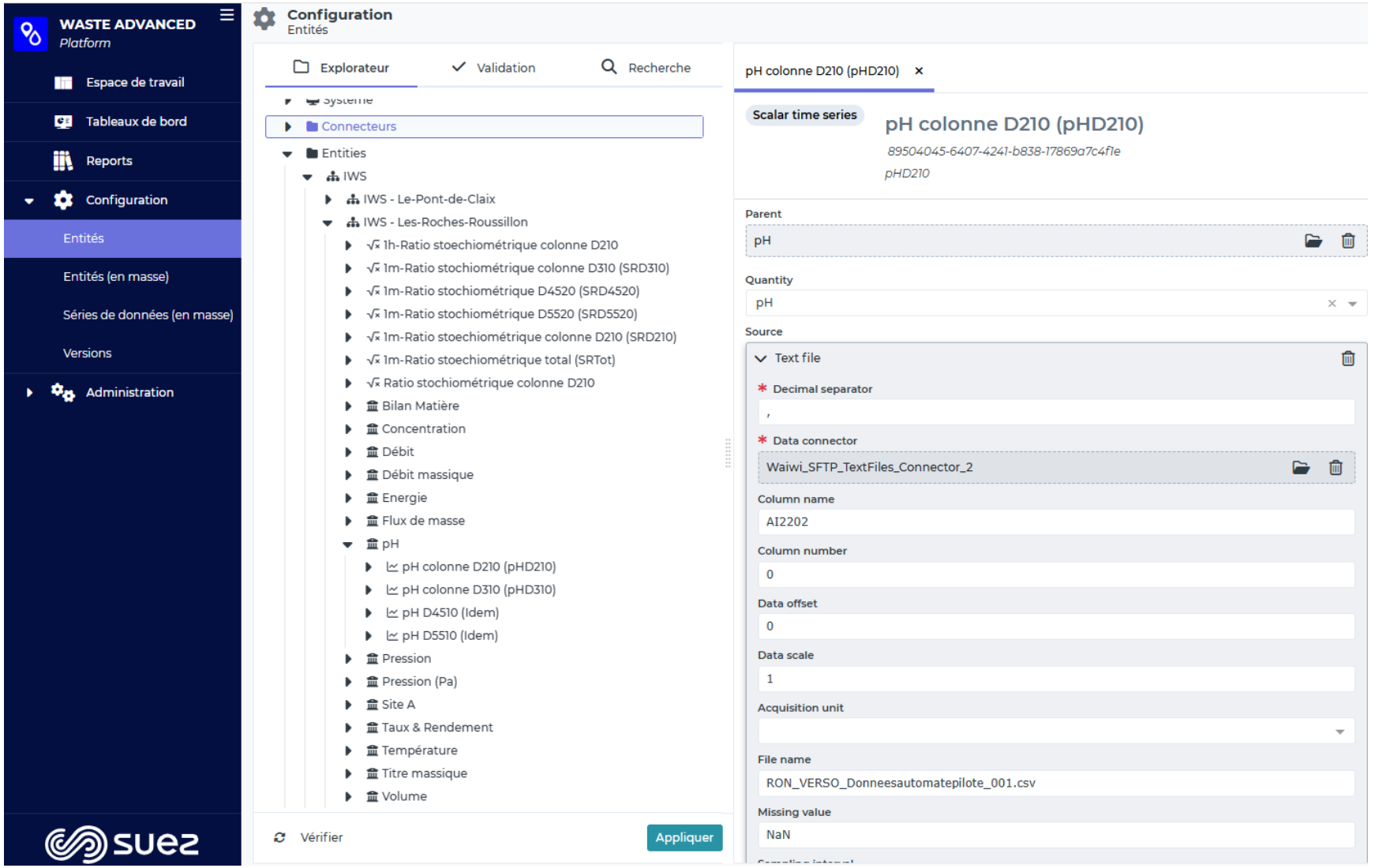
General

CS8: Sulphur recovery



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CS8: Sulphur recovery



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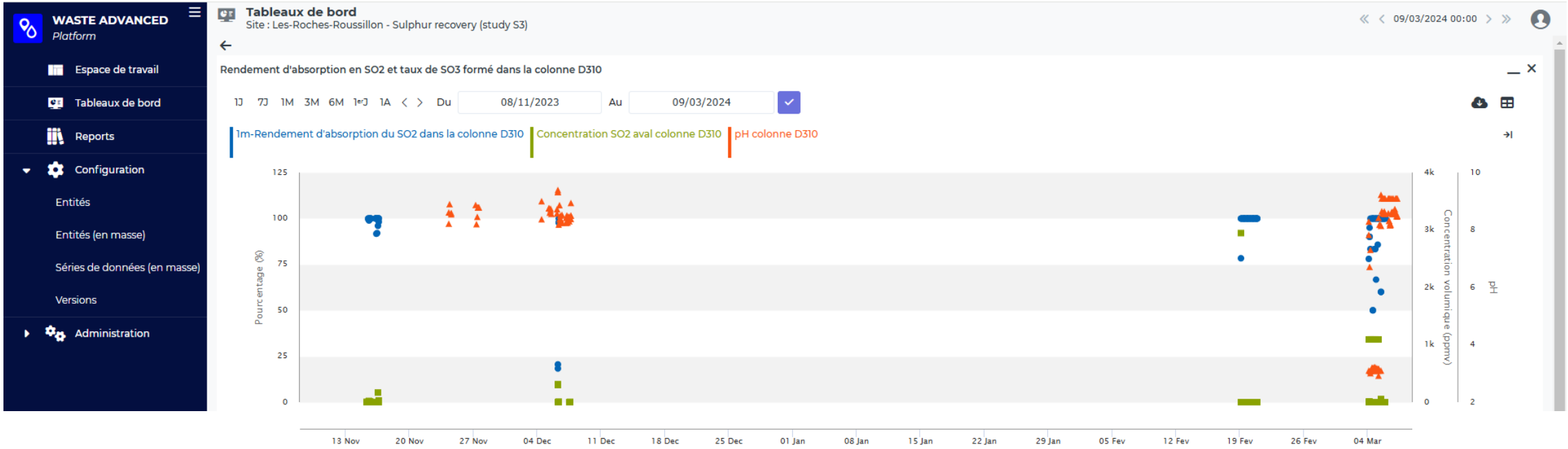
General

CS8: Sulphur recovery



Action to be done:

- Check the calculated indicators (joint work between IWS and 3S):
  - Unit
  - Order of magnitude
  - Calculation formula

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General

ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

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